Home Innovation
RESEARCH LABS™

National Green Building Standard™

2018 UPDATE

Attachments to Proposed Changes

Table of Contents

1. John Barrows – Ad Hoc TG, Section 102.4 Alternative compliance methods
   Proposed Change LogID 6497 1
2. Greg Johnson – TG-2, Section 403 Intent (Site Design)
   Proposed Change LogID 6147 6
3. Greg Johnson – TG-2, Section 403.1 Natural resources & 503.1 Natural resources
   Proposed Change LogID 6462 & 6463 13
4. Greg Johnson – TG-2, Section 403.6 Landscape Plan
   Proposed Change LogID 6163 14
5. Greg Johnson – TG-2, Section 403.7 Wildlife habitat & 503.6 Wildlife habitat
   Proposed Change LogID 6465 & 6466 27
6. Greg Johnson – TG-2, Section 403.7 Wildlife habitat & 503.6 Wildlife habitat
   Proposed Change LogID 6465 & 6466 29
7. Greg Johnson – TG-2, Section 403.7 Wildlife habitat & 503.6 Wildlife habitat
   Proposed Change LogID 6465 & 6466 36
8. Greg Johnson – TG-2, Section 403.7 Wildlife habitat & 503.6 Wildlife habitat
   Proposed Change LogID 6465 & 6466 38
9. Greg Johnson– TG-2, Section 503.5 Landscape plan
   Proposed Change LogID 6164 47
10. Greg Johnson– TG-2, Section 503.5 Landscape plan
    Proposed Change LogID 6222 62
11. Steven Rosenstock – TG-2, Section 505.6 Multi-unit plug-in electric vehicle charging & 11.505.6 Multi-unit plug-in electric vehicle charging
    Proposed Change LogID 6151 & 6152 100
12. Steven Rosenstock – TG-2, Section 505.6 Multi-unit plug-in electric vehicle charging & 11.505.6 Multi-unit plug-in electric vehicle charging
    Proposed Change LogID 6151 & 6152 179

13. Steven Rosenstock – TG-2, Section 505.6 Multi-unit plug-in electric vehicle charging & 11.505.6 Multi-unit plug-in electric vehicle charging
Proposed Change LogID 6151 & 6152 207

14. Steven Rosenstock – TG-2, Section 505.6 Multi-unit plug-in electric vehicle charging & 11.505.6 Multi-unit plug-in electric vehicle charging
Proposed Change LogID 6151 & 6152 285

15. Greg Johnson – TG-2, Section Other for Chapter 5
Proposed Change LogID 6459 288

16. Greg Johnson – TG-2, Section Other for Chapter 5
Proposed Change LogID 6459 290

17. Greg Johnson – TG-2, Section Other for Chapter 5
Proposed Change LogID 6459 362

18. Eric Skare – TG-3, Section 602 Intent (Enhanced Durability and Reduced Maintenance)
Proposed Change LogID 6214 381

19. Rob Brooks – TG-3, Section 606.2 Wood-based products & 12.1(A).606.2 Wood-based products
Proposed Change LogID 6327 & 6328 490

20. Jeremy Velasquez – TG-3, Section Other for Chapter 9
Proposed Change LogID 6479 493

21. Jeremy Velasquez – TG-3, Section Other for Chapter 9
Proposed Change LogID 6476 530

22. Craig Conner – TG-3, B100 Scope and applicability (Appendix B: whole building ventilation system specifications)
Proposed Change LogID 6563 567

23. Steven Rosenstock – TG-5, Section 702.2.1 ICC IECC analysis (Energy performance levels) & TG-7, Section 305.3.5.1 Energy consumption reduction
Proposed Change LogID 6150 & 6149 569

24. Thomas Culp – TG-5, Section 703.2.5.1 Fenestration Specifications & Section 703.2.5.2 Enhanced Fenestration Specifications
Proposed Change LogID 6066 & 6067 571

25. Steven Rosenstock – TG-5, Section 703.3.3 Heat pump heating efficiency
Proposed Change LogID 6168 577

26. Steven Rosenstock – TG-5, Section 703.3.6 Ground source heat pump installation
Proposed Change LogID 6065 578

27. Steven Rosenstock – TG-5, Section 703.3.6 Ground source heat pump installation
Proposed Change LogID 6065 584

28. Steven Rosenstock – TG-5, Section 703.5.1 Water heater Energy Factor & Section 703.5.5 Solar water heater
Proposed Change LogID 6166 & 6167 586

29. Craig Conner – TG-5, 703.7.3 Passive cooling design
Proposed Change LogID 6448 589

30. Carl Seville – TG-5, Section 705.6.2.1 Air leakage validation of building or dwelling units
Proposed Change LogID 6251 591

31. Steven Rosenstock – TG-5, Section 706.8 Electrical vehicle charging station
Proposed Change LogID 6153 593

32. Steven Rosenstock – TG-5, Other for Chapter 7 & TG-7, Other for Chapter 11
Proposed Change LogID 6220 & 6221 594

33. Steven Rosenstock – TG-5, Other for Chapter 7 & TG-7, Other for Chapter 11
Proposed Change LogID 6220 & 6221 598

34. Steven Rosenstock – TG-5, Other for Chapter 7 & TG-7, Other for Chapter 11
Proposed Change LogID 6220 & 6221 600

35. Steven Rosenstock – TG-5, Other for Chapter 7 & TG-7, Other for Chapter 11
Proposed Change LogID 6220 & 6221 602

36. Keith Dennis – TG-7, Section 305.3.5.1 Energy consumption reduction
Proposed Change LogID 6171 604

37. Keith Dennis – TG-7, Section 305.3.5.1 Energy consumption reduction
Proposed Change LogID 6171 616

Resilient and Adaptation-Related Practices within the ICC/ASHRAE 700-2015 National Green Building Standard

Category	Specific Practice	Practice Overview	Event
Lot Design, Preparation, and Development	501.1 (1) (a)	An infill lot is selected	Natural Disaster
Lot Design, Preparation, and Development	501.2 (1)	1/2 mile walking to mass transit	Natural Disaster
Lot Design, Preparation, and Development	501.2 (2)	5 miles to mass transit w/ parking	
Lot Design, Preparation, and Development	501.2 (3)	Walkway and Street Crossing systems	
Lot Design, Preparation, and Development	501.2 (4)	1/2 mile to 6+ community resources	
Lot Design, Preparation, and Development	501.2 (5)	Dedicated, right-of-way bicycle lanes	
Lot Design, Preparation, and Development	503.1 (1)	Identify and conserve natural resources, including vegetation, during construction	Storms Landslide (unstable soils) Drought Intense Heat
Lot Design, Preparation, and Development	503.1 (2)	Implement a plan to conserve high-priority natural resources	
Lot Design, Preparation, and Development	503.1 (3)	Items listed are protected under direction of qualified professional	
Lot Design, Preparation, and Development	503.2 (1) (2) & (4)	Terrain adaptive architecture used	Storms Landslide (unstable soils) Drought
Lot Design, Preparation, and Development	503.2 (2)	Hydrological/soil stability study completed	
Lot Design, Preparation, and Development	503.2 (4)	Long-term erosion effects reduced using building clustering, terracing, retaining walls, or destabilization	
Lot Design, Preparation, and Development	503.4(1)	Site assessment to preserve natural drainage and existing permeable soils	Storms Flooding
Lot Design, Preparation, and Development	503.4(3)(c)	LID/Green SWM to prevent discharge of 95th percentile storm	
Lot Design, Preparation, and Development	503.4(4)(c)	Permeable materials for over 50% of exterior surfaces (parking, drives, patios, etc.)	
Lot Design, Preparation, and Development	503.5(1)	Native Plant Protection (50%)	Landslide (unstable soils) Drought
Lot Design, Preparation, and Development	503.5 (2)	Non-invasive vegetation that is native or regionally appropriate are selected	Drought
Lot Design, Preparation, and Development	503.5 (7)	Summer Shading for at least 30% of walls (5 years after planting, mean shadow cast by summer solstice 10 am, 12pm, and 3 pm position)	Intense Heat
Lot Design, Preparation, and Development	503.5 (8)	Vegetative wind breaks designed to protect lot and surrounding lots	High Wind Intense Cold
Lot Design, Preparation, and Development			Drought Intense Heat Landslide (unstable soils)
Lot Design, Preparation, and Development	504.3 (5)	Reduced Soil Compaction	Storms Flooding
Lot Design, Preparation, and Development	505.1 (4)	Water Permeable Surfaces	Storms Flooding

Category	Specific Practice	Practice Overview	Event
Lot Design, Preparation, and Development	505.2 (1)	50+% hardscape shaded, high SRI, or permeable materials	Intense Heat Flooding Storms
Lot Design, Preparation, and Development	505.2(2)	75+% Green Roof	Intense Heat Storms
Lot Design, Preparation, and Development	505.5	A community garden(s) on the lot provides for local food production	Earthquakes
Resource Efficiency	601.2 (3)	Performance-based structural design used to optimize lateral force-resisting systems	High Wind Earthquake
Resource Efficiency	601.8	Foundations used to minimize soil disturbance: frost-protected shallow, isolated pier and pad, deep, post, or helical piles	Intense Cold Storms Flooding
Resource Efficiency	601.9	75+% of exterior wall area have the structural and thermal characteristics of mass walls	High wind Intense Cold Intense Heat
Resource Efficiency	602.1.1.1	Capillary break and vapor retarder installed at concrete slabs in accordance with requirements listed	Storms Flooding
Resource Efficiency	602.1.1.2	Capillary break between footing and foundation to prevent moisture migration into foundation wall	
Resource Efficiency	602.1.2 (1) or (2)	Install rubberized coating and/or drainage mat	
Resource Efficiency	603.1.3.1	Where required for habitable and usable space below grade, exterior drain tile installed	
Resource Efficiency	603.1.3.2	Interior and exterior foundation perimeter drains installed and sloped to discharge to daylight, dry well, or sump pit.	
Resource Efficiency	602.1.7.3	Envelope designed for moisture control based on hygrothemral simulation	
Resource Efficiency	602.1.8	Where required , water-resistive barrier and/or drainage plane system installed behind exterior veneer and/or siding.	
Resource Efficiency	602.1.9	Flashing installed as required in NGBS	Storms
Resource Efficiency	602.1.10	Exterior doors are protected from precipitation and solar radiation via storm doors, porch roof/awning, extended roof overhang, recessed open door.	Storms
Resource Efficiency	602.1.11	Tile backing materials installed under tiled surfaces in wet areas	Storms
Resource Efficiency	602.1.12	Roof overhangs provided over a minimum of 90% of exterior walls	Storms
Resource Efficiency	602.1.13	Ice barrier installed at roof eaves of pitched roofs in accordance with NGBS for areas with history of ice forming.	Intense Cold
Resource Efficiency	602.1.14	All horizontal ledgers are sloped away to provide gravity drainage	Storms
Resource Efficiency	602.2 (1) or (3)	At least 90% of roof surface either high SRI, or ENERGY STAR cool roof.	Intense Heat
Resource Efficiency	602.2 (2)	At least 90% of roof surface vegetated.	Storms Intense Heat
Resource Efficiency	602.3	Gutter and downspout system or splash blocks and effective grading provided to carry water at least 5 feet away from perimeter foundation walls	Storms Flooding
Resource Efficiency	602.4.1, 604.4.2, & 602.4.3	Final grade sloped away from edge of building at minimum slope of 5%, and water is directed to drains or swales.	Storms Flooding

Category	Specific Practice	Practice Overview	Event
Energy Efficiency	701.4.3.1	Building Thermal Envelope Air Sealing	Intense Heat Intense Cold
Energy Efficiency	701.4.3.2	Air Sealing and Insulation	Intense Heat Intense Cold
Energy Efficiency	701.4.3.3	Multifamily Air Leakage Alternative	Intense Heat Intense Cold
Energy Efficiency	701.4.3.4	Fenestration Air Leakage	Intense Heat Intense Cold
Energy Efficiency	703.1.2	Building Envelope Leakage	Intense Heat Intense Cold
Energy Efficiency	703.2.1	UA Improvement	Intense Heat Intense Cold
Energy Efficiency	703.2.2	Mass Walls	Intense Heat Intense Cold
Energy Efficiency	703.2.3	Radiant Barrier in Attic	Intense Heat Intense Cold
Energy Efficiency	703.2.4	Advanced Building Envelope Leakage	Intense Heat Intense Cold
Energy Efficiency	703.2.5.1	Fenestration	Intense Heat Intense Cold
Energy Efficiency	703.2.5.1.1	Dynamic Glazing	Intense Heat Intense Cold
Energy Efficiency	703.3.7	ENERGY STAR (or equal) ceiling fans installed	Intense Heat
Energy Efficiency	703.5.5	Solar domestic water heating system is installed, per NGBS requirements	Intense Cold Power/Utility Outage
Energy Efficiency	703.5.3	Drain-heat recovery system installed	Intense Cold
Energy Efficiency	703.7.1	Building orientation, sizing of glazing, skylights, and design of overhangs are in accordance with all NGBS requirements for solar optimization	Intense Cold Power/Utility Outage
Energy Efficiency	703.7.2	Automated solar protection or dynamic glazing is installed to provide shading for windows.	Intense Heat
Energy Efficiency	703.7.3	Building is designed in accordance with all NGBS requirements for passive cooling	Intense Cold Power Outage

Category	Specific Practice	Practice Overview	Event
Energy Efficiency	703.7.4	Building is designed in accordance with all NGBS requirements for passive heating	Intense Cold Power Outage
Energy Efficiency	705.2.2	Installation of a Tubular Daylighting Device or skylight in rooms with windows	Power/Utility Outage
Energy Efficiency	705.6.3	Insulation with minimum R-value of R-3 applied to hot water pipes	Cold Weather
Energy Efficiency	705.6.4	Potable hot water demand re-circulation system	Intense Cold
Energy Efficiency	706.5	On-site renewable energy systems are installed on the property	Power/Utility Outage
Energy Efficiency	706.7	Grid interactive water and/or space heating and cooling systems installed	Intense Heat Intense Cold
Water Efficiency	801.2 (1) & (3)	ENERGY STAR (or equal) dishwasher and washer with water factor of 4.0 or less installed	Drought
Water Efficiency	801.3 (3)	All showerheads have less than 1.6 flowrates	
Water Efficiency	801.4.1 (2)	All lavatory faucets have a max flow rate of 1.5 gpm	
Water Efficiency	801.5 (1)	All water closets have a an effective flush volume of 1.28 gpf or less. All urinals have a flush volume of 0.5 gpf or less.	
Water Efficiency	801.5 (4) (c)	One or more water closets and urinals are waterless and/or composting.	Natural Disaster
Water Efficiency	801.6.4 (3)	No irrigation is installed and a landscape plan is developed	Drought
Water Efficiency	801.7.1 (d)	All irrigation demands are met by rainwater capture	
Water Efficiency	802.1 (2)	Irrigation from reclaimed, gray, or recycled water on-site	Drought
Water Efficiency	801.7.2 (1) or (2)	Rainwater is used to supply one or more indoor appliances or fixtures, or total domestic demand.	Drought Power/Utility Outages
Water Efficiency	802.1 (1)	Water closet(s) flushed with reclaimed, recycled, or gray water	Drought
Water Efficiency	802.2	Reclaimed, graywater, or rainwater systems are rough plumbed (and permanently marked, tagged or labeled) into building	Drought
Water Efficiency	802.4	Engineered biological system or intensive bioremediation system installed, and treated water used on-site.	Drought
Water Efficiency	802.6	Advanced wastewater (aerobic) treatment system installed and treated water used on-site.	Drought
Indoor Environmental Quality	902.1.5	Fenestration designed for stack effect or cross-ventilation.	Power/Utility Outages
Indoor Environmental Quality	903.1.1 or 903.1.2	Cold water pipes insulated to at least R-4 or not installed in unconditioned spaces.	Intense Heat Intense Cold

Category	Specific Practice	Practice Overview	Event
Operation, Maintenance, and Building Owner Education	1001.1 (3)	Product Manufacturer's manuals for installed major equipment, fixtures, and appliances	ALL
Operation, Maintenance, and Building Owner Education	1001.1 (10)	Local public transportation options	
Operation, Maintenance, and Building Owner Education	1001.0 (9)	Information on the importance and operation of the home's fresh air ventilation system	
Operation, Maintenance, and Building Owner Education	1001.1 (12)	Where frost-protected shallow foundations are used, owner is informed of precautions.	
Operation, Maintenance, and Building Owner Education	1001.0 (13)	List of local service providers for regularly scheduled service and maintenance to ensure proper performance of equipment	
Operation, Maintenance, and Building Owner Education	1001.1 (17)	Information on native landscape materials and/or those with low water requirements	
Operation, Maintenance, and Building Owner Education	1001.1 (19)	Instructions for inspecting for termite infestation	
Operation, Maintenance, and Building Owner Education	1001.1 (20)	Instruction for maintaining gutters and downspouts and importance of diverting water at least 5 feet away from foundation.	
Operation, Maintenance, and Building Owner Education	1001.1 (21)	Where stormwater management measures are installed, information on the location, purpose, and upkeep of these measures	
Operation, Maintenance, and Building Owner Education	1001.1 (24)	Retrofit energy calculator that provides baseline for future energy retrofits.	
Operation, Maintenance, and Building Owner Education	1001.2	Training of initial homeowners in equipment operation and maintenance, controls systems, and occupant actions that will improve environmental performance of the building.	ALL

Risk Management and Healthcare Policy
Dovepress
open access to scientific and medical research

Open Access Full Text Article

REVIEW

Value of urban green spaces in promoting healthy living and wellbeing: prospects for planning

This article was published in the following Dove Press journal:
Risk Management and Healthcare Policy
27 August 2015
Number of times this article has been viewed

Andrew Chee Keng Lee[1]
Hannah C Jordan[1]
Jason Horsley[2]

[1]Section of Public Health, School of Health and Related Research, University of Sheffield, [2]Sheffield City Council, Sheffield, UK

Abstract: There has been considerable work done in recent years exploring the value of urban green space for health and wellbeing. Urban green spaces provide environmental benefits through their effects on negating urban heat, offsetting greenhouse gas emissions, and attenuating storm water. They also have direct health benefits by providing urban residents spaces for physical activity and social interaction, and allowing psychological restoration to take place. Consequently, there is a real need to understand the mechanisms by which these benefits accrue. Previously, much of the focus has been on the characteristics of the urban green space that are likely to influence its use, such as its accessibility, quality, facilities, attractiveness, and security. This assumes a causal relationship, when in reality the relationship is more complex and multifactorial. It is more likely that it is the functionality of the green space, be it for exercise or sociocultural activities, rather than its character, which translates to the reported benefits. Challenges exist, such as competing urban planning priorities, economic considerations, and market forces. There is thus a need for urban planning to match the health benefits sought with the needs of the community and the functionality that the urban green space will serve.
Keywords: urban green space, public open space, urban planning, public health

Introduction

Globally, the epidemics of obesity and mental illness affecting populations in many developed and developing countries are worsening around the world. Worryingly, obesity rates are on the rise, with figures as high as a quarter of the adult population in England and a third of adults in the USA affected.[1,2] Similarly, the annual prevalence of mental illness is high, with conditions such as depression affecting approximately one in 20 of the population.[3] Both of these public health issues are products of contemporary lifestyles in an increasingly urbanized world, and greater understanding of the determinants of urban health will become increasingly important for policy makers.

These two public health issues have traditionally been seen as the remit of health professionals and health care providers. However, in recent decades, there has been a growing awareness of the possible value of urban planning interventions in addressing them.[4] For example, some of the mental health issues arising in contemporary society and physical health challenges resulting from modern diets and sedentary lifestyles can be tackled through various activities undertaken in green environments.[5] Research into urban green space has grown considerably, particularly regarding its potential health benefits as well as approaches to optimizing them.

We provide here a narrative summary of the published literature on urban green space. We broadly define urban green space as any "green space", "public open space",

Correspondence: Andrew Chee Keng Lee
Section of Public Health, School of Health and Related Research, University of Sheffield, Regent Court,
30 Regent Street, Sheffield S1 4DA, UK
Tel +44 11 4222 0872
Fax +44 11 4272 4095
Email andrew.lee@shef.ac.uk

or "park" in an urban setting. While there may be subtle qualitative differences between these settings, we have used the terms synonymously for the purpose of this review.

Green spaces, urban planning, and design

The utility of urban green spaces for urban planners can be seen through many lenses.[6] Urban green spaces fulfil a range of different roles, such as social spaces and areas for recreation and cultural purposes. They also have economic and environmental purposes. Indeed, urban greening projects have been undertaken to maintain and increase property values due to their esthetic characteristics and functionality.[7]

Conversely, neighborhood environmental decay in rundown areas negatively affects residents' sense of security and heightens perceptions (and possibly the incidence) of crime. One US study suggests that urban greening may counteract this.[8] There were observed reductions in gun crime and vandalism following the greening of vacant urban land. Residents reported feeling less stressed as a result. There was also an increase in physical activity, which may have been due to residents being more inclined to exercise in a cleaner, greener, and "safer" environment.

The other key value of urban green spaces are the environmental benefits they provide.[7,9] For example, they counteract the urban heat island effect, thereby reducing the energy costs of cooling buildings. Urban greenery minimizes air, water, and noise pollution, and may offset greenhouse gas emissions through CO_2 absorption.[10] Urban greenery also provides storm water attenuation, thereby acting as a measure for flood mitigation.[11] Further ecological benefits include preservation of biodiversity and nature conservation.[12] Consequently, due to the range of environmental services they afford, urban green spaces can be viewed as a public good.

From the health perspective, urban green spaces are spaces that allow for health-promoting activities, such as physical activity or rest and relaxation, to take place. In this way, they have a direct relationship with the quality of life of urban dwellers. The range of purported health benefits of urban green spaces is considerable and this is covered in the following section.

Links to exercise, mental health, and overall wellbeing

Numerous studies in the past decade have reported the association between contact with green spaces and health benefits both at the individual and population level.[13,14] These have included beneficial associations with health outcomes, such as cardiovascular and respiratory mortality.[15] The three main hypothesized mechanisms for these benefits include: provision of opportunities for physical activity, recovery from stress and attention fatigue, and facilitation of social contact.

Physical activity/exercise

There is a growing body of evidence indicating that physical activity levels may be influenced by the urban environment. Studies have found associations between availability of urban green space and physical activity levels.[16] The provision of urban green spaces such as parks provides an important place for people to be active.[17] A significant proportion of vigorous physical activity in childhood takes place in urban parks.[18] Urban green space is therefore particularly important in urban areas where access to the open countryside is limited.[19] Indeed, accessibility of green spaces influences not just the likelihood of physical activity being undertaken but also its frequency.[20] It is also linked to a lower likelihood of being overweight or obese. Green spaces therefore may help facilitate active lifestyles in the urban setting.[21] In addition, they may be used as therapeutic spaces for rehabilitative exercise, such as for persons with coronary artery disease,[22] and have been associated with lower rates of diseases such as type 2 diabetes mellitus.[23]

Mental health and wellbeing

Urban green space may provide residents with opportunities for contact with the natural environment. Such contact has positive restorative effects on mental health and wellbeing and may also help to provide a buffer against stressful life events.[24,25] The benefits of green space on mental health and wellbeing may also arise from participation in activities occurring in these spaces, such as social interaction or physical exercise.[26] These benefits include alleviation of stress and anxiety, and improved mood and attention.

Social contact

As noted earlier, urban green spaces also provide opportunities for social interactions to take place. This in turn could help reduce social isolation, generate social capital, and lead to greater personal resilience and wellbeing.[7] This seems to be particularly important for elderly population groups.[27,28] Interestingly, in a few studies, social factors (eg, neighborliness) had a greater influence on the frequency of use of urban parks than the physical features of the parks.[29,30]

When, why, and how do people use green spaces?

It is important to understand the user's intended purpose for going to a green space. These are unsurprisingly varied. It is often a venue for exercise and physical activity either on an individual or group basis. In addition, some users may use the green space for a secondary purpose, such as a transport route to another location.[31]

Other uses of green spaces identified from previous studies include relaxation and stress reduction, to obtain peace and quiet, or to experience nature. Studies have also observed that people use green spaces for rest and restoration and as means to de-stress.[32,33] Green spaces perceived to be "serene", "social", and "natural" were said to have greater restorative effects. One meta-analysis reported that exercise undertaken in all green environments improved both self-esteem and mood. It also suggested that the presence of a water feature in a green space improved these positive effects.[5]

Urban green spaces are also used as places where social interaction occurs.[29,32] One ethnographic study from Scotland observed that green space had different "social" meanings and understandings for different user groups. This in turn shaped how people "used" green spaces and facilitated different types of social interaction. Conversely, different types of green space facilitate different kinds of interactions between people. Regular social interaction by park users, eg, could form the basis of greater community ties, foster a sense of identity and belonging, and generate more social capital.[34]

It is important to recognize that not all users see green spaces in the same way. Studies have shown that there is an implied "correct" way to use green space, specifically for an appreciation of nature, quiet contemplation, and gentle recreation.[35] Users who perceive the green spaces as a "playground", who value the entertainment opportunities, cafes, organized events, and facilities can be seen as in conflict with these ideas.[32] An appreciation of the variety of ways in which people use green spaces is therefore vital for effective planning.

Determinants of use of public green spaces

The determinants of use of public green spaces are also complex, interconnected, and varied.[28] The availability of urban green space is first and foremost a key requirement.[36] There is some suggestion that size matters, with greater benefits associated with larger green spaces.[14] The size of the urban green space may also dictate how it is used, in that larger spaces may be more likely to be used for physical activity, while smaller spaces are primarily used for "socializing" and "rest and restitution".[32]

Another key determinant for use of green spaces, cited in numerous studies, is their accessibility.[7] This includes the distance from home, in that persons living in close proximity to a green space are more likely to use it and to do so more frequently.[37] The optimal distance has been said to be less than 0.5 km or 5 minutes' walking time. Ease of accessibility is also important, such as the presence of cycle paths and minimal obstruction (eg, no need to cross busy roads). A survey of the use of green space in Odense, Denmark, showed that in 46% of the respondents the green space people used most was often not the closest one to them. They also found that self-reported poor health, having a child under 6 years, or having a dog made people significantly more likely to use their nearest green space.[31]

The qualities and characteristics of the urban green space are likely to be important as well.[36] In addition to factors such as distance to the green space, formal green spaces are more likely to be used. This is probably because such areas tend to have features that facilitate physical activity, such as good path networks and a perception of safety.[20] Other studies have also reported how both the presence of environmental features and residents' subjective awareness of those features are important in influencing behavior change.[21,30]

Perceptions of environmental hygiene, security, and safety are other important features. Rundown public open spaces may often be associated with unsavory activities, such as illegal gambling, homelessness, and prostitution, as well as crime and vandalism.[29] Such associations may deter key user groups, especially women and children, as well as the elderly.[37]

One study from Australia found that the quality of the space was more important than quantity on likelihood of psychological distress.[38] Quality was described as the presence of walking paths, shade, water features, irrigated lawns, birdlife, lighting, sporting facilities, playgrounds, type of roads in the vicinity and presence of water nearby. The study also noted that different types of user groups have different requirements of public open spaces, eg, some may find water features calming and attractive while parents of young children may see them as safety hazards.

In addition to the qualities and characteristics of the park, as noted earlier, social factors also play an important role in determining the accessibility and use of parks.[28] These include feelings of community cohesion.[30] Where feelings of social cohesion are absent, individuals may be less likely to use parks. This local sociocultural aspect of neighborhoods may adversely contribute to inequalities in health. Indeed, this may account for some subpopulation variations in green space use, eg, where ethnic and minority groups may be less likely to use green spaces.[31,36]

Mechanisms of action and revealed functionality

Limitations of the evidence base

Many studies have explored the features and characteristics of urban green spaces that are associated with positive health benefits. However, the evidence for these links is weak, inconsistent, and occasionally contradictory owing to the heterogeneity of the studies undertaken.[15,37,39,40] In addition, there are limitations affecting the observational, ecological, and cross-sectional studies that have been carried out, ie, multiple confounding factors and the long time lag between exposure to green space and manifestation of effects.[13,41]

We have previously reported on the other limitations of many studies, such as failure to use a comparison group, use of inappropriate measures, selection bias, short follow-up periods, and failure to account for the fact that use of urban green space may be biased toward physically active groups rather than the population as a whole. Many studies found associations between health indicators and urban green space that were null or not statistically significant.[13] A recent systematic review found that studies utilizing objective physical activity measures such as pedometers and those examining direct measures of obesity were, respectively, 18% and 6.2% less likely to find a beneficial relationship.[42] There is also the issue of ecological fallacy, ie, not everyone who lives in a leafy suburb with good access to urban green space will necessarily derive a health benefit.[14,43]

Consequently, there is currently insufficient robust evidence to prove a causal relationship between urban green space and health benefits. While finding objective measures of benefit has been challenging with mixed results, the self-reported benefits of green spaces have tended to be much more consistent.[15]

Mechanism of action for the health benefits of urban green space

So why are there such mixed findings in the literature? Part of the issue may be how previous studies have explored the associations between health and green space. Several studies have sought to identify "features" and "characteristics" of urban green spaces that are linked with health outcomes, eg, hygiene, size, esthetic appeal, and facilities.[28] However, this approach makes an assumption of direct causality between the features of an urban green space and outcomes. Once again, our previous review found that it was difficult to ascertain to what extent the environmental attributes of an urban green space were responsible for any health benefits seen.[13]

In reality, the relationship is more likely to be complex, multifactorial, and prone to considerable confounding.[13] Health outcomes are more likely to be directly linked to the activities that are undertaken in the urban green space, ie, based on its functionality (Figure 1). In other words, it is likely that the health benefits accrued are a result of use of urban green spaces and not just from their presence. One research priority therefore would be to study and unravel the possible mechanisms that lead to health benefits, and reveal the functionality of the space that is health-promoting.

Implications for research and practice

Assuming functionality is linked to health outcomes, the different uses of urban green space is likely to yield different health benefits. For example, based on the studies reviewed thus far, eg, social benefits such as the reduction of social isolation is predicated on social contact happening in an urban green space. That space may have to be situated in the right locality, carry some social meaning for the neighborhood, and its user groups permit or facilitate social interactions to occur.[30] The observation that some minority groups do not use certain green spaces indicates that such spaces may be contested spaces that limit accessibility and acceptability to certain groups only. Consequently, modifications of the physical environment alone may be insufficient to promote physical activity if there are significant psychosocial processes at play. These social ties, social networks, and social interactions may differ quite considerably between affluent and more deprived neighborhoods. Therefore, concomitant modifications of the social environment may be required.[44] In addition, there is also a need to identify what health outcomes are sought, what activities in urban green spaces contribute to these outcomes, and in turn identify what features of an urban green space would encourage such activities. A blunderbuss approach to development of urban green spaces may not translate into the desired health outcomes.

The weaknesses of the evidence base to date highlight the need for more rigorous scientific research to determine whether altering the built environment will result in increased levels of physical activity and decreased obesity rates. More research attention needs to be paid to these relationships, building on advances in research design and analytical approaches.

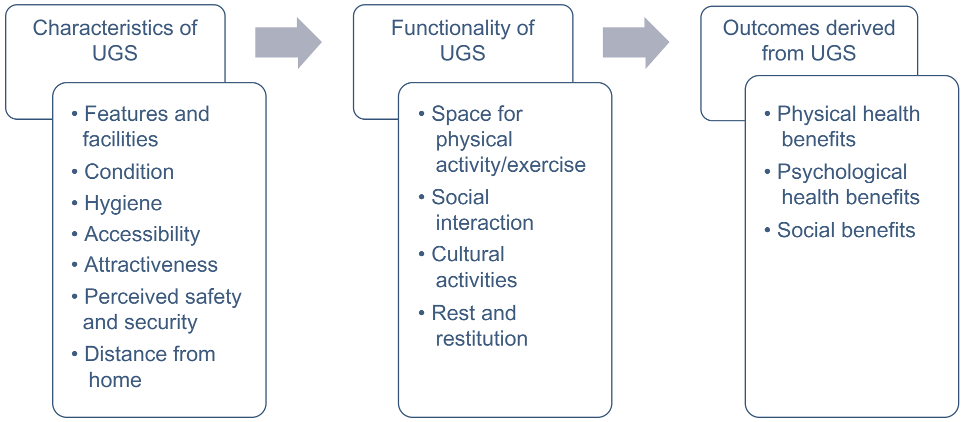


Figure 1 Relationship between urban green space characteristics, functionality, and outcomes.
Abbreviation: UGS, urban green space.

Potential threats to urban green space and possible solutions

Urban green spaces will inevitably be threatened in an environment where urban space is limited and there is a relative shortage of housing and land available for development. Urban green space costs money to maintain. Where green space is perceived as being run down, it may be at greater risk of being developed rather than refurbished. Resource constraints and reductions in public spending are likely to have a disproportionate impact on urban green space as it has to compete with other public services that have higher priority or political sanction, as has happened in the UK.[45] In the absence of a robust scientific basis for the health benefits of urban green space, it is difficult to make the case for allocating scarce public health resources to an endeavor for which there is limited information and which could be perceived as simply a "fad".

Furthermore, urban green space planning cannot be seen in isolation from other local government priorities such as transport and housing. Efforts to engineer health-promoting towns and cities are often beleaguered by poor integration between planning, transport, housing, and health policies. Training, communication, and an understanding of the levers for change are essential prerequisites for urban planners to be able to address the joint concerns of planning and health, as embodied in green space planning.

Another potential threat to public green space is where the space is available but access to it is restricted. This is often seen where urban land is redeveloped for housing and green space is provided but is only accessible to residents. This is an attractive approach for developers, as the "exclusive" green space may increase the retail value of the property; however, such approaches inevitably increase inequities in access. Similarly, urban green space initiatives to make more deprived neighborhoods healthier and more attractive can drive up property values and displace the residents for whom the initiatives were designed to be of benefit.[46]

Conclusion and perspectives

The literature to date has several key implications for urban planning. Firstly, urban planning can and should have a public health component in view of the purported health benefits. Improving the accessibility is likely to lead to greater use of urban green space. In practice, this could take the form of health impact assessments of urban developments.[21] If urban green space planning is part of a wider health promotion policy, active marketing and promotion of its use is likely to be needed, especially where levels of provision or preexisting use is insufficient. Radical shifts in current approaches to urban design may be called for.

Secondly, residents use urban green spaces in a variety of ways. Therefore, it is important to understand how the green space may be used and what the needs of residents are.[29,30] In order to enable urban development to better match local needs and values, public engagement in the planning and design process is key.[7] Furthermore, if urban greening programs are carried out without due attention to the form these green spaces are to take or to related aspects such as city transport strategies, there may be no benefit in terms of population health.[43]

There remain several unknowns. Firstly, how much urban green space is needed, ie, what is the optimal green space ratio?[7] Secondly, what enhancements are required and what degree of features are needed to facilitate usage and the benefits accrued from urban green space?[21] How do we encourage its use?

Finally, there is a need for further economic work to calculate the cost to benefit/utility of urban green space.[31]

This is challenging in view of the multiplicity of uses and potential co-benefits accrued, as well as difficulties quantifying both the costs and attributable benefits. In view of the multiplicity of purposes served by urban green spaces, as well as the range of benefits to urban areas, they are more than a peripheral nicety and are a key aspect of urban planning and design.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Public Health England Obesity. Adult weight data factsheet. Public Health England; 2014. Available from: http://www.noo.org.uk/securefiles/150708_0057//AdultWeight_Aug2014_v2.pdf. Accessed May 15, 2015.
2. Ogden CL, Carroll MD, Kit BK, et al. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA*. 2014;311(8):806–814.
3. Ferrari AJ, Somerville AJ, Baxter AJ, et al. Global variation in the prevalence and incidence of major depressive disorder: a systematic review of the epidemiological literature. *Psychol Med*. 2013;43(3):471–481.
4. Barton H, Grant M. Urban planning for healthy cities. *J Urban Health*. 2013;90(1):129–141.
5. Barton J, Pretty J. What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environ Sci Technol*. 2010;44(10):3947–3955.
6. Van Leeuwen E, Nijkamp P, de Noronha Vaz T. The multifunctional use of urban greenspace. *Int J Agr Sustain*. 2010;8(1–2):20–25.
7. Haq SM. Urban green spaces and an integrative approach to sustainable environment. *J Environ Protect*. 2011;2(5):601–608.
8. Branas CC, Cheney RA, MacDonald JM, et al. A difference-in-differences analysis of health, safety, and greening vacant urban space. *Am J Epidemiol*. 2011;174(11):1296–1306.
9. Strohbach MW, Arnold E, Haase D. The carbon footprint of urban green space – a life cycle approach. *Landscape Urban Plan*. 2012;104(2):220–229.
10. Pataki DE, Carreiro MM, Cherrier J, et al. Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. *Front Ecol Environ*. 2011;9(1):27–36.
11. Roy S, Byrne J, Pickering C. A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban For Urban Gree*. 2012;11(4):351–363.
12. Young RF. Managing municipal green space for ecosystem services. *Urban For Urban Gree*. 2010;9(4):313–321.
13. Lee AC, Maheswaran R. The health benefits of urban green spaces: a review of the evidence. *J Public Health*. 2011;33(2):212–222.
14. Mitchell R, Astell-Burt T, Richardson EA. A comparison of green space indicators for epidemiological research. *J Epidemiol Community Health*. 2011;65(10):853–858.
15. Richardson EA, Mitchell R. Gender differences in relationships between urban green space and health in the United Kingdom. *Soc Sci Med*. 2010;71(3):568–575.
16. Mytton OT, Townsend N, Rutter H, et al. Green space and physical activity: an observational study using health survey for England data. *Health Place*. 2012;18(5):1034–1041.
17. Macintyre S, Macdonald L, Ellaway A. Do poorer people have poorer access to local resources and facilities? The distribution of local resources by area deprivation in Glasgow, Scotland. *Soc Sci Med*. 2008;67(6):900–914.
18. Lachowycz K, Jones AP, Page AS, et al. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? *Health Place*. 2012;18(3):586–594.
19. Maas J, Verheij RA, Groenewegen PP, et al. Green space, urbanity, and health: how strong is the relation? *J Epidemiol Community Health*. 2006;60(7):587–592.
20. Coombes E, Jones AP, Hillsdon M. The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Soc Sci Med*. 2010;70(6):816–822.
21. Durand CP, Andalib M, Dunton GF, et al. A systematic review of built environment factors related to physical activity and obesity risk: implications for smart growth urban planning. *Obes Rev*. 2011;12(5):e173–e182.
22. Grazuleviciene R, Vencloviene J, Kubilius R, et al. The effect of park and urban environments on coronary artery disease patients: a randomized trial. *BioMed Res Int*. 2008;2008:403012.
23. Astell-Burt T, Feng X, Kolt GS. Is neighborhood green space associated with a lower risk of type 2 diabetes? Evidence from 267,072 Australians. *Diabetes Care*. 2014;37:197–201.
24. Hartig T, van den Berg AE, Hagerhall CM, et al. Health benefits of nature experience: psychological, social and cultural processes. In: Nilsson K, Sangster M, Gallis C, et al, editors. *Forests, Trees and Human Health*. Rotterdam, The Netherlands: Springer; 2011.
25. van den Berg AE, Maas J, Verheij RA, et al. Green space as a buffer between stressful life events and health. *Soc Sci Med*. 2010;70(8):1203–1210.
26. Nutsford D, Pearson AL, Kingham S. An ecological study investigating the association between access to urban green space and mental health. *Public Health*. 2013;127(11):1005–1011.
27. Sugiyama T, Thompson CW. Associations between characteristics of neighbourhood open space and older people's walking. *Urban For Urban Gree*. 2008;7(10):41–51.
28. Bedimo-Rung AL, Mowen AJ, Cohen DA. The significance of parks to physical activity and public health: a conceptual model. *Am J Prev Med*. 2005;28(2):159–168.
29. Lo AY, Jim CY. Differential community effects on perception and use of urban greenspaces. *Cities*. 2010;27(6):430–442.
30. Seaman PJ, Jones R, Ellaway A. It's not just about the park, it's about integration too: why people choose to use or not use urban greenspaces. *Int J Behav Nutr Phys Act*. 2010;7:78.
31. Schipperijn J, Ekholm O, Stigsdotter UK, et al. Factors influencing the use of green space: results from a Danish national representative survey. *Landscape Urban Plan*. 2010;95(3):130–137.
32. Peschardt KK, Schipperijn J, Stigsdotter UK. Use of small public urban green spaces (SPUGS). *Urban For Urban Gree*. 2012;11(3):235–244.
33. Peschardt KK, Stigsdotter UK. Associations between park characteristics and perceived restorativeness of small public urban green spaces. *Landscape Urban Plan*. 2013;112:26–39.
34. Dinnie E, Brown KM, Morris S. Community, cooperation and conflict: negotiating the social well-being benefits of urban greenspace experiences. *Landscape Urban Plan*. 2013;112:1–9.
35. Kessel A, Green J, Pinder R, et al. Multidisciplinary research in public health: a case study of research on access to green space. *Public Health*. 2009;123(1):32–38.
36. van Dillen SM, de Vries S, Groenewegen PP, et al. Greenspace in urban neighbourhoods and residents' health: adding quality to quantity. *J Epidemiol Community Health*. 2012;66(6):e8.
37. Rosso AL, Auchincloss AH, Michael YL. The urban built environment and mobility in older adults: a comprehensive review. *J Aging Res*. 2011;2011:816106.
38. Francis J, Wood LJ, Knuiman M, et al. Quality or quantity? Exploring the relationship between public open space attributes and mental health in Perth, Western Australia. *Soc Sci Med*. 2012;74(10):1570–1577.
39. Richardson E, Pearce J, Mitchell R, et al. The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility. *BMC Public Health*. 2010;10(1):240.
40. Thompson CJ, Boddy K, Stein K, et al. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environ Sci Technol*. 2011;45(5):1761–1772.

41. Lachowycz K, Jones A. Greenspace and obesity: a systematic review of the evidence. *Obes Rev*. 2011;12(5):e183–e189.
42. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The relationship between built environments and physical activity: a systematic review. *Am J Public Health*. 2012;102(10):e7–e13.
43. Richardson EA, Mitchell R, Hartig T, de Vries S, Astell-Burt T, Frumkin H. Green cities and health: a question of scale? *J Epidemiol Community Health*. 2012;66(2):160–165.
44. Oka M. Toward designing an environment to promote physical activity. *Landscape J*. 2011;30(2):280–298.
45. Allender S, Gleeson E, Crammond B, et al. Policy change to create supportive environments for physical activity and healthy eating: which options are the most realistic for local government? *Health Promot Int*. 2012;27(2):261–274.
46. Wolch JR, Byrne J, Newell JP. Urban green space, public health, and environmental justice: the challenge of making cities 'just green enough'. *Landscape Urban Plan*. 2014;125:234–244.

FIRE & LIFE SAFETY SECTION
OF THE INTERNATIONAL ASSOCIATION OF FIRE CHIEFS
4025 FAIR RIDGE DRIVE • FAIRFAX, VA 22033-2868 • TEL: 703/273-0911 • www.iafc.org

April 17, 2015

To: Developers of Green Building Codes, Standards, Rating Systems and Guidelines

The International Association of Fire Chiefs Fire & Life Safety Section supports incentives and requirements for the use of design, construction, and maintenance practices, in green building codes and standards, including vegetation management plans, to address the hazards related to fire in the wildland-urban interface.

While it is preferable to not build in the wildland-urban interface it is unrealistic to believe that it will not happen. Where it happens, conformance with the provisions and principles of the International Wildland-Urban Interface Code is needed to safeguard life; to protect property; and, to mitigate the threats to the environment posed by building in the wildland-urban interface.

The environmental benefits of limiting the exchange of fire between buildings and wildland fuels are both significant and evident. Wildland fire prevention:

- Prevents the contamination of the atmosphere from particulates and other products of combustion, including carbon released into the atmosphere. This can include persistent organic pollutants released by combusting building materials.
- Prevents the loss of soils from erosion where stabilizing vegetation has been burned away by the event.
- Prevents wildland fires from spreading to buildings, meaning that the environmental impacts associated with the manufacture and installation of the materials used to construct those buildings – and reconstruct those buildings - are not wasted.
- Conserves critical water resources by reducing the need for water for suppression.

Advocates for both fire safety and the environment should support fire safe management practices in the wildland-urban interface by supporting their incorporation in green building codes, standards, rating systems, and guidelines.

Sincerely,

Adolf Zubia

Adolf Zubia, Chief
Fire & Life Safety Section Chair

To address concerns with water use for turfgrass in arid climates we propose that points for turf limitations be awarded only where annual precipitation averages 12 or less inches per year.

The positive environmental benefits that turfgrass can provide have been extensively documented for the committee previously in the process. They include oxygen production, stormwater management, biomass accumulation, replacement of hardscapes, bioremediation, carbon sequestration, environmental cooling, nitrogen and phosphorous capture, fire safe site design, atmospheric cleansing, control of water and wind erosion and more.

Turfgrass limitations make even less sense at the development or master community (or multifamily) level than they do on individual lots. To create exterior open space that encourages interaction with the environment, social interaction, passive recreation, and promotes physical activities via athletic fields and golf courses should be a prime goal of urban site development. Disincentives for areas of turfgrass are counterproductive.

Turfgrass is the vegetative material of choice for athletic activity, both organized and informal. It is unparalleled as a vegetative surface for viewing performances and other uses and social gatherings. It is an accessible traveling surface as it allows for unobstructed, omnidirectional movement. Where public safety is a concern, it is an inviting feature because it doesn't shelter undesirable lurking.

Master community development incorporates the sort of open green space that people need to maintain safe, healthy bodies and minds. Green spaces and recreation areas are fundamental to sustainable development. It is the development of human habitat.

The following pictures are of the 37 parks constructed as part of the Stapleton master community in Denver CO. These parks are maintained and managed by the Stapleton Master Community Association.

From the website: *"A Denver park is a beautiful thing. It's a fresh perspective. A good conversation. A place to lose a few pounds or the weight of the world. A park can change your mood. Lift your spirits. And turn an ordinary day into one to remember. Kids expand their imaginations and learn to play together. People break free of their over-scheduled lives. That's the power of a park—a Denver park.*

Stapleton also makes these claims: that approximately a third of Stapleton is dedicated to recreational open space for Denver and surrounding communities; that Westerly Creek was transformed from a buried drainpipe into an ecological showcase: part recreational park, part riparian ecosystem, part stormwater management system; and, that water-saving methods include drought-tolerant landscaping in yards and public spaces .

Turfgrass is a visible design element in 28 of the pictures and a featured element in more than half. The narrative is from the community's website with relevant details highlighted for this comment.

The pictures show a healthy, sustainable community that relies on turfgrass to meet multiple environmental and human well-being needs. Particularly where water supplies are sufficient, turf disincentives are disincentives to healthy communities.

29TH AVE PARKWAY – East 29th Ave Neighborhood – Inspired by the Tuileries Garden in Paris, this pathway is lined with trees, benches and flowers. It's particularly active in the summer when people walk with their dogs, strollers and wagons (sometimes all three at once) to and from the farmers markets.

32ND AVE PARKWAY – Central Park West Neighborhood – A green corridor that provides a direct connection to Central Park. A meandering footpath that makes getting from A to B a sincere pleasure.

35TH AVE PARKWAY – Central Park North Neighborhood – Take the trail to the trail. Runners and walkers start their adventure on this parkway and connect to Westerly Creek and the Sand Creek Regional Trail. It opens to football-shaped lawn at Xenia Street where you'll find a family of dogs having a picnic

ARC PARK – Eastbridge Neighborhood – Two playgrounds with an open lawn in the center, and a walkway that follows the low, stone wall arching through the park.

ARROWHEAD PARK – Eastbridge Neighborhood – Delivers great views of the Front Range. A quiet respite with open space and benches.

BOSTON STREET GARDENS – Wicker Park Neighborhood – Coming Soon! Has a walking path that stretches between seasonal flower gardens, places where you can relax under shady trees and take in the elegant homes with colors and architectural styles hand-selected to create this charming city street scene

BOUQUET PARK – Bluff Lake Neighborhood – landscaping and plantings that appeal to the sense of smell. Plus a cutting edge garden.

CENTRAL PARK – Borders Westerly Creek, Central Park West & Central Park North Neighborhoods – The third largest park in Denver includes playground equipment, a pond, climbing wall, fountains, gathering spaces, paved and dirt jogging trails, multi-sport fields, lookout spot, sledding hill, barbecues, bocce ball courts, full-length promenade and shade structures.

CHERRY PIE PARK – Bluff Lake Neighborhood – Inspired by the sense of taste. Features cherry trees, a recipe holder and edible landscape.

COMMUNITY GARDEN – South End Neighborhood – If you are lucky enough to have a spot, the community garden is a great source of better-tasting salads

CONSERVATORY GREEN – Conservatory Green Neighborhood – Two-acre performance green, water feature, shade structure and lots of gathering spaces.

CONSTELLATION PARK – South End Neighborhood – Recognizing people's fascination with night's sky, Constellation Park features an open area for stargazing and stones that form the Big Dipper. Includes a playground for youngsters too small to reach the telescope.

DOG PARK – South End Neighborhood – Three-acre off leash park

F-18 PARKS A B C D – Central Park North Neighborhood – Gathering spaces inspired by elegant, formal parks found in Savannah, Georgia.

FALL PARK – Eastbridge Neighborhoods – Lookout across Westerly Creek from a shady pergola. Here, maple trees (and a mix of foliage) blaze with the colors of autumn.

FOUNDERS GREEN – East 29th Avenue Neighborhood – The hub of social activities; home of the farmers markets, movies on the green, StapletonRocks!, Stapleton Beer Fest and much more (50+ events/year). Features fountains, public art and at its center a two-acre performance area.

GREEN LINKS – Conservatory Green Neighborhood – Linear parks that mix urban agriculture with prairie grasses. Vegetable gardens, flower gardens and massive logs and boulders for nature-inspired play. Plus benches, walking/jogging paths and playground equipment.

HARVEST PARK – Willow Park East Neighborhood – A shaded community table, playground and edible plants such as pumpkins to be harvested in the fall.

HERITAGE PARK – East 29th Avenue Neighborhood – Open space that serves a deeper purpose: managing storm water. This is one of many Denver parks designed to help clean and move excess water.

LILAC LANE PASSAGEWAY – Conservatory Green Neighborhood – Pedestrian passageway between streets, lined with lilacs. A beautiful way to get from A to B.

MEASUREMENT PARK – 29th Avenue Neighborhood – Another of Stapleton's many water-wise parks – helping manage, clean and move storm water.

MEWS – Central Park West Neighborhoods – Linear green spaces that take the place of streets. Homes are oriented toward these quiet parks fostering a unique sense of community. And each block has its own character; a mews may feature a playground, a giant sand pit or a community table.

PIZZA PARK– Willow Park East Neighborhood – Coming soon! In this park shaped like a pizza slice you will find an outdoor kitchen featuring picnic tables, a grill and a pizza oven, surrounded by edible herbs that might be used in your cooking!

QUILTED GARDEN PARK – Willow Park East Neighborhood – Inspired by quilting and prairie folk art, this park includes a picnic table surrounded by a patchwork of plantings, a sandbox, playground and an art piece that looks like an exaggerated pin cushion

RUMBLE PARK – Bluff Lake Neighborhood – Inspired by the sense of sound. Features include sound tubes for kids, stone structures and an amphitheater as well as a paved walking path, green belt and benches.

SAIL PARK – Eastbridge Neighborhood – Sometimes you just need some green grass, a bench to sit on and the warm sun on your face.

SONGBIRD PARK – South End Neighborhood – Gazebo-type gathering spaces, benches, geometric walking paths, a fountain and two very nice residences for our feathered friends.

SPINNING SPOKES PARKLET – Conservatory Green Neighborhood – Named for its wheel-like landscape design, two of the "spokes" have community garden plots and one spoke features an artful wire and metal post pergola covered in grape vines. Of course, there's also a bike track for kids with start and finish signs.

SPRING PARK – Eastbridge Park Neighborhood – From its elevated position, Spring Park delivers great views of Westerly Creek and Colorado's Front Range. Enjoy the shade structure, open space, and the only May pole in Stapleton.

SQUARE PARK – Eastbridge Neighborhood – The concept for Square Park is unique because it's filled with trees instead of being bordered by them like many of the neighborhood parks in Stapleton. Be sure to check out the honey locust trees that will someday create a canopy of shade.

SUMMER PARK – Eastbridge Park Neighborhood – Features a nice playground, adjacent to a lawn for impromptu sports. Large shade trees are planted along the south side to provide relief from the hot, summer sun.

TERRA PARK – East 29th Avenue Neighborhood – The center of this water-wise park is very low so it can collect excess storm water. The water is cleansed through sand and then it's on its way to Westerly Creek

TRIANGLE PARK – East 29th Avenue Neighborhood – Look for the formal plaza design and the massive trees rescued from the original Stapleton Airport.

UPLANDS PARK – Conservatory Green Neighborhood – Weaves an active green corridor through the Conservatory Green neighborhood. The park will be full of delightful surprises like bocce ball courts and outdoor living rooms.

VALENTIA STREET PARKWAY – Conservatory Green Neighborhood – This tree- and flower-lined footpath connects Conservatory Green Plaza with the future Prairie Meadows Park. Concrete-framed landforms provide a modern-design throughout the Conservatory Green neighborhood

WICKER PARK – Wicker Park Neighborhood – Coming Soon! In the heart of the neighborhood, a park where your idea of ‘play” can take many forms. The park will include large grassy area to kick a soccer ball, or just relax and watch the kids on the playground

WINTER PARK – Eastbridge Neighborhood – On the winter solstice, stand at the center of the snowflake-emblazoned plaza and watch the sun drop between two, perfectly-positioned vertical stones on a nearby hill. Conifer trees provide a welcome burst of color during the snowy winter months.

To help bees, skip herbicides and pesticides, keep lawns naturally diverse

October 7, 2016

UMass Amherst urban ecologists say practices that support nesting and foraging opportunities for bees could have important implications for bee conservation in suburban areas. Credit: UMass Amherst

Declining populations of pollinators is a major concern to ecologists because bees, butterflies and other insects play a critical role in supporting healthy ecosystems. Now a new study from urban ecologists at the University of Massachusetts Amherst suggests that when urban and suburban lawns are left untreated with herbicides, they provide a diversity of "spontaneous" flowers such as dandelions and clover that offer nectar and pollen to bees and other pollinators.

Private lawns make up a significant part of urban lands in the United States, an estimated 50 percent of city and suburbs, say Susannah Lerman and co-author Joan Milam, an adjunct research fellow in environmental conservation. They write, "Practices that support nesting and foraging opportunities for bees could have important implications for bee conservation in suburban areas."

Lerman, an adjunct UMass Amherst faculty member who is also with the U.S. Forest Service, says, "We are still surprised at how many bees we found on these untreated lawns."

In this study of lawns in suburban Springfield, Mass., she and Milam found that "spontaneous lawn flowers could be viewed as supplemental floral resources and support pollinators, thereby enhancing the value of urban green spaces." Details appear in the current issue of *Annals of the Entomological Society of America*.

For this study, supported by the National Science Foundation, the researchers enlisted owners of 17 lawns in suburban Springfield. Between May 2013 and September 2014, the homeowners did not apply chemical pesticides or herbicides to lawns.

"We documented 63 plant species in the lawns, the majority of which were not intentionally planted," the authors report. Lerman and Milam visited each yard six times per year for two years, finding a total of 5,331 individual bees representing 111 species, of which 97 percent were native to North America.

Of particular interest was the discovery of a large population of Lasioglossum illinoense, a widespread sweat bee species and common in its range, but known in Massachusetts only from a single specimen collected in the late 1920s. The population of L. illinoense in Springfield lawns documents the northeastern range limit for this species.

Conserving native bees for their vital pollination services is of national interest, Lerman and Milam point out, and this new information on native bee distribution and abundance is important for making informed conservation and management decisions regarding pollinator conservation.

Overall, one of their main findings, say Lerman and Milam, is that "when lawns are not intensively managed, lawn flowers can serve as wildlife habitat and contribute to networks of urban green spaces."

Further, "developing outreach to homeowners and lawn care companies to encourage, rather than eliminate, lawn flowers such as dandelions and clover and thin grass cover or bare spots could be a key strategy for urban bee conservation programs targeting private yards."

Explore further: **Scientists show cities can serve as a refuge for insect pollinators**

Provided by: University of Massachusetts Amherst

Flowering Bee Lawns

Lawns are traditionally ornamental or recreational plantings of turfgrass that are mowed and managed to achieve a desired aesthetic. While turfgrasses are used for a variety of functions, such as sports fields and erosion control, lawns are typical of homes and businesses and are generally established for aesthetic purposes showing neatness and care.

A flowering lawn differs from a traditional lawn in having flowering plants as well as turfgrasses. Benefits of a flowering lawn include: increased lawn resilience to environmental pressures, natural diversity that benefits bees and other pollinators and insects, and the beauty of the flowers themselves.

While flowering lawn weeds such as dandelions and creeping charlie are often seen as a nuisance, they can actually have benefits to lawns in addition to bees. They may be better adapted than turfgrasses to difficult site conditions such as compacted soil, drought, flooding, shade, and low nutrient availability.

The downside to lawn weeds such as dandelion and creeping charlie is that they are widely reviled by homeowners. This “bad rep” can create social pressures to remove them even if the lawn manager is tolerant of diverse lawns and realizes how plant diversity benefits pollinators. A homeowner may choose to keep flowering weeds if they do not spread aggressively into neighboring lawns. A good alternative is to follow our instructions for planting less aggressive flowers into lawns.

Are you interested in the benefits of a flowering lawn? Are you going to seed flowers directly into your lawn, or would you like to plant a flowering lawn from scratch? Will you seed native, or non-native flowers into your lawn? What about common weedy flowers in lawns? Here (PDF) we provide a number of practices that can increase your success, and provide native and non-native flower suggestions based on our current research trials at the University of Minnesota.

Flowering Lawn Informational Handout click here

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Funding for this project was provided by
the Minnesota Environment and Natural Resources Trust Fund
as recommended by
the Legislative-Citizen Commission on Minnesota Resources
(LCCMR)

Bees in Agriculture

College of Food, Agricultural and Natural Resource Sciences
University of Minnesota

Department of Entomology
219 Hodson Hall, 1980 Folwell Ave., St. Paul, MN 55108

Bee Lab
www.BeeLab.umn.edu
Ian Lane, Eric Watkins, Marla Spivak, Mary Meyer
Bee Squad

Flowering Bee Lawns for Pollinators

Flowering Lawns: What Are They, and Why?

Definition of a flowering lawn

Lawns are traditionally ornamental or recreational plantings of turfgrass that are mowed and managed to achieve a desired aesthetic. While turfgrasses are used for a variety of functions, such as sports fields and erosion control, lawns are typical of homes and businesses and established for generally aesthetic purposes showing neatness and care. A flowering lawn differs from a traditional lawn in having flowering plants as well as turf grasses. Benefits of a flowering lawn include increased lawn resilience to environmental pressures, natural diversity that benefits insects and other animals, and the beauty of the flowers themselves.

Landscape, biodiversity benefits

One of the main challenges facing bees, and all wildlife, is the loss of habitat. People change the landscape in many ways when converting land to different uses, and most of those changes are detrimental to biodiversity. One excellent example of this is agriculture. Farmers often plant large and uniform stands of crops to increase their management efficiency, and then attempt to exclude crop competitors such as weeds and insects. This system, while efficient at producing food, has resulted in increasingly large areas of low quality habitat for wildlife. One method proposed for offsetting this loss of biodiversity is called reconciliation ecology. Reconciliation ecology is a conservation philosophy that seeks to improve the ability of human landscapes to support biodiversity, while still allowing for human use. This is an important concept, as it acknowledges the human role in conserving biodiversity, and seeks to find new management solutions that do not put human use and biodiversity needs in conflict.

Watch Dr. Marla Spivak, professor at the University of Minnesota, discuss the importance of biodiversity and bees in this TED talk Why Are Bees Disappearing.

Lawns are not entirely different from farms in that they are managed as large single or similar species plantings, with chemical inputs sometimes used to reduce non-grass plants usually viewed as competitors. Lawns are unlike much of agriculture though, in that they are perennial in nature and not managed as a commodity. This subjective and changing use of lawns gives them potential for modification through reconciliation ecology. If we can preserve the human use of lawns while improving their ability to support biodiversity by incorporating flowering plants, we can create a win-win situation or both people and nature.

Your Current Lawn: Flowers or Weeds?

While lawns are usually managed for uniform stands of only grass, flowering plants, often considered weeds, are common and adapted to lawn conditions. Whether introduced or native, many weeds provide pollen, nectar, or both to foraging bees throughout the year.

Pros and cons

While flowering lawn weeds are often seen as a nuisance, they can actually have benefits to lawns in addition to bees. Weeds may be better adapted than turfgrasses to difficult site conditions such as compacted soil, drought, flooding, shade, and low nutrient availability. For example, white clover has been shown in many studies to increase available nitrogen in the soil, due to the symbiotic soil bacteria that live in nodules on clover roots, which turn atmospheric nitrogen into plant available nitrogen. Flowering plants can fill in for grass species in unfavorable conditions to ensure continuous ground cover, which in turn reduces soil erosion and nutrient run off.

The downside to lawn weeds is that many are aggressive, non-native and prone to being invasive in cultivated and natural areas. Non-native plants are good resources for bees with a broad host range, but are typically not good forage for specialized bee species. Many of the most common weed species, such as dandelion, are also widely reviled by homeowners. This “bad rep” can create social pressures to remove weeds even if the lawn manager is tolerant of diverse lawns and realizes how plant diversity benefits pollinators.

How to Enhance your Lawn to Promote Pollinators

Preparing the Lawn

Enhancing a lawn with flowering species can be done through either a new lawn planting that includes the desired flowers or seeding flowers directly into an existing lawn. Seeding into an existing lawn is more economical but can be challenging to get good establishment, as the new flowers must compete for space with the established grass. Good seed germination is critical for both methods, and requires adequate moisture, good soil to seed contact, and protection from flash rain events that could wash seeds away. The University of Minnesota Extension Service has an excellent guideline on lawn renovation through either over seeding or new plantings of turfgrass seed (http://www.extension.umn.edu/garden/yard-garden/lawns/lawn-renovation/). For flowering lawns you need to add flower seed to the above recommendations. If you are interested in seeding flowers directly into your lawn, there are a number of practices that can increase your success.

1.) It is critical to **pick the right flower species** for your site. Consider where the lawn is: Is it in a depression where water pools? Is it in full sun or shade? Also consider the type of soil, which dictates the species that can thrive in your site.
2.) Any seeds sown into an established lawn will need to compete with the grass. The first step is providing enough seed to ensure the plants can become established. In our preliminary trials at the University of Minnesota, 200 seeds/ft.^{2} has worked well for a seeding rate of Dutch white clover (*Trifolium repens*) lanceleaf self-heal (*Prunella vulgaris* ssp. *Lanceolata*) and creeping thyme (*Thymus serpyllum*). If you have a very dense lawn, give the flowers a competitive edge by disrupting the lawn directly before seeding. In our research trials, mowing the lawn very short (1.5 in.) prior to seeding, known as scalping, had the best effects on establishment. Scalping allows more sunlight to hit the soil surface aiding the germinating seeds, and helps to slow the competition of the established grass. This practice is stressful for the lawn grasses, but they should recover barring any extreme stresses such as drought.
3.) After planting, it is important that the seeds get enough moisture to germinate. Seeding in spring is recommended, however it may be necessary to **provide supplemental irrigation** for the first week or two until the flowers have germinated. Irrigation practices should be determined by the weather, but typically watering twice a day for 15-20 minutes in the early morning and early afternoon, allowing the foliage to dry before nightfall, will keep the soil moist.

Starting over with a new lawn is much more involved, but allows more flexibility in the final lawn plant community. In this case, follow protocols for preparing your site as outlined in the lawn renovation link provided above, including flower species as a part of the seeding mix. Our research on flower establishment in different grasses found that for new plantings, Kentucky bluegrass (*Poa pratensis*) and hard fescue (*Festuca trachyphylla*) allowed the best establishment of Kura clover (*Trifolium ambiguum*). In our trial we used kura clover as a model species because it is slow to establish, making it similar to establishing native flowers.

As an example, we used 'Beacon' hard fescue in our trials to establish a large flowering lawn composed of a number of flowering species. We broadcast seeded grass seed at a rate of 4 lb/1000 ft^2 in late fall (mid November) in what is known as a dormant seeding. We then seeded individual flower species over the hard fescue seed at a rate of about 39 seeds/ft^2. After all seed was applied, we laid germination mats over our planting to protect the seed from extreme rain events that could wash away the seeding. Our trials established naturally without need of supplemental irrigation, as the cool wet spring provided ideal germination conditions. However, if rainfall is not sufficient, irrigation should be provided until the plants have germinated in the spring.

To see a Flowering Bee Lawn, the Minnesota Landscape Arboretum has a public demonstration site that can be visited any time the Arboretum is open. More information on how the Arboretum planted their demonstration site is available here.

Enhancing with Native Flowers

What we know

Native flowers are very important to native bees, especially those that specialize on a small group of related plants. Through our trials at the University of Minnesota, we have learned that the best native plants for lawns share some common traits. They tend to have high germination rates, grow quickly, and are adapted to the soil in which they are sown. Low growth stature to avoid mowing is helpful, but is not a prerequisite if the plant grows quickly. Here are some native species that seem to have potential from our trials.

Ground plum (*Astragalus crassicaprus*)

Ground plum is a low growing species in the pea family. It is native and common to the prairies of Minnesota where soils are well drained. Ground plum has a higher germination rate than many native plants, but is still low compared to cultivated plants. This slow growth rate makes it a better candidate for new lawn planting sites that are well drained. The early bloom of ground plum happens before mowing season is in full swing, and the flowers are visited by long tongued bees such as bumble bees and mason bees.

Lanceleaf coreopsis (*Coreopsis lanceolata*)

Lanceleaf coreopsis is a late spring bloomer in the aster family. Its size can vary dramatically, but typically ranges from between 0.5-2 ft. tall. The vegetative parts of the plant will survive mowing as low as 3 in., but the flowering portions typically shoot above this height. This plant could have potential in lawns, but special mowing practices may need to be observed during bloom as well as some tolerance for their unique appearance. The blooms of lanceleaf coreopsis are attractive to many short and long tongued bees. This plant is highly visited by long-horned bees (*Melissodes*) for pollen.

Lanceleaf self-heal *(Prunella vulgaris* ssp. *lanceolata)*

Self-heal is a member of the mint family, and is distributed widely in the US and Europe. There are three self-heal subspecies, with ssp. *vulgaris* being native to Europe, and ssp. *lanceolata* being native to Minnesota and the U.S. This species prefers rich soils with plenty of water and its quick germination and low growth habit make it ideal for overseeding into mature lawns or as a component of a new lawn planting. We found flowers of self-heal to be negatively impacted by mowing heights of 2.5 in., so we recommend at least a 3.5 in. mowing height. The bloom lasts 2-3 weeks in early to midsummer.

Common bee pollinators visiting flowers on the observation plots in Minnesota include bumble bees, sweat bees, and miner bees.

Calico aster (*Symphyotrichum lateriflorum*)

Calico aster is a late blooming flower in the aster family that typically grows around 3 ft. tall. However when mowed, calico aster will form small dense rosettes and will bloom below a 3.5 in. cutting height. A high germination rate and rapid growth make it a prime candidate for future lawn trials, and for people to experiment with in their own lawns. The flowers of calico aster attract short tongued bees such as sweat bees, and the pollen is also useful to many bees that specialize on flowers in the aster family.

Challenges for Flowering Lawns

One of the inherent challenges of working with native plants is that they are not domesticated, and do not respond to cultivation the same way domesticated species do. A primary example of this is that germination of native plant species can be very low. Seeds often need a special signal that the time is right to germinate. For example, native plant seeds often need a cold stratification period (like winter) before they will break dormancy. All these conditions make native plants more challenging to work with.

Another major challenge of establishing flowering lawns with native plants is the availability of seed. Many promising species are not actively cultivated by local seed producers, and thus are not viable options for trials at this time. Many species are only available in root-stock that is directly buried in the soil, a much more expensive planting method. Interest in providing pollinator foraging resources in lawns will hopefully encourage seed producers to identify and test plant material for larger scale production.

Enhancing with Non-Invasive, Non-Native Flowers

What we know

While non-native plants have some downsides, they can still be very useful in flowering lawns. Lawns by their very nature are challenging environments, but many non-native flowers are ideally suited to lawns. For our research we avoided all of the most common lawn weeds and focused primarily on two species.

Dutch white clover (*Trifolium repens*)

White clover is a ubiquitous lawn flower in the pea family found throughout North America. It is originally from Europe, and was probably introduced by some of the first American settlers. White clover is widely cultivated for grazing pasture due to its high leaf nitrogen. The flowers of white clover are also highly attractive to a number of bee species, with an especially high value to bumble bees and honey bees. White clover thrives in lawns and other areas under cutting management, and used to be a standard components of lawn seed mixes. A high germination rate, rapid growth, and tolerance for a broad range of conditions make this species ideal for overseeding into lawns or in new lawn plantings.

Creeping Thyme (*Thymus serpyllum*)

Creeping thyme is a flower in the mint family from Europe that is cultivated as an ornamental in the Unites States. As its name suggests, it has a spicy herbal aroma like the culinary herb. Similar to its culinary cousin, this species has a slow and prostrate growing habit that makes it uniquely suited to lawns. Due to a high germination rate, overseeding into established lawns and new lawn plantings is possible, but its slow growth habit greatly reduces the time to full establishment; in fact, it may not establish for several years. Creeping thyme is best suited to sites that are well drained, and blooms best with mowing heights above 3.5 in.

What we need to know/ challenges

There are many species of non-native flowers that are, for better or worse, in our lawns for the long haul. Some of these species are relatively well behaved outside of lawns, but many can become invasive in other areas. When considering non-native plants for flowering lawns, it is important to have a good sense of how aggressive they can be outside of their desired location and if they have any value to bees. Unfortunately that is no easy task. Some non-native species that have value for bees, such as Siberian squill (*Scilla siberica*) and bugle weed (*Ajuga reptans*), are aggressive and rapidly spread outside of their planting area. Others such as sweet alyssum (*Lobularia maritima*) and English lawn daisy (*Bellis perennis*) may stay constrained to lawns, but have questionable value to wildlife and are not reliably winter hardy in central Minnesota.

Management of a Flowering Lawn

Once flowers are established in the lawn, managing flowers or other weeds that are not desirable can be a challenge. Hand weeding will always be the preferred option for weed control in a flowering lawn, although this can be quite labor intensive. Spot treating weeds with selective herbicides can limit plants that are not wanted. Using a broadcast broadleaf herbicide will kill most flowers that you have planted. The exception is Dutch white clover, which is fairly resistant to one common herbicide, 2,4-D. Iron chelate products can also be used to spot-treat broadleaf weeds as they establish and this is an organic option for weed control. Synthetic and organic preemergence herbicides applied in the spring can help to prevent the germination of summer annual weedy grasses, like crabgrass and foxtail. Corn gluten meal, which acts as both a preemergent herbicide and a fertilizer, is an organic option that will work once all grasses and flowers are established in lawns. Some synthetic preemergent products could be damaging to flowers, so be sure to read the label and follow all application directions.

Mowing the flowering lawn to a height of between 3.5 and 4 in. will ensure that flowering plants survive and produce flowers to sustain pollinators. Higher mowing heights will also reduce the required mowing frequency and will enable the grasses and flowering plants to have a deeper, more robust root system improving the quality and stress tolerance of the lawn. The one third rule is a good guide to help determine mowing frequency: do not cut off more than one third of the vegetation at one time. If the desired mowing height is 4 in., then the lawn should be mowed when it reaches 6 in., cutting off 2 in. or one third. Be sure to maintain sharp mower blades to reduce mowing stress. Returning clippings when mowing will also help to add nutrients back to the soil.

Soil moisture status should be monitored and replenished through irrigation during extended drought periods and this will change based on the season and year. In an average year, irrigation requirements will be minimal, with lawns requiring from 0-3 irrigation events over the course of a growing season from May to October. Generally speaking, 2-3 in. of precipitation per month should be enough to sustain the quality of a flowering lawn, assuming the precipitation does not occur all at once. In dry years, irrigation requirements will be greater. If no precipitation occurs over a 2-week period, consider irrigating with 0.5 to 1 in. of water. This can be accomplished with an in-ground irrigation system, portable sprinklers or by hand watering.

Fertilizer requirements will be minimal if clippings are returned, mowing heights are kept high, and the soil quality is good. Soils with greater levels of organic matter (> 5% by weight) will hold more nutrients and moisture. Organic matter can be determined from a soil test. See http://soiltest.cfans.umn.edu. If organic matter is less than 5%, consider incorporating high quality compost or peat into the lawn during the renovation process. This can be accomplished through tillage, if conducting a complete renovation, or through aerating, topdressing lightly with the chosen material and working it into the aeration holes. For lawns with low density and vigor, consider making one fertilizer application in the fall around Labor Day. This application should generally supply 1 pound of nitrogen and 0.5 pounds of potassium per 1000 ft^2. For example, a 20-0-10 fertilizer contains 20% nitrogen, 0% phosphorus, and 10% potassium. Applying this fertilizer at a rate of 5 pounds per 1000 ft^2 will achieve the desired nitrogen and potassium rates. Be sure to select a fertilizer that has at least 30% of the nitrogen in the slow release form; 30% of 20 = 6% of the nitrogen in this fertilizer example should be slow release. This will help to reduce environmental loss of nitrogen and provide long-term nutrition. Organic fertilizers are also a good option and will contain slow release nitrogen. Any more fertilizer than recommended will most likely encourage grass over flowers. For additional nutrients, such as phosphorus, consider having your soil tested.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Funding for this project was provided by
the Minnesota Environment and Natural Resources Trust Fund
as recommended by
the Legislative-Citizen Commission on Minnesota Resources (LCCMR)

Bee Lab www.BeeLab.umn.edu Bee Squad
Ian Lane, Eric Watkins, Marla Spivak, Mary Meyer

Annals of the Entomological Society of America, 109(5), 2016, 713–723
doi: 10.1093/aesa/saw043
Advance Access Publication Date: 3 August 2016
Research article

Bee Fauna and Floral Abundance Within Lawn-Dominated Suburban Yards in Springfield, MA

S.B. Lerman[1,2,3] and J. Milam[1]

[1]Department of Environmental Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA 01003 (slerman@cns.umass.edu; jmilam@eco.umass.edu), [2]USDA Forest Service, Northern Research Station, 160 Holdsworth Way, Amherst, MA 01003, and [3]Corresponding author, e-mail: slerman@cns.umass.edu

Received 19 November 2016; Accepted 31 May 2016

Abstract

Private yards comprise a significant component of urban lands, with managed lawns representing the dominant land cover. Lawns blanket > 163,000 km^2 of the United States, and 50% of urban and suburban areas. When not treated with herbicides, lawns have the capacity to support a diversity of spontaneous (e.g., not planted) flowers, with the potential to provide nectar and pollen resources for pollinators such as native bees. In order to determine the extent to which suburban lawns support these important species, we surveyed lawns in 17 suburban yards in Springfield, MA, between May and September 2013 and 2014. Householders participating in the study did not apply chemical pesticides or herbicides to lawns for the duration of the study. We collected 5,331 individual bees, representing 111 species, and 29% of bee species reported for the state. The majority of species were native to North America (94.6%), nested in soil (73%), and solitary (48.6%). Species richness was lower for oligolectic (specialists on a single plant; 9.9%) and parasitic species (12.6%). Abundance percentages for number of individuals were similar. We documented 63 plant species in the lawns, the majority of which were not intentionally planted. The most abundant lawn flowers were dandelion (*Taraxacum officinale*) and clover (*Trifolium sp.*). Nearly 30% of the spontaneous plant species growing in the lawns were native to North America. Our study suggests that the spontaneous lawn flowers could be viewed as supplemental floral resources and support pollinators, thereby enhancing the value of urban green spaces.

Key words: suburban yard, urban ecology, biodiversity, lawn, bee conservation

The United States encompasses one of the most densely urbanized regions in the world, with 82% of the populace living in urban areas (United Nations Population Division 2014). Urbanization is reported to degrade, fragment, and isolate natural habitats, changing both abiotic and biotic ecosystem properties that impact wildlife (Czech et al. 2000, Alberti et al. 2003, Foley et al. 2005, Cane et al. 2006, Shochat et al. 2010, Jha and Kremen 2013). Bees are ecologically and economically important because they are keystone species, they provide important ecosystem services to humans in the form of crop pollination (Kearns et al. 1998), and they may be undergoing regional population declines (National Research Council 2007).

Urban bee populations may be compromised by pesticide exposure, pathogens and parasites, reduced or degraded nesting habitat, limited or poor quality floral resources, and climate change (Cane and Tepedino 2001, Potts et al. 2010, Burkle et al. 2013), all of which can be associated with the intensification of urbanization (Ahrne et al. 2009, Winfree et al. 2009, Threlfall et al. 2015). Conversely, the presence of green spaces such as community gardens and residential yards (Fetridge et al. 2008, Matteson et al. 2008) retain habitat features, such as floral rich patches, and exposed soil, that are documented to enable many bee species to persist in urban areas (e.g., Owen 1991, McIntyre and Hostetler 2001, Tommasi et al. 2004, Baldock et al. 2015), yet few specialists bees have been recorded in these habitats (Frankie et al. 2005). In addition to responding to local habitat features, bees are also influenced at the broader landscape scale. For example, smaller fragments of habitat embedded within the urban matrix tended to support a higher proportion of small-bodied bees compared to larger, native grassland habitat in Boulder Colorado (Hinners et al. 2012). Further, Hinners and colleagues (2012) concluded that the bees recorded in the urban matrix have access to both native and novel habitats, which boosted overall species richness, especially when the amount of native habitat was significant. Thus, the resources found within urban green spaces might supplement the resources provided by native habitat resources. With the continued expansion of urban and suburban developments, it becomes imperative to understand how habitat elements within these landscapes can support wild bees and other beneficial insects (Lowenstein et al. 2015). Because bees are key pollinators, ensuring their persistence in urban areas is important for retaining urban biodiversity by providing pollination services for plants (both native and ornamental), and subsequently food and mast for other organisms (Sheffield et al. 2003, Biesmeijer et al. 2006, National Research Council [NRC] 2007).

Reports of bee assemblages within different urban and suburban green spaces confirm and support the presence of bees in these spaces, though these habitats vary, with some studies reporting rich native bee communities while others highlight more depauperate systems. In a study assessing community gardens in New York City, Matteson and colleagues (2008) documented that 19% of the 54 bee species they collected were exotic. This may be partially explained by an abundance of exotic and cultivated plant varieties in urban settings (Thompson et al. 2004, Frankie et al. 2005). In contrast, a study from a New York suburb that focused on flower gardens embedded within yards documented that only 5% of the 110 species of bees collected in 21 yards were exotic (Fetridge et al. 2008). Further, they found that ecological characteristics of the suburban bee community were more closely aligned with bee communities from a nearby forest preserve rather than more urban sites (e.g., New York City) with regards to nesting substrate (65% nested in soils) and the presence of parasitic species (19%; Fetridge et al. 2008). In northwest Ohio, private yards with a higher percentage of native plants supported greater bee richness and abundance (Pardee and Philpott 2014). At a Kentucky turf grass research station and in public parks, Larson and colleagues (2014) documented a rich assemblage of pollinators, including 37 bee species visiting dandelions and white clover, both of which were growing spontaneously in turf and park lawns. In two northern California cities, Frankie et al. (2005) surveyed bees visiting ornamental plants in residential gardens and reported that sites with a rich diversity of bee-attracting plants supported the greatest diversity and abundance of bees. These and other studies indicate that floral and nesting resources found within urban green spaces can support bee communities in urban areas. However, the ubiquitous lawn within yards has largely been ignored regarding its capacity to support urban bee abundance and diversity (Fetridge et al. 2008). Thus, a better understanding of this landcover's potential may provide the foundation for additional recommendations and guidelines to support urban bee conservation and management.

Residential yards and gardens (hereafter yards) comprise a large percentage of urban and suburban land cover and green spaces (40–50%; Nowak et al. 2001). Yards are generally dominated by lawn cover (the focus of our research), though often include tended gardens ranging from flower and vegetable patches to foundational shrubs and trees. In fact, lawns cover >164,000 km^2 of the United States, roughly 2% of all US land cover (Milesi et al. 2005). Landscaping choices such as the use of native or exotic plants, the presence and extent of lawns, and the use of pesticides can have implications for the wildlife inhabiting these yards (Gels et al. 2002, Goddard et al. 2010). For example, yards landscaped with native plants attracted more native lepidopteran larvae and insectivorous compared with yards landscaped with exotic plants (Burghardt et al. 2009). In Phoenix, AZ, lawn-dominated yards encouraged invasive birds whereas yards landscaped with desert plants supported higher abundances of native birds (Lerman and Warren 2011). Since bee abundance is closely related to pollen and nectar afforded by flowering plants (Frankie et al. 2005), and a large percentage of private yards consist of lawns, landscaping behaviors such as lawn mowing practices and the application of herbicides and pesticides likely have implications for the weedy floral diversity in the lawns. This could further implicate bee habitat quality (Fetridge et al. 2008).

Many environmental organizations encourage gardening practices that invite pollinators to public and private spaces (Mader et al. 2011), such as the National Pollinator Garden Network (NPGN), a collaboration of stakeholders from the garden, pollinator and conservation communities working together to support the health of pollinating animals. One of NPGN's major initiatives is the sponsoring of the Million Pollinator Garden Challenge (http://millionpollinatorgardens.org). These efforts have gained much recognition and attention, including the White House with their unprecedented National Strategy to Promote the Health of Honey Bees and Other Pollinators (Pollinator Health Task Force 2015), and represent a "call to action" to enrich bee habitat. Other conservation and wildlife organizations recommend the removal of certain plants deemed unworthy for wildlife habitat. For example, the Cornell Lab of Ornithology's YardMap program (http://yardmap.org) recommends reducing lawns because of the reputation of chemically treated lawns as nonhabitat for wildlife (Bormann et al. 2001, Tallamy 2007). However, to the best of our knowledge, the habitat value of lawns has yet to be evaluated. Given the large extent of lawns, this land cover requires increased scientific attention to better understand their habitat values for bees in urban and suburban settings.

The goal of our study was to characterize bee communities within suburban lawns to gauge the value of this habitat to bee conservation. Specifically, we 1) quantify bee abundance and species composition in suburban lawns to facilitate comparison of our results with prior research; 2) summarize the ecological characteristics of bees using untreated lawns, including nesting habitat, sociality, and floral specificity, because the response of bees to urban green spaces is known to be associated with natural history characteristics such as floral specificity and nesting ecology (Fetridge et al. 2008). The association of bees and lawns may be affected by the flight distance capabilities of bees and the extent to which they range over other habitats (Cane 2001, Zurbuchen et al. 2010). Accordingly, we 3) analyze body size of bees in suburban lawns to estimate foraging distance following Cane (1987). Finally, because nectar and pollen resources are essential to bee survivorship and reproduction, and are known to strongly influence their distribution (Potts et al. 2003), we 4) record the spontaneous floral resources (i.e., weeds) in the untreated suburban lawns. Although land conversion in the United States from urban to suburban has declined since the housing boom of the 1990s, between 2007 and 2010, urban and suburban areas have increased by 2.1%, and land developed between 1992 and 2010 has exceeded 10.3 million hectares (USDA 2010). Thus, a better understanding of the habitat resources in suburban yards might help to alleviate the detrimental impact of habitat loss. Practices that support nesting and foraging opportunities for bees could have important implications for bee conservation in suburban areas.

Materials and Methods

Study Area

We conducted the study in 17 yards in Springfield (Hampden County), MA, the third largest city in Massachusetts. Due to the somewhat invasive nature of sampling in private yards, we relied on volunteer households. We recruited households via ReGreen Springfield, a local tree planting organization. Yards were categorized as medium-density residential landuse and embedded within a suburban matrix. Participants owned and occupied single-family housing units. The yards encompassed a range of habitat features but were predominantly composed of lawns, although some sported limited flower borders or hedges, and none contained vegetable gardens (Fig. 1). Yards were not treated with herbicides or watered for the duration of the study, and were representative of Springfield yards. Participating yard parcel size ranged from 0.03 to 0.18 ha (typical of medium-density housing stock within Springfield), with a total of 1.26 ha sampled (Table 1). Canopy cover within a 50-m radius (centered at the center of each parcel) ranged between 2 and 49%, with a mean of 21% (Lerman, unpublished data). To promote spatial independence, all sites were at least 500 m apart with the exception of two yards, which were across the street neighbors. We assessed the degree of spatial autocorrelation with Mantel tests, which supported their independence ($r = 0.14$, $P = 0.13$).

Fig. 1. Examples of the lawn-dominated yards participating in the study from Springfield, MA.

Bee Sampling Methods

We collected bees between May and September 2013 and 2014, with a maximum of six sampling rounds per yard per year. Bees were collected from each yard approximately every three weeks (all collection rounds completed within 4 d of each other) on calm, sunny days using bee bowls and hand-held insect nets. Bee bowls consisted of white plastic 3.25 oz (96 ml) cups (Solo brand, model number p325w) painted florescent blue, yellow, or left white. In each lawn 30 bowls were placed in 10 arrays of three bowls, one of each color, and filled with a solution of soapy water (Dawn Ultra Dishwashing soap, original scent) to break the surface tension. Arrays were placed a minimum of 3 m apart near flowers growing in the lawn and in areas of the yard that received full sun for the majority of the day. We chose this method over a random transect method to standardize trap deployment in these small yards (0.03 to 0.18 ha) that were broken up by driveways, walkways, fences, and houses and other structures. Bowls were deployed for 24 h prior to a mowing event. Weather (cloud cover and temperature) was recorded. Bees collected in bowls were strained, and the specimens placed in whirl-paks with 70% ethanol alcohol and locality labels. The contents of each 30-bowl array were combined into one sample. We randomized the collection order for the yards amongst the different sampling rounds.

Because bowls tend to bias a collection toward smaller bees (Cane et al. 2000, Roulston 2000), we conducted 15-min hand-netting surveys in each yard for each sampling event concurrently with the bowl collection. We opportunistically hand-netted for bees on lawn and yard flowers. Upon capture, netted bees were placed in vials containing soapy water and then transferred into whirl-paks containing 70% ethanol alcohol. All bees were washed in soapy water, dried with a hair drier, pinned and labeled following LeBuhn et al. (2003). Bees were identified to the species level when possible using a number of different keys (Mitchell 1960, 1962; Gibbs 2010,

Table 1. Site characteristics, sampling effort, and bee and lawn flower biodiversity of 17 yards in Springfield, MA

Site ID	No. of sampling rounds	Total grass (m^2)	Ha	Bee species richness	Bee abundance ($n = 5{,}331$)	Lawn flower richness	Lawn flower abundance	Soil (%)	Canopy cover (%)
16_1	3	949	0.09	23	57	9	552	17.5	11.4
16_2	12	828	0.08	39	614	24	20,951	9.4	48.9
FP_1	6	262	0.03	21	87	3	1,733	3.7	29.7
EFP_1	6	349	0.03	39	329	13	16,986	27.9	1.0
EFP_2	5	456	0.05	22	103	15	15,591	0.0	0.2
16_3	12	793	0.08	47	305	21	23,089	3.8	13.0
EFP_4	6	324	0.03	38	215	8	492	7.1	13.7
EFP_5	5	489	0.05	21	99	18	12,365	3.0	6.0
16_4	6	1,805	0.18	41	300	19	3,223	6.8	39.7
EFP_6	12	825	0.08	46	494	21	10,907	4.7	3.5
EFP_7	12	830	0.08	45	489	38	18,597	9.7	5.6
EFP_8	6	756	0.08	27	75	9	165	5.0	41.1
FP_2	6	310	0.03	33	172	5	2,492	6.5	47.1
16_5	12	753	0.08	42	778	19	8,221	3.1	25.0
EFP_9	6	829	0.08	32	397	9	1,791	3.0	33.4
EFP_10	12	659	0.07	40	317	20	8,068	5.4	26.7
EFP_11	12	1,431	0.14	53	500	29	21,234	15.1	11.2

2011; Gibbs et al. 2012). Vouchers are deposited with the US Forest Service Urban Natural Resources Institute.

Bee abundance and richness were calculated as the total number of individual bees and total number of species collected from both collection methods for the two years. Individuals not determined to the species level were omitted in the richness calculation but included in the total abundance. We calculated the proportion of each species based on the total number of bees collected per species and dividing by the total number of bees collected, as well as the frequency of occurrence across the sampled yards by determining the number of yards a species was collected and then dividing by the total number of yards sampled.

To facilitate easy comparison among urban bee studies, bees were classified with respect to ecological characteristics following Fetridge et al. (2008) and Matteson et al. (2008), based on the format provided by Giles and Ascher (2006). We compiled additional information from the primary literature, natural history accounts, and Discoverlife (Mitchell 1960, Hurd 1979, Michener 2007, Ascher and Pickering 2012). We classified bees based on their: 1) origin (native or exotic); 2) floral specialization (oligolectic or polylectic; oligolectics specialize on either a single plant species or family following Cane and Sipes (2006) whereas polylectics do not have a strict dietary preference); 3) nesting substrate (soil, cavity, soft or rotting wood, wood, or pithy stems); 4) sociality (solitary, subsocial, eusocial, or parasitic); and 5) body size (small, medium, and large). To estimate body size we measured the intertegular (IT) distance (distance between wing bases) (Cane 1987) on up to three individual females of each species. Based on these measurements, we averaged the intertegular distance for each species. This level of accuracy was adequate for the purposes of this study since we then grouped species into small (<1.5 mm), medium (1.6–3 mm), and large (>3.1 mm) size classes (Hinners et al. 2012). For species where specific ecological characteristic information was lacking, we inferred conditions based on closely related species. We calculated the percentage of ecological characteristics for these groups as the total number of individuals collected as well as total number of species to characterize the dominance of these different traits.

Flora Sampling

Prior to each collection event, we identified and estimated the total number of lawn flower blossoms in bloom to assess available floral resources. Lawn flowers were those growing spontaneously amidst the planted turf grass. We then classified the origin of each plant based on Lorenzi and Jeffery (1987). To quantify for the nonflowering plants, we conducted two intensive sampling events per yard, per year using the quadrat sampling method. The plots consisted of three 1-m^2 plots per yard whereby we identified every plant and bare soil, and assigned a percent coverage of that species / cover type for the plot. We included plants that we were unable to identify (i.e., “unknown 1,” “unknown 2”) to account for total floral abundance per lawn.

Results

Bee Fauna

We collected 5,331 bees belonging to 111 spp. (3,194 bee specimens consisting of 96 species in 2013, and 2,137 bee specimens from 82 spp. in 2014) in Springfield lawns. The majority of species (78%) were recorded from less than half of all the yards sampled. Species richness per yard ranged between 21 and 53 bees with a mean of 36 species (Table 1). From these specimens we document five New World bee families (Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae), 22 genera and 16 county records (Table 2), filling in gaps for the known distribution of bees in Massachusetts (J. Milam, personal observation. All but 18 specimens were identified to species: the exceptions were nine *Lasioglossum* (*Dialictus*) sp. males, eight *Ceratina* sp. in poor condition, and one *Nomada* sp. (female) recorded as *N. bidentate* because this taxonomic group is currently being revised (S. Droege, personal communication). We combined *Hylaeus affinis* and *H. modestus* observations because current keys cannot reliably separate them (Grundel et al. 2011). The most abundant species collected (17%) was *Lasioglossum illinoensis*, a bee previously thought to be at the northern edge of its range in southern Connecticut (Zarrillo et al. 2016), followed by *L. pilosum*, *Ceratina strenua*, *Halictus confusus*, and *H. ligatus* representing 36% of all individuals. Nearly three quarters of the collected species were represented by fewer than 10 individuals (Table 2), and 33 species were singletons. Species represented in the majority of the yards (>88%), but not collected in abundance included *Bombus impatiens*, *Agapostemon virescens*, *A. texanus*, *Apis mellifera*, *L. ephialtum*, *L. pectorale*, and *L. oenotherae*. Although the pan traps caught the majority of species (108 species compared with 33 species from the hand-netting), 7% of the specimens were captured using the 15-min hand netting survey method (Table 2).

We summarize the taxonomic and ecological characteristics of the bees collected from the suburban lawns in Table 3. The Andrenidae made up 17.1% of all species and 2.9% of all individuals. The Apidae were well represented with 22.5% of all species and 24.5% of all individuals collected belonging to this family. Bees from the Halictidae family were abundant with 44.1% of all species and 70.4% of all individuals. Few Megachilidae were captured (10.8% of the species and 1.4% of individuals; Table 3). Individuals in the family Colletidae were not well represented with 5.4% of species and only 0.8% of all individuals. Of the 111 bee species collected from Springfield yards, the majority of species and individuals were native to North America (94.6 and 94.1%, respectively). Six species were exotics that are well established in eastern North America (Cane 2003). The most common bee species comprised small- or medium-sized bees (45.0 and 43.2%, respectively) while small-bodied bees were most abundant (71.9%; Table 3)

The majority of the species and individuals were polylectic (76.6 and 96.5%, respectively) and soil nesters (73.0 and 73.9%). Almost three quarters of the bees collected were eusocial (69.8%) while nearly half of all species were solitary bees (48.6%; Table 3). We recorded 11 oligolectic species representing 147 individual specimens. Of note was the widespread *L. oenotherae*, recorded at 88% of all sites. We collected nine *Peponapis pruinosas*, from five yards. In addition, we captured six oligolectic *Andrena* spp. from five sites, a single *Colletes*, and two *Melissodes* (Table 2).

An eighth of the species collected were parasitic (bees that lay their eggs on or near pollen provisions collected by other bees), represented by two families, three genera, 14 species, and 38 individuals (Table 2). The occurrence of parasitic bees is dependent on the presence of their hosts. For the *Nomada* and *Sphecodes* bees, their associated hosts (see Sheffield et al. 2003) were present in all of the collection locations. The most abundant parasites were represented by the genus *Nomada*, which are parasitic primarily on the genus *Andrena*, but also of *Agapostemon*, *Halictus*, *Lasioglossum*, and *Colletes*, all genera represented in our study. We captured two species of parasitic *Lasioglossum* (*Dialictus*), *L. platyparium*, and one *L. izawsum* that are parasitic of pollen-collecting *Dialictus* spp., although we did not collect their presumed associated hosts (*L. katherineae* and *L. versatum,* respectively; Gibbs et al. 2012).

Table 2. Bee species and ecological characteristics of bees collected in Springfield, MA, yards from 2013 and 2014

Species	Abund[a]	% Indiv[b] ($n = 5{,}331$)	% Pres[c] ($n = 17$)	Family	Orig[d]	Pollen[e]	Nest[f]	Behav[g]	Size[h]	Method[i]
Colletes inaequalis Say, 1837	22	0.41	59	Colletidae	N	P	S	S	M	B
***Colletes latitarsis* Robertson, 1891**	1	0.02	6	Colletidae	N	O	S	S	M	P
Colletes thoracicus Smith, 1853	1	0.02	6	Colletidae	N	P	S	S	L	H
***Hylaeus (Hylaeus) mesillae* (Cockerell, 1896)**	8	0.15	24	Colletidae	N	P	C	S	S	P
Hylaeus (Prosopis) affinis (Smith, 1853) / *modestus* Say, 1837	9	0.17	29	Colletidae	N	P	C	S	S	P
Hylaeus undet.	1	0.02	6	Colletidae	N	P	C	S	S	H
Agapostemon (Agapostemon) sericeus (Förster, 1771)	11	0.21	41	Halictidae	N	P	S	S	M	P
Agapostemon (Agapostemon) texanus Cresson, 1872	51	0.96	88	Halictidae	N	P	S	S	M	B
Agapostemon (Agapostemon) virescens (Fabricius, 1775)	175	3.28	100	Halictidae	N	P	S	S	M	B
Augochlora (Augochlora) pura (Say, 1837)	1	0.02	6	Halictidae	N	P	SW	S	M	P
Augochlorella aurata (Smith, 1853)	17	0.32	47	Halictidae	N	P	S	E	S	P
***Halictus (Nealictus) parallelus* Say, 1837**	5	0.09	24	Halictidae	N	P	S	E	M	B
Halictus (Odontalictus) ligatus Say, 1837	295	5.53	100	Halictidae	N	P	S	E	M	B
Halictus (Protohalictus) rubicundus (Christ, 1791)	26	0.49	76	Halictidae	N	P	S	E	M	B
Halictus (Seladonia) confusus Smith, 1853	385	7.22	100	Halictidae	N	P	S	E	S	B
Lasioglossum (Dialictus) anomalum (Robertson, 1892)	1	0.02	6	Halictidae	N	P	S	E	S	P
***Lasioglossum (Dialictus) bruneri* (Crawford, 1902)**	28	0.53	47	Halictidae	N	P	S	E	M	B
Lasioglossum (Dialictus) coreopsis (Robertson, 1902)	2	0.04	6	Halictidae	N	P	S	E	S	B
Lasioglossum (Dialictus) cressonii (Robertson, 1890)	18	0.34	53	Halictidae	N	P	SW	E	S	P
Lasioglossum (Dialictus) ellisiae (Sandhouse, 1924)	8	0.15	41	Halictidae	N	P	S	E	S	P
***Lasioglossum (Dialictus) ephialtum* Gibbs 2010**	208	3.90	100	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) fattigi (Mitchell, 1960)	1	0.02	6	Halictidae	N	P	S	E	S	P
***Lasioglossum (Dialictus) illinoense* (Robertson, 1892)**	929	17.43	94	Halictidae	N	P	S	E	S	P
***Lasioglossum (Dialictus) imitatum* (Smith, 1853)**	89	1.67	71	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) izawsum Gibbs, 2011	1	0.02	6	Halictidae	N	P	[S]	P	S	P
***Lasioglossum (Dialictus) katherineae* Gibbs, 2011**	1	0.02	6	Halictidae	N	P	S	E	S	P
***Lasioglossum (Dialictus) laevissimum* (Smith, 1853)**	3	0.06	18	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) leucocomum (Lovell, 1908)	44	0.83	59	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) lineatulum (Crawford, 1906)	5	0.09	29	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) oceanicum (Cockerell, 1916)	2	0.04	12	Halictidae	N	P	S	E	M	P
Lasioglossum (Dialictus) oblongum (Lovell, 1905)	1	0.02	6	Halictidae	N	P	SW	E	S	P
Lasioglossum (Dialictus) pilosum (Smith, 1853)	764	14.33	100	Halictidae	N	P	S	E	S	B
***Lasioglossum (Dialictus) planatum* (Lovell 1905)**	4	0.08	24	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) platyparium (Robertson 1895)	3	0.06	18	Halictidae	N	P	[S]	P	S	P
Lasioglossum (Dialictus) smilacinae (Robertson, 1899)	17	0.32	41	Halictidae	N	P	S	E	S	B
***Lasioglossum (Dialictus) subviridatum* (Cockerell, 1938)**	2	0.04	12	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) taylorae Gibbs, 2010	1	0.02	6	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) tegulare (Robertson, 1890)	264	4.95	94	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) undet.	12	0.23	6	Halictidae	N	P	–	–	–	P
Lasioglossum (Dialictus) versans (Lovell, 1905)	1	0.02	6	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) versatum (Robertson)	1	0.02	6	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) vierecki (Crawford, 1904)	26	0.49	24	Halictidae	N	P	S	E	S	P
***Lasioglossum (Dialictus) viridatum* (Lovell, 1905)**	2	0.04	12	Halictidae	N	P	S	E	S	P
Lasioglossum (Dialictus) weemsi (Mitchell 1960)	44	0.83	76	Halictidae	N	P	S	E	S	P
Lasioglossum (Evylaeus) cinctipes (Provancher, 1888)	2	0.04	12	Halictidae	N	P	S	E	M	P
Lasioglossum (Hemihalictus) foxii (Robertson, 1895)	1	0.02	6	Halictidae	N	P	S	S	S	P
Lasioglossum (Hemihalictus) nelumbonis (Robertson, 1890)	7	0.13	18	Halictidae	N	P	S	S	S	P
Lasioglossum (Hemihalictus) pectorale (Smith, 1853)	105	1.97	100	Halictidae	N	P	S	S	S	P
Lasioglossum (Lasioglossum) acuminatum McGinley, 1986	4	0.08	24	Halictidae	N	P	S	S	M	P
Lasioglossum (Lasioglossum) coriaceum (Smith, 1853)	10	0.19	29	Halictidae	N	P	S	S	M	P
Lasioglossum (Leuchalictus) leucozonium (Schrank, 1781)	35	0.66	71	Halictidae	E	P	S	S	M	B
Lasioglossum (Sphecodogastra) oenotherae (Stevens, 1920)	125	2.34	88	Halictidae	N	O	S	S	M	B
Sphecodes confertus Say, 1837	1	0.02	6	Halictidae	N	P	[S]	P	–	P
Sphecodes coronus Mitchell, 1956	1	0.02	6	Halictidae	N	P	[S]	P	S	P
Sphecodes fattigi Mitchell, 1956	1	0.02	6	Halictidae	N	P	[S]	P	S	P
Sphecodes illinoensis (Robertson, 1903)	6	0.11	24	Halictidae	N	P	[S]	P	S	P
Sphecodes mandibularis Cresson, 1872	5	0.09	18	Halictidae	N	P	[S]	P	S	P
Andrena (Andrena) carolina Viereck, 1909	1	0.02	6	Andrenidae	N	O	S	S	M	P
Andrena (Andrena) frigida Smith, 1853	1	0.02	6	Andrenidae	N	O	S	S	M	P
Andrena (Callandrena s.l.) asteris Robertson, 1891	1	0.02	6	Andrenidae	N	O	S	S	M	P
***Andrena (Callandrena s.l.) helianthi* Robertson, 1891**	1	0.02	6	Andrenidae	N	O	S	S	M	P
Andrena (Callandrena s.l.) placata Mitchell, 1960	1	0.02	6	Andrenidae	N	O	S	S	M	P
Andrena (Larandrena) miserabilis Cresson, 1872	21	0.39	59	Andrenidae	N	P	S	S	M	B
Andrena (Leucandrena) barbilabris (Kirby, 1802)	1	0.02	6	Andrenidae	N	P	S	S	M	P
Andrena (Melandrena) carlini Cockerell, 1901	10	0.19	41	Andrenidae	N	P	S	S	M	B
***Andrena (Melandrena) commoda* Smith, 1879**	1	0.02	6	Andrenidae	N	P	S	S	M	P
Andrena (Melandrena) regularis Malloch, 1917	3	0.06	12	Andrenidae	N	P	S	S	M	B
Andrena (Melandrena) vicina Smith, 1853	2	0.04	12	Andrenidae	N	P	S	S	M	P
Andrena (Plastandrena) crataegi Robertson, 1893	3	0.06	6	Andrenidae	N	P	S	S	M	P

(continued)

Table 2. continued

Species	Abund[a]	% Indiv[b] (n = 5,331)	% Pres[c] (n = 17)	Family	Orig[d]	Pollen[e]	Nest[f]	Behav[g]	Size[h]	Method[i]
Andrena (Scrapteropsis) alleghaniensis Viereck, 1907	14	0.26	41	Andrenidae	N	P	S	S	M	B
Andrena (Scrapteropsis) imitatrix Cresson, 1872	3	0.06	12	Andrenidae	N	P	S	S	M	P
Andrena (Simandrena) nasonii Robertson, 1895	9	0.17	18	Andrenidae	N	P	S	S	S	P
Andrena (Taeniandrena) wilkella (Kirby, 1802)	3	0.06	18	Andrenidae	E	P	S	S	S	H
Andrena (Trachandrena) hippotes Robertson, 1895	1	0.02	6	Andrenidae	N	P	S	S	M	P
***Andrena (Tylandrena) erythrogaster* (Ashmead, 1890)**	3	0.06	6	Andrenidae	N	O	S	S	M	P
Calliopsis (Calliopsis) andreniformis Smith, 1853	78	1.46	71	Andrenidae	N	P	S	S	S	P
Anthidium (Anthidium) manicatum (Linnaeus, 1758)	8	0.15	29	Megachilidae	E	P	C	S	L	P
Anthidium (Proanthidium) oblongatum (Illiger, 1806)	9	0.17	41	Megachilidae	E	P	C	S	M	B
Hoplitis (Alcidamea) producta (Cresson, 1864)	10	0.19	41	Megachilidae	N	P	P	S	M	P
Megachile (Eutricharaea) rotundata (Fabricius, 1793)	5	0.09	24	Megachilidae	E	P	C	S	M	B
Megachile (Litomegachile) mendica Cresson, 1878	6	0.11	29	Megachilidae	N	P	C	S	M	B
Megachile (Megachile) centuncularis (Linnaeus, 1758)	5	0.09	24	Megachilidae	N	P	C	S	M	B
Megachile (Megachile) montivaga Cresson, 1878	2	0.04	12	Megachilidae	N	P	C	S	M	P
Megachile (Xanthosarus) latimanus Say, 1823	1	0.02	6	Megachilidae	N	P	C	S	L	P
Osmia (Melanosmia) bucephala Cresson, 1864	4	0.08	24	Megachilidae	N	P	C/P	S	L	P
Osmia (Melanosmia) distincta Cresson, 1864	1	0.02	6	Megachilidae	N	P	C/P	S	M	P
Osmia (Melanosmia) pumila Cresson, 1864	20	0.38	65	Megachilidae	N	P	C/P	S	M	B
Osmia (Melanosmia) atriventris Cresson, 1864	3	0.06	12	Megachilidae	N	P	C/P	S	M	P
Apis (Apis) mellifera Linnaeus, 1758	256	4.80	100	Apidae	E	P	C[1]	E	L	B
Bombus (Pyrobombus) bimaculatus Cresson, 1863	8	0.15	41	Apidae	N	P	C[1]	E	L	B
Bombus (Pyrobombus) impatiens Cresson, 1863	234	4.39	100	Apidae	N	P	C[1]	E	L	B
Bombus (Pyrobombus) perplexus Cresson, 1863	4	0.08	24	Apidae	N	P	C[1]	E	L	B
Bombus (Pyrobombus) vagans Smith, 1854	4	0.08	18	Apidae	N	P	C[1]	E	L	P
Bombus (Separatobombus) griseocollis (DeGeer, 1773)	10	0.19	41	Apidae	N	P	C[1]	E	L	B
Ceratina (Zadontomerus) calcarata Robertson, 1900	207	3.88	82	Apidae	N	P	P	B	S	B
Ceratina (Zadontomerus) dupla Say, 1837	18	0.34	41	Apidae	N	P	P	B	S	B
Ceratina (Zadontomerus) mikmaqi (Rehan + Sheffield, 2011)	6	0.11	29	Apidae	N	P	P	B	S	P
Ceratina (Zadontomerus) strenua Smith, 1879	495	9.29	100	Apidae	N	P	P	B	S	B
Ceratina (Zadontomerus) undet.	8	0.15	6	Apidae	N	P	P	B	S	P
Melissodes (Eumelissodes) agilis Cresson, 1878	3	0.06	18	Apidae	N	O	S	S	M	P
Melissodes (Eumelissodes) subillatus LaBerge, 1961	1	0.02	6	Apidae	N	P	S	S	M	P
Melissodes (Eumelissodes) trinodis Robertson, 1901	2	0.04	6	Apidae	N	P	S	S	M	P
Melissodes (Heliomelissodes) desponsus Smith, 1854	1	0.02	6	Apidae	N	O	S	S	M	P
Melissodes (Melissodes) bimaculatus (Lepeletier de Saint Fargeau, 1825)	3	0.06	18	Apidae	N	P	S	S	L	P
Nomada articulata Smith, 1854	7	0.13	24	Apidae	N	P	[S]	P	S	P
Nomada australis Mitchell, 1962	1	0.02	6	Apidae	N	P	[S]	P	S	P
Nomada bidentate	1	0.02	6	Apidae	N	P	[S]	P	M	P
Nomada cressonii Robertson, 1893	1	0.02	6	Apidae	N	P	[S]	P	S	P
Nomada illinoensis Robertson, 1900	1	0.02	6	Apidae	N	P	[S]	P	S	P
Nomada luteoloides Robertson, 1895	1	0.02	6	Apidae	N	P	[S]	P	M	P
Nomada maculata Cresson, 1863	8	0.15	35	Apidae	N	P	[S]	P	M	P
Panurginus potentillae (Crawford 1916)	2	0.04	12	Apidae	N	P	S	S	S	P
***Peponapis (Peponapis) pruinosa* (Say, 1837)**	9	0.17	29	Apidae	N	O	S	S	L	P
Xylocopa (Xylocopoides) virginica (Linnaeus, 1771)	16	0.30	53	Apidae	N	P	W	B	L	B

[a] Abundance is the total number of specimens collected for both years across all sites.

[b] % of Individuals is the percentage of total collection identified as this species ($n = 5,331$).

[c] % Sites is the percentage of sampled yards with this species ($n = 17$ sites).

[d] Origin: Each species is classified as native (N) or exotic (E) to North America based on Cane (2003).

[e] Pollen specificity: Each species is classified as either oligolectic (O; a pollen specialist collecting pollen from a single plant family or genus) or polylectic (P; a pollen generalist collecting pollen from multiple plant families).

[f] Nest substrate: Classification of the nest substrate of each species. Soil (S), cavity (C), soft/rotting wood (SW), wood (W), or pith (P); nest substrates in brackets indicate the host of a parasitic species. Nesting preference annotated with C1 for cavities in preexisting, constructed or manmade burrows or crevices to house reproductive chambers (e.g. Cane et al. 2007).

[g] Behavior: Classification of the nesting behavior of each species. Solitary or communal (S), subsocial (B), eusocial (E), or parasitic (P).

[h] Size is the intertegular distance classification. < 1.5 mm = Small (S), 1.6–3 mm = Medium (M), > 3.1 mm = Large (L). When only males collected, no measurements taken (–).

[i] Method is the bee capture method. Hand-netted (H), pan traps (P), both hand-netted and pan traps (B).

Underlined ecological characteristics indicate when species characteristics were inferred from closely related species.

Species in bold represent county records.

We captured five species in the genus Sphecodes, which are primarily parasites of others in its family *Halictidae* (Sheffield et al. 2003).

Lawn Flora

We recorded 63 different flowering plant species in 17 lawns during 2013 and 2014. Dandelion (*Taraxacum officinale*) was the most widespread flower, found in all lawns in both years (Table 4). White clover (*Trifolium repens*), purple violet (*Viola sororia*), yellow wood-sorrel (*Oxalis stricta*), Canadian horseweed (*Conyza canadensis*), annual fleabane (*Erigeron annuus*), dwarf cinquefoil (*Potentilla canadensis*), and Pennsylvania smartweed (*Polygonum pensylvanicum*) were recorded in at least 60% of all sites for the two years (Table 4). In 2013, horseweed, hairy rock cress (*Arabis hirsute*), and white clover represented more than 67% of all flowers, whereas in 2014, white clover, yellow wood-sorrel, purple smartweed and purple violet were the most abundant species (Table 4). A third of the flower species recorded were native to North America whilst 60% of the flowers have origins in Europe, Asia, and or Africa. The remaining 6% of the plants either had a worldwide distribution or were from South America. In 2013, the majority of flowers were from North America; however, in 2014, there wasn't a clear majority (Table 4).

In the quadrat vegetation surveys, we recorded an additional 38 nonflowering species growing within the Springfield lawns. Kentucky bluegrass (*Poa pratensis*), *Zoysia* grasses, smooth crabgrass (*Digitaria ischaemum*), and fine fescues (*Festuca* spp.) were the most widespread and dominant species growing in the lawns, and with the exception of crabgrass, most likely intentionally planted. Bare soil was present in 16 of the 17 yards. Although the mean percent of the plots classified as bare soil was relatively low (6.3% in 2014 and 8% in 2013), some of the yards were estimated as having up to 27.9% classified as bare soil.

Table 3. Ecological characteristics summarized for bees collected in Springfield, MA, in 2013 and 2014

Taxonomic / ecological grouping	No. of species	Total indiv	% Species ($n = 111$)	% Indiv ($n = 5{,}331$)
Family				
Colletidae	6	42	5.4	0.8
Halictidae	49	3,751	44.1	70.4
Andrenidae	19	157	17.1	2.9
Megachilidae	12	74	10.8	1.4
Apidae	25	1,307	22.5	24.5
Exotic / Native				
Exotic	6	316	5.4	5.9
Native	105	5,015	94.6	94.1
Floral specificity				
Oligolectic	11	147	9.9	2.8
Polylectic	100	5,184	90.1	97.2
Nest substrate				
Cavity / Pith	14	82	12.6	1.5
Cavity[1]	6	516	5.4	9.7
Wood	1	16	0.9	0.3
Pith	5	744	4.5	14.0
Soil	81	3,940	73.0	73.9
Soft / rotting wood	3	20	2.7	0.4
undet	1	13	0.9	0.2
Behavior				
Solitary or communal	54	819	48.6	15.4
Parasitic	14	38	12.6	0.7
Eusocial	38	3,712	34.2	69.8
Subsocial	5	750	4.5	14.1
Body size				
Small (<1.5 mm)	50	3,821	45.0	71.9
Medium (1.6–3 mm)	48	938	43.2	17.6
Large (>3.1 mm)	13	558	11.7	10.5

Discussion

We encountered an abundant and diverse bee fauna in lawn-dominated yards in Springfield, MA, with >5,300 bee specimens, and 111 species representing 29% of the bee species reported for Massachusetts (J. Milam, personal observation). The general expectation for urban biodiversity, including bees, is a homogenized community dominated by exotic species (McKinney 2006). However, homogenization might be scale dependent (i.e., city scale; Groffman et al. 2014), and intensive field studies have the potential to dispel our notion of cities as depauperate of rich animal communities. This diversity of bees suggests that bees live within the vicinity of the lawns and that lawns may provide floral and nesting resources, as confirmed by our hand-netting surveys which targeted lawn flowers, and that the majority of our bees were small-bodied.

The species diversity and degree of specialization of the bee communities at our study sites was comparable to other studies of bees in suburban yards. Although Fetridge and colleagues (2008) recorded similar species richness (110 spp.), they focused sampling on the flowerbeds, which were set within a matrix of large, well-manicured lawns that varied in use of herbicides, pesticides, and commercial fertilizers. Fetridge et al. (2008) did not sample for bees in the lawns because lawn flowers were sparse due to frequent mowing and in some yards, there was the added factor of the application of herbicides. Frankie et al. (2005) recorded 76 bee species in their survey of flower-rich gardens that included a mix of native and exotic plants in two northern California suburbs. A large proportion of the California bees captured by Frankie et al. (2005) were generalists, primarily explained by the abundance of exotic plants. A Vancouver, British Columbia, study

Table 4. Lawn flower diversity and geographical origin for yard in Springfield, MA, in 2013 and 2014

Origin	No. of species	% Species ($n = 63$)	Total abundance	% Flower abundance	% Flower abundance 2013 ($n = 52{,}770$)	% Flower abundance 2014 ($n = 113{,}637$)	Total abundance 2013	Total abundance 2014
Asia	2	3.2	3,658	2.2	0.1	0.5	42	535
Eurasia	18	28.6	15,262	9.2	7.1	10.2	3,720	11,542
Eurasia / Africa	5	7.9	51,314	30.8	18.3	35.9	9,721	41,593
Europe	13	20.6	4,714	2.8	2.5	3.0	1,323	3,391
North America	21	33.3	54,853	33.0	63.9	18.6	33,718	21,135
South America	1	1.6	7,642	4.6	0.6	6.5	317	7,325
Worldwide	3	4.8	23,249	14.0	5.8	17.8	3,081	20,168

surveying four different urban land-uses, including flower gardens in backyards, recorded 56 bee species (Tommasi et al. 2004). In Chicago, Tonietto et al. (2011) compared green roofs with prairies and parks and recorded 63 species, though the green roofs had the lowest richness and abundance. Urban bee communities such as those from the studies listed above and from Springfield tend to be generalist bees that are able to forage on exotic flowering plants. Nonetheless, these and other urban bee studies demonstrate the importance of urban green spaces in general and residential yards in particular in supplementing the urban bee communities (Hinners et al. 2012, Baldock et al. 2015, Threfall et al. 2015).

Studies of bee communities in urban and suburban areas differ with respect to the abundance of exotic bee species in these habitats. Our results were similar to suburban yards in New York (Fetridge et al. 2008) as well as northern California yards (Frankie et al. 2005), yet contrasted with the findings of Matteson et al. (2008), who reported a much higher percentage of exotic bees in New York City community gardens. The New York City community gardens differed with regards to the urban matrix, whereas these small garden plots were located amidst more intensely developed areas compared to suburban yards, and thus could explain the differences in exotic species (Matteson et al. 2008). We collected few Hylaeus spp., none of which were exotic. In contrast to Matteson et al. (2008) whose most abundant species collected were exotic Hylaeus (*H. leptocephalus*, *H. hyalinatus*), and the less common *H. punctatus* (representing 20% of all individuals). Fetridge et al. (2008) recorded the presence of *H. hyalinatus,* which represented 4% of individuals in NY suburban gardens. The European honeybee was the most abundant and widespread exotic species collected in our study. Although we did not detect any backyard beekeeping within proximity of any of our sites, honeybees can travel up to 6 km during the course of foraging activities (Beekman and Ratnieks 2000). It is also possible honeybees at our sites could be wild-nesting naturalized bees.

Suitable nesting substrates can act as a limiting resource to bee diversity and abundance for some populations of bees (Potts and Willmer 1997, Potts et al. 2005). Many ground-nesting bees prefer loose, well-drained sandy or loamy soils (Cane 1991) in exposed sunny spots. Our study location is on the extensive, relatively flat-topped outwash plains and deltaic sand and gravel sediments deposited into glacial Lake Hitchcock by the Chicopee River (F. R. Morrison, personal communication). Soils derived from these glacial deposits provide suitable substrate for ground-nesting bees. Indeed, almost 75% of all bees collected in this study nested in soil, including the sand-specialists *L. pilosum*, *Agapostemon texanus*, and *L. tegulare*. The number of ground-nesting bees in our study was much higher than the two New York studies (Fetridge et al. 2008, Matteson et al. 2008). The majority of bees in community gardens consisted of cavity nesting species, largely represented by exotic *Hylaeus* species (Matteson et al. 2008). It is suggested that the higher reported abundance of cavity-nesting species in urban settings and remnant habitat fragments compared to natural or suburban habitats, could be the presence of available manmade nesting sites (Hernandez et al. 2009). However, for our study only 18% of all bee spp. and 11.2% of all individual bees were cavity or pith-nesters (not including bees using preexisting cavities or manmade burrows). The low number of cavity nesting bees in our study is interesting, but might be linked to a tornado that destroyed many buildings, trees, and vegetation in 2011 that were subsequently removed as part of the cleanup effort.

Although not abundant in the Springfield yards, the availability of dead or dying vegetation such as blackberries and raspberries (*Rubus* sp.) and sumac (*Rhus* sp.) encourage pith-nesting species like the highly abundant *Ceratina strenua*. Pith-nesting *Ceratina* species were well represented in our study, particularly *C. strenua*, which represented 9.3% of all bees captured and found in all of the 17 yards. In contrast, *C. strenua* was not reported from Matteson et al. (2008) and represented only 2.7% of the bees in the study by Fetridge et al. (2008). Although we did not evaluate the abundance of *Rubus* and *Rhus* spp. in surrounding yards, we suspect that they are present nearby. The presence of cavity and pithy-stem nesting bee species in our samples suggests that, although the lawns do not provide required nesting substrates, they do provide foraging resources. We suggest future studies to target nesting behaviors of suburban bees to better understand how nesting resources might be limiting or whether bees take advantage of additional novel nesting substrates.

Because bees depend upon flowers for food and nest provisioning, flowering plants are a dominant mechanism for structuring bee communities. It follows that the distribution of specialist or oligolectic bees are restricted by the distribution of their hosts (Potts et al. 2003). Bee communities in our study were dominated by polylectic species. This pattern aligns with patterns found in other urban bee studies (e.g., Fetridge et al. 2008, Matteson et al. 2008, Frankie et al. 2005, Tonietto et al. 2011) that document bees foraging on flowers planted to enhance yard aesthetics. Nevertheless, we collected 11 oligolectic species. Of note was the abundant and widespread *Lasioglossum oenotherae* ($n = 125$, recorded in 88% of all yards), a bee specializing on evening primrose (Onagraceae), followed by *Peponapis pruinosas* ($n = 9$), a specialist on squash flowers (*Cucurbita* L.). Less abundant specialist bees captured included two early spring bees *Andrena erythrogaster* ($n = 3$), and *A. frigida* ($n = 1$) specializing on willows (*Salix* L.); and *A. carolina*, a specialist on blueberries (*Vaccinium* L.), and *Colletes latitarsis*, a specialist on ground cherry (*Physalis* L.). The low numbers of Colletidae spp. captured in our study is likely a factor of our not collecting on or the lack of appropriate flowers visited by Colletidae with floral preferences. The Asteraceae specialists included *A. asteris*, *A. helianthi*, *A. placata*, *Melissodes desponsa*, *M. subillata*, and *M. trinoidis*. Host plants for these bees were not found in the Springfield yards, but these bee species represented medium-bodied sized bees and therefore have foraging ranges that might encompass neighboring yards (Greenleaf et al. 2007).

Foraging distances are found to vary with environmental conditions such as floral density and distribution (Ricketts 2001). The majority of the bees in our study were polylectic, small-bodied bees with small foraging ranges, likely on the same order of magnitude as the size of the study lawns (Greenleaf et al. 2007) and thus were conceivably supported by the abundant floral resources within the study yards, and reinforced by the hand-netted bees. The medium- to large-bodied bees with larger foraging distance potential could have flown into the yards from nearby yards or other urban green spaces searching for floral resources. We suggest the need for additional research on the nutritional value of the pollen from the lawn flowers to further our understanding of this potentially valuable resource.

The most abundant bee in our study, *L. illinoense* had not been recorded in Massachusetts since roughly the 1920s, based on a single record from the Museum of Comparative Zoology at Harvard University, collected in Boston, MA, by C. W. Johnson (M. Veit, personal communication), presumably between 1903 and 1932 when he was the Principal Curator for the Boston Society of Natural History (Gray 1933). This southern species was abundant in New York and Chicago surveys (Fetridge et al. 2008, Matteson et al.

2008, Tonietto et al. 2011), but not found in New York preserves (Fetridge et al. 2008).

Conservation Implications

Suburban lawns in our study provided resources to a surprisingly high number of bees, building on prior research that urban green spaces have an important role to play for urban bee conservation (Baldock et al. 2015). Our study provides baseline information on the resources provided by lawn-dominated yards embedded within a suburban matrix. Fortel and colleagues (2014) conducted a two-year monthly sampling effort along an urban gradient in France and recorded a third of all the wild bees from the country, with a peak in diversity at more intermediate levels of development. As part of the Natural History Museum of Los Angeles County's Biodiversity Science: City and Nature (BioSCAN) investigation, scientists discovered 30 unknown species of *Megaselia* flies in Los Angeles backyards (Hartop et al. 2015). Together, these studies suggest that there is habitat potential within urban green spaces.

The floral richness we recorded implies that untreated lawns are not as resource-poor as previously thought. The spontaneous plants might provide pollen and nectar resource for suburban bees (Potts et al. 2003, Larson et al. 2014). Our study suggests that when not intensively managed, these flowers can serve as wildlife habitat and contribute to networks of urban green spaces (Threlfall et al. 2015). Tommasi and colleagues (2004) found that dandelions and other weedy species in unmaintained areas of Vancouver had the most bee species visiting these plants. By investigating the pollen contents in trap nests for two cavity-nesting bees in Toronto, MacIvor et al. (2014) found that pollen from clover (*Trifolium repens*) dominated the nests and consisted of as much as 65% of the pollen collected. In addition to clover's capacity to fix nitrogen, it also has a relatively high protein value (35.4%; Roulston et al. 2000). None of the lawns in our study were treated with chemical herbicides, which by their nature eliminate flowering plants from lawns and would likely reduce their suitability for bees. Our results are consistent with other studies that suggest that less intensively managed lawns may provide suitable habitat for ground-nesting bees (Threlfall et al. 2015), by allowing for the presence of bare patches of soil and reduced compacted soils that can discourage ground nesting bees (Tonietto et al. 2011). Thus, developing outreach to homeowners and lawn care companies to encourage rather than eliminate lawn flowers such as dandelions and clover and thin grass cover or bare spots could be a key strategy for urban bee conservation programs targeting private yards (Larson et al. 2014).

Acknowledgments

We would like to thank L. Hilberg, S. Clymer, L. McPherson, B. Hodgkins, K. Bordewieck, A. Tonn, G. Hulten, D. Dorval, E. Rosner, and A. Beauchemin for field and lab assistance. We thank M. Veit and S. Droege for help identifying bees. D. Bloniarz assisted with household recruitment. D. King and F. Morrison provided insightful comments on a previous draft. We are extremely grateful for the residents in the East Forest Park, 16 Acres and Forest Park neighborhoods of Springfield, MA. The research is based upon work supported by the National Science Foundation under Grant DEB-1215859, SEES Fellowship Program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References Cited

Alberti, M., J. M. Marzluff, E. Shulenberger, G. Bradley, C. Ryan, and C. Zumbrunnen. 2003. Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. BioScience. 53: 1169.

Ahrne, K., J. Bengtsson, and T. Elmqvist. 2009. Bumble bees (*Bombus* spp) along a gradient of increasing urbanization. PLoS ONE 4: e5574.

Baldock, K.C.R., M. A. Goddard, D. M. Hicks, W. E. Kunin, N. Mitschunas, L. M. Osgathorpe, S. G. Potts, K. M. Robertson, A. V. Scott, G. N. Stone, et al. 2015. Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. Proc. R. Soc. B-Biol. Sci. 282: 20142849.

Beekman, M., and F.L.W. Ratnieks. 2000. Long-range foraging by the honey-bee, *Apis mellifera* L. Funct. Ecol. 14: 490–496.

Biesmeijer, J. C., S.P.M. Roberts, M. Reemer, R. Ohlemüller, M. Edwards, T. Peeters, A. P. Schaffers, S. G. Potts, R. Kleukers, C. D. Thomas, et al. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313: 351–354.

Bormann, F. H., D. Balmori, and G. T. Geballe. 2001. Redesigning the American lawn: A search for environmental harmony. Yale University Press, New Haven, CT.

Burkle, L. A., J. C. Marlin, and T. M. Knight. 2013. Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. Science 339: 1611–1615.

Cane, J. H. 1987. Estimation of bee size using intertegular span (Apoidea). J. Kans. Entomol. Soc. 1: 145–147.

Cane, J. H. 1991. Soils of ground-nesting bees (Hymenoptera: Apoidea): Texture, moisture, cell depth and climate. J. Kans. Entomol. Soc. 4: 406–413.

Cane, J. H. 2001. Habitat fragmentation and native bees: A premature verdict? Ecol. Soc. 5: 3.

Cane, J. H. 2003. Exotic non-social bees (Hymenoptera: Apoidea) in North America: Ecological implications, pp. 113–126. *In* K. Strickler and J. H. Cane (eds), For non-native crops, whence pollinators for the future? Thomas Say Publications, Entomological Society of America.

Cane, J. H., and V. J. Tepedino. 2001. Causes and extent of declines among native North American invertebrate pollinators: Detection, evidence, and consequences. Ecol. Soc. 5: 1.

Cane, J. H., and S. Sipes. 2006. Characterizing floral specialization by bees: Analytical methods and a revised lexicon for oligolecty, pp. 99–122. *In* N. M. Waser and J. Ollerton (eds), Plant-pollinator interactions: From specialization to generalization. University of Chicago Press, Chicago.

Cane, J. H., R. L. Minckley, and L. J. Kervin. 2000. Sampling bees (Hymenoptera: Apiformes) for pollinator community studies: Pitfalls of pan-trapping. J. Kans. Entomol. Soc. 4: 225–231.

Cane, J. H., R. L. Minckley, L. J. Kervin, T. H. Roulston, and N. M. Williams. 2006. Complex responses within a desert bee guild (Hymenoptera: Apiformes) to urban habitat fragmentation. Ecol. Appl. 16: 632–644.

Cane, J. H., T. Griswold, F. D. Parker. 2007. Substrates and materials used for nesting by North American *Osmia* Bees (Hymenoptera: Apiformes: Megachilidae). Ann. Entomol. Soc. Am. 100: 350–358.

Czech, B., P. R. Krausman, and P. K. Devers. 2000. Economic associations among causes of species endangerment in the united states. BioScience 50: 593–601.

Fetridge, E. D., J. S. Ascher, and G. A. Langellotto. 2008. The bee fauna of residential gardens in a suburb of New York City (hymenoptera: apoidea). Ann. Entomol. Soc. Am. 101: 1067–1077.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global Consequences of Land Use. Science. 309: 570–574.

Fortel, L., M. Henry, L. Guilbaud, A. L. Guirao, M. Kuhlmann, H. Mouret, O. Rollin, and B. E. Vaissière. 2014. Decreasing abundance, increasing diversity and changing structure of the wild bee community (hymenoptera: anthophila) along an urbanization gradient. PLoS ONE 9: e104679.

Frankie, G. W., R. W. Thorp, M. Schindler, J. Hernandez, B. Ertter, and M. Rizzardi. 2005. Ecological patterns of bees and their host ornamental flowers in two northern California cities. J. Kans. Entomol. Soc. 227–246.

Gels, J. A., D. W. Held, and D. A. Potter. 2002. Hazards of insecticides to the bumble bees *Bombus impatiens* (Hymenoptera: Apidae) foraging on flowering white clover in turf. J. Econ. Entomol. 95: 722–728.

Gibbs, J. 2010. Revision of the metallic species of Lasioglossum (Dialictus) in Canada (Hymenoptera, Halictidae, Halictini). Zootaxa 2591: 1–382.

Gibbs, J. 2011. Revision of the metallic Lasioglossum (Dialictus) of eastern North America (Hymenoptera: Halictidae: Halictini). Zootaxa 3073: 1–216.

Gibbs, J., L. Packer, S. Dumesh, and B. N. Danforth. 2012. Revision and reclassification of Lasioglossum (Evylaeus), L.(Hemihalictus) and L.(Sphecodogastra) in eastern North America (Hymenoptera: Apoidea: Halictidae). Zootaxa 3672: 1–117.

Goddard, M., A. Dougill, and T. Benton. 2010. Scaling up from gardens: Biodiversity conservation in urban environments. Trends Ecol. Evol. 25: 90–98.

Gray, A.F. 1933. Charles Willison Johnson, 1863-1932. The Nautilus. 46:129–134.

Greenleaf, S. S., N. M. Williams, R. Winfree, and C. Kremen. 2007. Bee foraging ranges and their relationship to body size. Oecologia 153: 589–596.

Groffman, P. M., J. Cavender-Bares, N. D. Bettez, J. M. Grove, S. J. Hall, J. B. Heffernan, S. E. Hobbie, K. L. Larson, J. L. Morse, C. Neill, et al. 2014. Ecological homogenization of urban USA. Front. Ecol. Environ. 12: 74–81.

Grundel, R., R. P. Jean, K. J. Frohnapple, J. Gibbs, G. A. Glowacki, and N. B. Pavlovic. 2011. A survey of bees (Hymenoptera: Apoidea) of the Indiana Dunes and Northwest Indiana, USA. J. Kans. Entomol. Soc. 84: 105–138.

Hartop, E. A., B. V. Brown, and R.H.L. Disney. 2015. Opportunity in our Ignorance: Urban biodiversity study reveals 30 new species and one new nearctic record for Megaselia (Diptera: Phoridae) in Los Angeles (California, USA). Zootaxa 3941: 451–484.

Hernandez, J. L., G. W. Frankie, and R. W. Thorp. 2009. Ecology of urban bees: A review of current knowledge and directions for future study. Cities Environ. 2: 1–15.

Hinners, S. J., C. A. Kearns, and C. A. Wessman. 2012. Roles of scale, matrix, and native habitat in supporting a diverse suburban pollinator assemblage. Ecol. Appl. 22: 1923–1935.

Hurd, P. D. Jr. 1979. Superfamily apoidea. catalog of hymenoptera in America north of Mexico, pp. 1741–2209. In K. V. Krombein, PlD. Hurd Jr, D. R. Smith, and B. D. Burks (eds.). Smithsonian Institution Press, Washington, DC.

Jha, S., and C. Kremen. 2013. Resource diversity and landscape-level homogeneity drive native bee foraging. Proc. Natl. Acad. Sci. 110: 555–558.

Kearns, C. A., D. W. Inouye, and N. M. Waser. 1998. Endangered mutualisms: The conservation of plant-pollinator interactions. Annu. Rev. Ecol. Syst. 29: 83–112.

Larson, J. L., A. J. Kesheimer, and D. A. Potter. 2014. Pollinator assemblages on dandelions and white clover in urban and suburban lawns. J. Insect Conserv. 18: 863–873.

LeBuhn, G., T. Griswold, R. Minckley, S. Droege, T. Roulston, J. Cane, F. Parker, S. Buchmann, V. Tepedino, N. Williams, et al. 2003. A standardized method for monitoring bee populations–the bee inventory (BI) plot. (http:// online. sfsu. edu/∼ beeplot)

Lerman, S. B., and P. S. Warren. 2011. The conservation value of residential yards: Linking birds and people. Ecol. Appl. 21: 1327–1339.

Lowenstein, D. M., K. C. Matteson, and E. S. Minor. 2015. Diversity of wild bees supports pollination services in an urbanized landscape. Oecologia 1–11.

MacIvor, J. S., J. M. Cabral, L. Packer. 2014. Pollen specialization by solitary bees in an urban landscape. Urban Ecosyst. 17: 139–147.

Mader, E., M. Shepherd, M. Vaughn, S. H. Black, and G. LeBuhn. 2011. Attracting native pollinators: The xerces society guide protecting North America's Bees and Butterflies. Story Publishing, North Adams, MA.

Matteson, K. C., J. S. Ascher, and G. A. Langellotto. 2008. Bee richness and abundance in New York city urban gardens. Ann. Entomol. Soc. Am. 101: 140–150.

McIntyre, N. E., and M. E. Hostetler. 2001. Effects of urban land use on pollinator (Hymenoptera: Apoidea) communities in a desert metropolis. Basic Appl. Ecol. 2: 209–218.

McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. Biol. Conserv. 127: 247–260.

Michener, C.C. 2007. The Bees of the World, 2nd edn. Johns Hopkins University Press, Baltimore, MD.

Milesi, C., S. W. Running, C. D. Elvidge, J. B. Dietz, B. T. Tuttle, and R. R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environ. Manage. 36: 426–438.

Mitchell, T. B. 1960. Bees of the eastern United States, vol. 1. North Carolina Agricultural Experiment Station.

Mitchell, T. B. 1962. Bees of the eastern United States, vol. 2. Tech. Bull. N. C. Agric. Exp. Stn. 152: 1–557.

National Research Council. 2007. Status of pollinators in North America. The National Academies Press, Washington, DC, p. 322.

Nowak, D. J., M. H. Noble, S. M. Sisinni, and J. F. Dwyer. 2001. People and trees: Assessing the US urban forest resource. J. For. 99: 37–42.

(NRC) National Research Council. 2007. Status of pollinators in North America. National Research Council. Committee on the Status of Pollinators in North America, National Academies Press, Washington, DC.

Owen, J. 1991. The ecology of a garden: The first fifteen years. Cambridge University Press, United Kingdom.

Pardee, G. L., and S. M. Philpott. 2014. Native plants are the bee's knees: Local and landscape predictors of bee richness and abundance in backyard gardens. Urban Ecosyst. 1–19.

Pollinator Health Task Force. 2015. National Strategy to Promote the Health of Honey Bees and other Pollinators (Strategy). Accessed from: https:// www.whitehouse.gov/sites/default/files/microsites/ostp/Pollinator%20 Research%20Action%20Plan%202015.pdf, Last accessed 14 June 2016.

Potts, S. G., and P. Willmer. 1997. Abiotic and biotic factors influencing nest-site selection by *Halictus rubicundus*, a ground-nesting halictine bee. Ecol. Entomol. 22: 319–328.

Potts, S. G., B. Vulliamy, A. Dafni, G. Ne'eman, and P. Willmer. 2003. Linking bees and flowers: how do floral communities structure pollinator communities? Ecology 84: 2628–2642.

Potts, S. G., B. Vulliamy, S. Roberts, C. O'Toole, A. Dafni, G. Ne'eman, and P. Willmer. 2005. Role of nesting resources in organising diverse bee communities in a Mediterranean landscape. Ecol. Entomol. 30: 78–85.

Potts, S. G., J. C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W. E. Kunin. 2010. Global pollinator declines: trends, impacts and drivers. Trends Ecol. Evol. 25: 345–353.

Ricketts, T. H. 2001. The matrix matters: effective isolation in fragmented landscapes. The American Naturalist. 158: 87–99.

Roulston, T. H., J. H. Cane, and S. L. Buchmann. 2000. What governs protein content of pollen: pollinator preferences, pollen-pistil interactions, or phylogeny? Ecol. Monogr. 70: 617–643.

Sheffield, C. S., P. G. Kevan, and R. F. Smith. 2003. Bee species of Nova Scotia, Canada, with new records and notes on bionomics and floral relations (Hymenoptera: Apoidea). J. Kans. Entomol. Soc. 357–384.

Shochat, E., S. B. Lerman, J. M. Anderies, P. S. Warren, S. H. Faeth, and C. H. Nilon. 2010. Invasion, competition, and biodiversity loss in urban ecosystems. BioScience. 60: 199–208.

Tallamy, D. W. 2007. Bringing nature home: How native plants sustain wildlife in our gardens. Timber Press, Portland, OR.

Tommasi, D., A. Miro, H. A. Higo, and M. L. Winston. 2004. Bee diversity and abundance in an urban setting. Can. Entomol. 136: 851–869.

Tonietto, R., J. Fant, J. Ascher, K. Ellis, and D. Larkin. 2011. A comparison of bee communities of Chicago green roofs, parks and prairies. Landscape and Urban Planning. 103: 102–108

Threlfall, C. G., K. Walker, N. S. Williams, A. K. Hahs, L. Mata, N. Stork, and S. J. Livesley. 2015. The conservation value of urban green space habitats for Australian native bee communities. Biol. Conserv. 187: 240–248.

Thompson, K., J. G. Hodgson, R. M. Smith, P. H. Warren, and K. J. Gaston. 2004. Urban domestic gardens (III): Composition and diversity of lawn floras. J. Veg. Sci. 15: 373–378.

U.S. Department of Agriculture. 2013. Summary Report: 2010 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa.

Winfree, R., R. Aguilar, D. P. Vázquez, G. LeBuhn, and M. A. Aizen. 2009. A meta-analysis of bees' responses to anthropogenic disturbance. Ecology 90: 2068–2076.

Zarrillo, T. A., J. S. Ascher, J. Gibbs, K. A. Stoner. 2016. New and noteworthy records of bees (Hymenoptera: Apodea: Anthophilia) for Connecticut. J. Kans. Entomol. Soc. (in press).

Zurbuchen, A., L. Landert, J. Klaiber, A. Müller, S. Hein, and S. Dorn. 2010. Maximum foraging ranges in solitary bees: Only few individuals have the capability to cover long foraging distances. Biol. Conserv. 143: 669–676.

Continued incentives for the limitation of turfgrass for all sites regardless of climate, topography, and functional needs is at best informed by popular misconceptions rather than science. When building in more sensible and sustainable locations than the desert (less than 12 inches of annual precipitation), turfgrass provides many ecosystem services and should not be arbitrarily limited.

In the last development cycle of the NGBS Task Group 2 proposed the use of the EPA water budget tool or equivalent (WBT) to determine allowable areas of turfgrass for point awards to ensure that site landscapes were water efficient and appropriate to the climate. WBTs are performance oriented and applicable to any site. If anything, WBTs are conservative when calculating site landscape water allowance because they do not add harvested precipitation to the site water supply. For buildings that cover a large percentage of the site, and particularly for multifamily buildings, this can be a significant contribution to site water resources

Use of the EPA WBT for water efficient landscape design is specified by the Sustainable Sites Initiative's 2014 *SITES v2*; the 2014 EPA *WaterSense New Home Specification*; *LEED for Homes v4*; and the White House Council on Environmental Quality's 2011 *Guidance for Federal Agencies on Sustainable Landscapes;* as well as by many local governments.

In the last cycle TG 2 also proposed eliminating the dubious practice of awarding points for prescriptive turf limitations. This was consistent with the elimination of turf limits in the 2012 International Green Construction Code and the EPA WaterSense Specification. This is consistent as well with the SITES v2 rating system, which has no turf limit. These authorities recognized that for most sites incentives to limit turf were counterproductive for environmental and human health reasons.

In response to a strong lobby from the Southern Nevada Homebuilders Association and the Southern Nevada Water Authority, as a measure of compromise in the last cycle, TG 2 recommended restoring turf limits as an **alternate** to the use of a water budget tool. It also recommended that use of a **WBT be awarded more points** than a 100% elimination of turf to create incentives to use the site appropriate tool and to discourage inappropriate turf limits where a site had adequate precipitation.

The consensus committee ignored TG 2 recommendations and amended the draft to award points to turf limits **and** use of a WBT. It also changed the point values to award 5 points to a 100% turf limit versus 2 points for use of the WBT. The 2015 NGBS permits up to 7 points for use of a WBT **and** elimination of all turfgrass regardless of climate and potential site impact; more than 10% of the points needed for a Silver rating.

For the NGBS to continue to reward turf area limitations is an out-right gift to builders in desert locales who already must comply with legislated limits like those in southern Nevada. Points for turf limitations are points for free in those locations and they distort the purpose of the NGBS by making it no longer a code plus system; its credibility is devalued.

For builders in other than desert locations, points for turf area limitations create incentives for negative environmental practices. Under the 2015 NGBS a site can easily earn 100 points – more than enough for a Gold rating - without having **any** vegetation on site. Being able to achieve a rating without any landscaping will encourage builders to return to the 20th century practice of selling homes with minimal or no landscaping to keep upfront costs down for the owner, with the owner planning to serve as their own landscaper, with questionable degrees of competency, when finances allow. Providing disincentives for any vegetation other than invasive species is wrong.

An examination of legislated turf limits and its consequences follows.

This information is from a suburb of Denver CO that has the following landscape design requirements. This jurisdiction requires both minimum and maximum areas of turf landscaping, acknowledging the value of the material. Photos were taken in June 2015.

Table 14.3A Home Yard Landscaping—Turf option **Front, Side, and Rear Yard Landscaping Requirements for Single-Family Detached, Two-Family, and Single-Family Attached Duplex Homes.**		
FRONT YARD		
	(A) Plant Quality and Type	(B) Requirements
1.	**Turf.** (At corner lots with a side yard visible to public view, turf areas shall include both front and side yard areas.)	**Minimum and Maximum Turf per Lot Size: (See Note 2)** Small – 40% Min. and 50% Max. Standard – 30% Min and 40% Max. Large – 25% Min. and 40% Max. Estate – 25% Min. and 40% Max.
2.	1 Shade Tree, and either	2 ½ inch caliper
	1 Ornamental Tree	2 inch caliper
	Or 1 Evergreen Tree	6 foot height
3.	Front yard shrubs per lot size: Small – 8 Standard – 16 Large – 26 Estate – 36	Shrubs – 5 gallon container Min. – Plant material shall conform with American Standard for Nursery Stock, Ansi Z60.1, current addition. Fabric may be omitted under annuals, perennials and groundcovers. Use a variety of shrubs and plant materials that will provide visual interest during all seasons.
SIDE YARDS		
	Internal side yard, not exposed to public view **– No plant material is required but mulches are required for soil stability.** External side yards on corner lots exposed to public view – **Shall be landscaped with turf, and shrubs and trees** at the rate of one tree and 10 shrubs per 40 linear feet of side yard.	
REAR YARDS		
	Turf or xeric landscaping is not required. **In rear yards the use of natural turf shall be limited to not more than 45% of the area to be landscaped**. No maximum restriction shall apply to the use of artificial turf. **Rear yards at corner lots exposed to public view shall be landscaped with turf or xeric landscaping.**	
NOTE 1: Perennials and ornamental grasses may be substituted for shrubs at 3 one-gallon perennial or ornamental grass species per one five-gallon shrub.		
NOTE 2: Lot sizes: Small 3,700sf – 5,999^{sf}; Standard 6,000^{sf} – 8,999^{sf}; Large 9,000^{sf} – 14,999^{sf} Estate 15,000^{sf} and greater.		

This jurisdiction's turf limits are based upon total area of the lot; areas of building, more patio, deck, driveway, etc. do not limit the allowable area of turf. The turf limits in the NGBS are far more restrictive because the percentage of reductions apply to landscape vegetated area, not total lot area.

In the context of the NGBS, as the following pictures are reviewed, it is more accurate to project an additional reduction in turf area against all pictured vegetation assuming a total equivalent area of vegetation might be provided under the NGBS. Less provided vegetation = even less turf.

While turf is not required in rear yards, turf is typically provided, up to the 45% rear yard limit, apparently driven by market demand. Rock mulch is being used on virtually all sites to limit the organic landscape areas. In this way the builders provide only what the city requires for vegetation.

The turf in this picture was limited as a percent of the gross lot area. These lots would earn no points using the NGBS prescriptive turf limit because it is tied to the vegetated area, not lot size.

For the sake of analysis, if it was stipulated that NGBS points could be earned against lot area, these lots (standard size = to 6,000^{sf} – 8,999^{sf}) can earn 5 points for their treatment of turf, 3 points for a prescriptive turf limit and 2 more points if the builder chooses to do the exercise of using the EPA water budget tool or equivalent to verify implementation of turf limits.

In other words, the landscape in this picture would qualify for 10% of the required points for a Bronze rating, 8% of the points needed for Silver, and 5% of the points needed for Gold.

This design severely limits the cooling benefits of turfgrass which in turn drives additional energy consumption.

It has been reported that, "*the front lawns of 8 average houses have the same cooling effect as 24 (3-4 ton capacity) home central air conditioning units*."[1]

Reducing turfgrass contributes to the heat island effect which in turn increases demand for energy.

Research has shown ground level temperatures of grass-covered land areas to be 30 to 40 degrees cooler than bare soil, 40 to 60 degrees cooler than artificial turf, and 50 to 70 degrees cooler than hardscaped (asphalt or concrete) areas.

According to the Alliance for Water Efficiency "*Well-maintained turf provides considerable cooling effect; the turf from as few as eight average front lawns can provide cooling equivalent to air-conditioning for 18 homes.*[2]

Typical interior lot line treatment in this jurisdiction is rock mulch, sometimes with shrubbery, often not.

Because of biomass accumulation and humus development through nutrient cycling and the associated growth of roots and crowns, turfgrass is an efficient net sequesterer of carbon even when maintained with gasoline powered equipment.

Further, since the mid 1990s gasoline equipment emissions have been reduced by more than 80% to meet EPA requirements meaning even greater net sequestration.

Note that the market share for electric and battery powered equipment is expanding rapidly.

Substituting rock mulch, for turf eliminates an active carbon sink just as using bark would. Decomposing bark has some positive soil characteristics, but it releases carbon and more potent greenhouse gases as it decays.

---

[1] Grass Facts. *Department of Agriculture, State of Michigan.* Retrieved May 3, 2005, from http://www.michigan.gov/mda/0,1607,7-125-1570_2476_2481-9345--,00.html.

[2] http://www.allianceforwaterefficiency.org/Grass_and_Turf_Introduction.aspx

Another yard dominated by rock because of turf restrictions. Note the runout from a rain leader on the right that irrigates …………….. rock.

Researchers at Ohio State University, estimated net SOC sequestration in lawn soils using a mathematical model derived from typical homeowner lawn maintenance practices.

The average SOC accumulation rate for U.S. lawns was determined to be 80.0 kg C $lawn^{-1}$ yr^{-1}. Additional C accumulation results from fertilizer and irrigation management. Hidden C costs (HCC) of typical lawn management practices include mowing, irrigating, fertilizing, and pesticide application.

The net SOC sequestration was assessed by subtracting the HCC from gross SOC sequestered. Lawn maintenance practices ranged from low to high management. Low management or minimal input (MI) includes mowing only, with a net SOC sequestration rate of 63.5 – 69.7 kg C $lawn^{-1}$ yr^{-1}. Do-It-Yourself (DIY) management by homeowners is 106.9 – 122.4 kg C $lawn^{-1}$ yr^{-1}. High management is based on University and industry-standard best management recommendation practices (BMPs) and has a net SOC sequestration rate of 85.3 – 142.9 kg C $lawn^{-1}$ yr^{-1}.[3]

Results supported the conclusion that lawns are a positive net sink for atmospheric CO_2 under all evaluated levels of management practices with a national technical potential ranging from 63.5 – 142.9 kg C $lawn^{-1}$ yr^{-1}. [1]

[3] Zirkle, G., Lal, R., Augustin, (May 2011). *Modeling Carbon Sequestration in Home Lawns* HortScience vol. 46 no. 5 808-814

Turfgrass obviously captures more carbon than rock, bare soil, or mulch, but multiple studies have also shown the carbon sequestration performance of turfgrass to be comparable or superior to natural systems including forests and prairies:

W. Bandaranayake, Y. L. Qian,* W. J. Parton, D. S. Ojima, and R. F. Follett, (2003). *Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model;* Agron. J. 95:558–563

M.E. Peach, (2014). *Management Intensity Effects on Lawn Soil Carbon Content in the Eugene–Springfield, Oregon Urban Ecosystem;* Masters Thesis, Univ. of Oregon

Pouyat, R.V., Yesilonis, I.D., Nowak, D.J. (2006) *Carbon storage by urban soils in the USA.* J. Environ. Qual. 35:1566–1575

Yaling Qian and Ronald F. Follett, (2002). *Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data*; Agron. J. 94:930–935

Sahu, R. (2008). *Technical Assessment of the Carbon Sequestration Potential of Managed Turfgrass in the United States.* Outdoor Power Equipment Institute (OPEI). Alexandria, VA

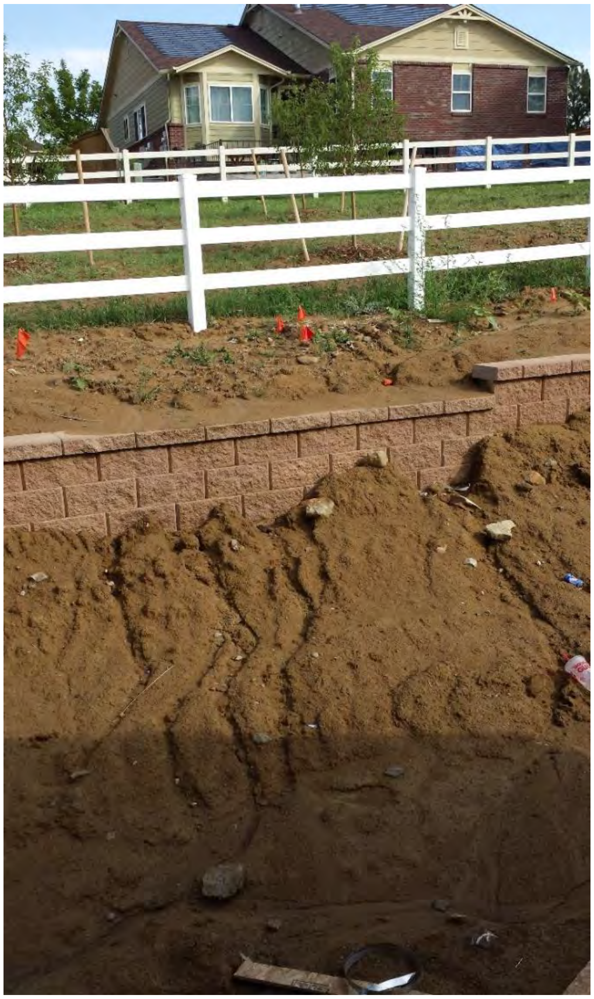
Selhorst, A.L. (2007). *Carbon Sequestration and Emissions due to Golf Course Turfgrass Development and Maintenance in Central Ohio* (Thesis, The Ohio State Univ. Columbus)

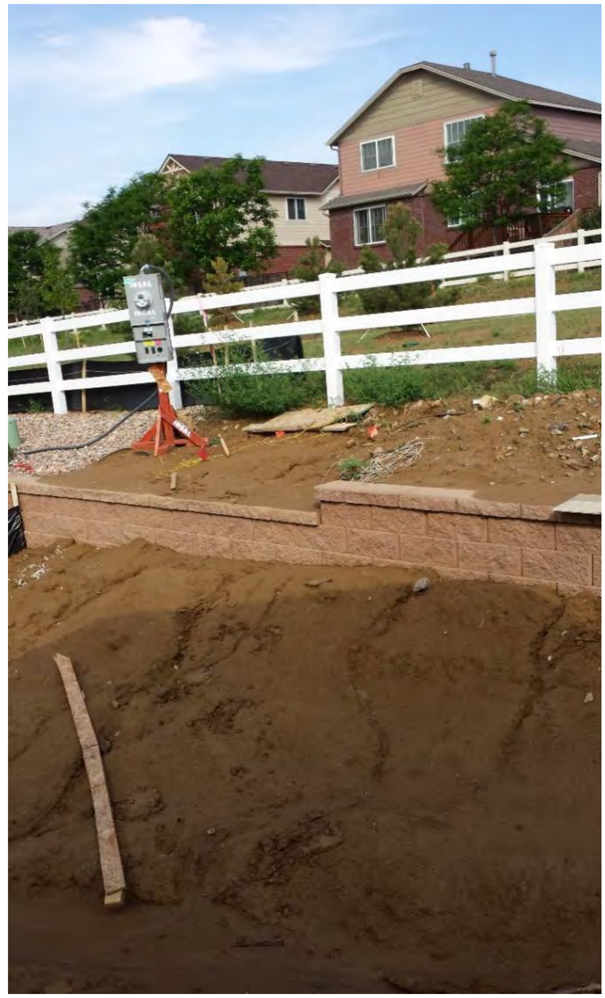
The EPA suggests sodding as a best management practice for quick control of erosion. It says:

"*Sodding permanently stabilizes an area with a thick vegetative cover. Sodding provides immediate stabilization and should be used in critical areas or where establishing permanent vegetation by seeding and mulching would be difficult. Sodding is also a preferred option when there is high erosion potential during the period of vegetative establishment from seeding.*"[4] The EPA also says that sod removes up to 99 percent of total suspended solids in runoff.

Climate change models indicate that that Northern and Eastern states will see sharply increased precipitation with storm events increasing both in frequency and intensity. The Midwest is projected to stay relatively wet. Sustainable landscapes in these regions will need to be able to mitigate the impacts of stormwater runoff (erosion, sedimentation, pollutant transport). Turfgrass does all of those things.

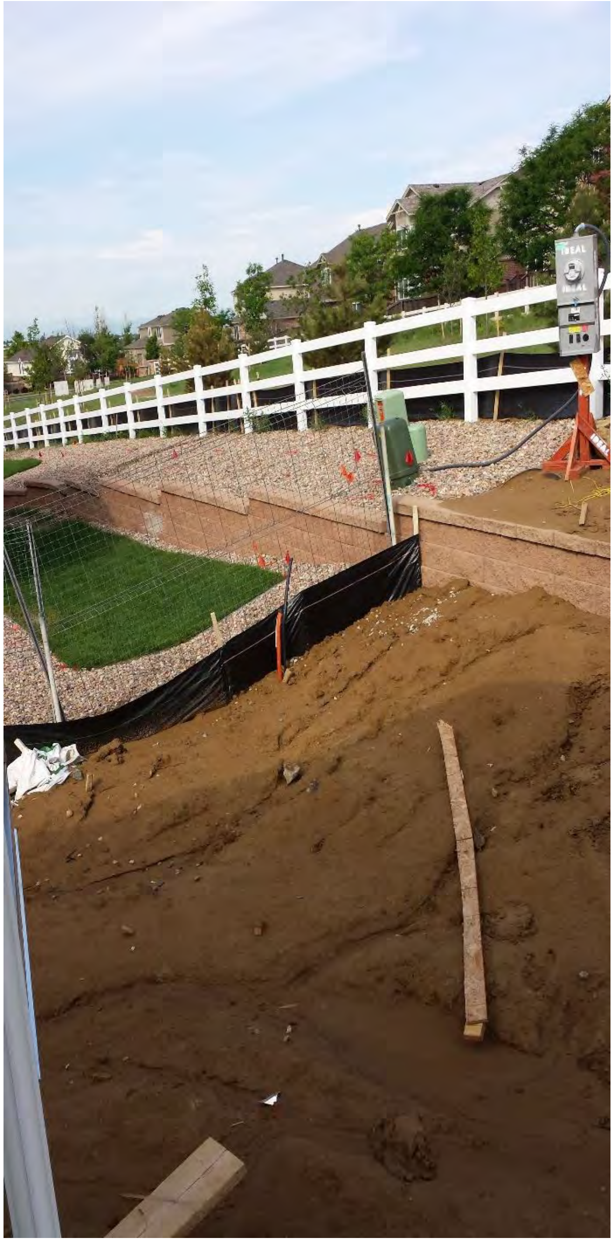
[4] *National Management Measures to Control Nonpoint Source Pollution from Urban Areas* (November 2005, EPA-841-B-05-004)

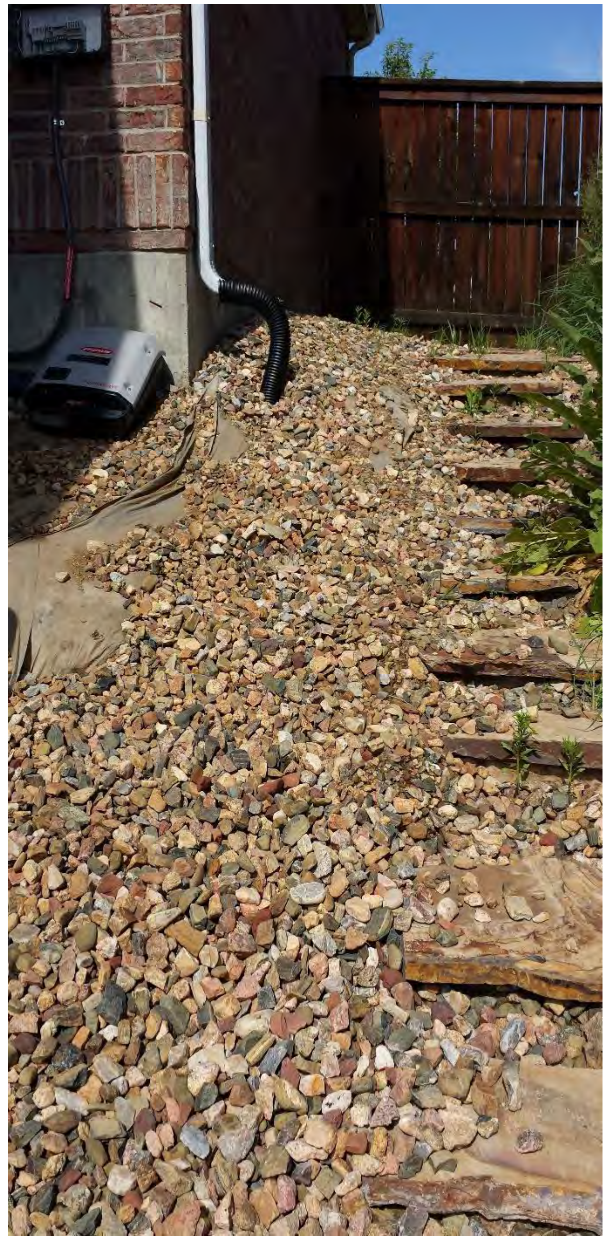




The area between the white fences appears to be common area for a community green belt; perhaps a utility easement. It also appears to have been seeded in addition to having trees planted there.

7





The final design for the new site on the left is more rock, less oxygen production, less evaporative cooling, less biomass accumulation, less nutrient cycling, less carbon storage, less water infiltration, less atmospheric cleansing, less habitat, and more points under the 2015 NGBS.

The picture on the right is of an established site. Note that stormwater has begun washing the stone away.

This is a picture of where organic mulch (and some of the rock) was washed away from the base of a clump of ornamental grass.

Some of the organic mulch was captured in the rock mulch but most of it washed to the bottom of the slope. This was true of all plants on this slope.

The ornamental grass roots are stabilizing the soil surrounding it.

Given the dense clay soil profile there will be little if any infiltration of water here.

However, turfgrass with 12 inches of organic soil base would stabilize the entire slope around ornamental vegetation, slowing water flow and enhancing filtration and infiltration.

Research shows that a healthy, well-managed lawn with dense turfgrass has near zero storm water runoff and provides an effective infiltration mechanism.

In his public comment to GG 243-11 of the International Green Construction Code, Dr. Brian Horgan, assistant professor of horticulture at the University of Minnesota, wrote that *"The thatch-forming capabilities of turfgrass in combination with a permanent and* *dense plant structure yields a less channelized pathway for water movement, which increases resistance, horizontal spread, and infiltration of surface runoff."*

This photo shows more organic and stone mulch being washed away.

Note the weeds sprouting along the steps and at the edge of the photo at the fence.

Each of these ornamental landscape plantings could have been surrounded and protected with turfgrass.

Dense turf does not allow most weeds to establish; mowing prevents most weeds that have gained a foothold from further propagating.

Plants that do survive maintenance – often called lawn weeds – frequently flower below mowing height and support pollinator and other foraging.

Examples of such plants include Clover, Lesser Celandines, Selfheal, and Bird's Foot Trefoil, Thyme, Siberian Squill, Crocus, Violet, and Chamomile. Even Dandelion and Ground Ivy provide good pollinator forage.

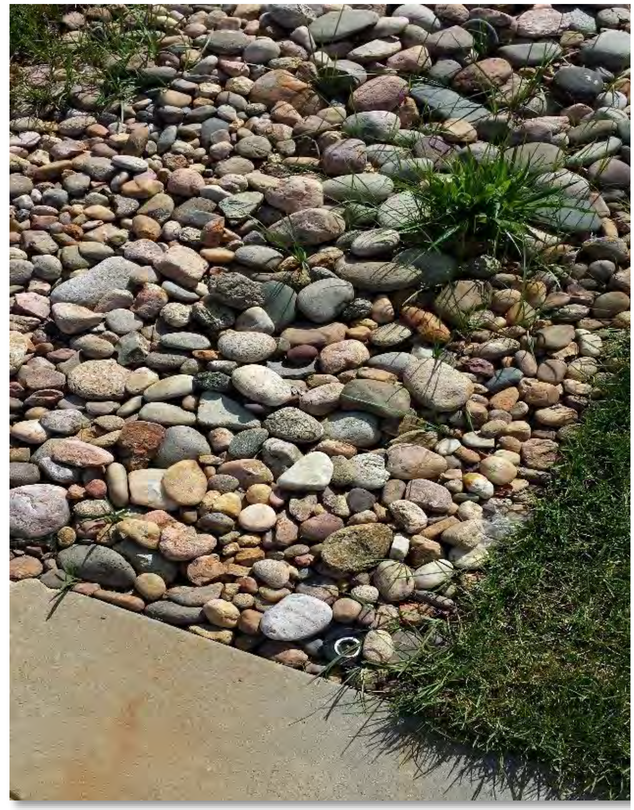
This is an area of rock mulch invaded by both weeds and spreading lawn grass; this was common at established sites in this jurisdiction. Deposits from water runoff and atmospheric soil deposition from wind erosion fill the interstitial spaces of the rock, creating a medium for unwanted plant growth.

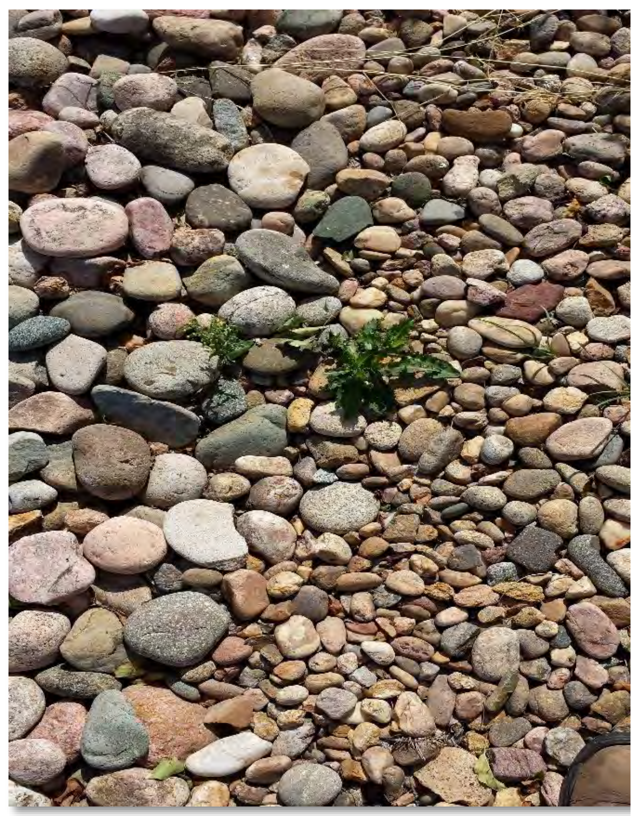
A key benefit of turfgrass is that it reduces airborne dust particulates (and other airborne pollutants) and offers one of the most cost-efficient methods to control wind erosion of soil.[5]

It is likely that undesirable plant growth in rock areas will be treated with pesticides to kill current vegetation and to temporarily prevent future growth.

[5] Beard, J. B. and Robert L. Green (1994). *The Role of Turfgrasses in Environmental Protection and Their Benefits to Humans.* Journal Environmental Quality. 23:452-460

More unwanted vegetation invading rock mulch.



The tree and shrubbery in the picture to the right may provide some habitat value but the rock mulch provides none.

Surrounding the woody plants with turf would improve biodiversity and habitat value. It would allow ground dwelling insects' access to those woody plants without transiting the rock.

Research is proving that turfgrass sustains many other biota and is in fact a bio-diverse environment. Dr. D. J. Shetlar, of Ohio State University reports that *"Recent studies performed in Ohio and New York have found that turfgrass, in fact, often supports 20 to 50 thousand arthropods per square meter. This is comparable with several ecosystems and easily exceeds the biodiversity of agricultural lands."*[6]

Shetlar also states that *"Even without going to the gene level, turfgrass is proving to be an incredibly biologically active ecosystem at all trophic levels that is inhabited by diverse animals, though they are admittedly small"!*[7]

"Turfgrass lawns are everywhere in urban and suburban landscapes," said Loren B. Byrne, in an address at the 2003 Ecological Society of America annual meeting. *"Little is known about the tiny arthropods that live in and under the grass, but these are some of the most diverse and abundant creatures on Earth. They are essential for decomposition of organic material and for nutrient cycling.*[8]

It should go without saying, but many birds forage in turfgrass for worms, grubs, and insects. Some small mammals do so as well. It is common for rabbits to feed on grass and other plants in turfgrass systems at night. Half of the US's 80 million lawns (see following table) are maintained with no chemicals or fertilizers, meaning other plants (often pollinator friendly) share that turfgrass area; forage value for prey species at multiple trophic levels is automatically greater which in turn supports more predators.

[6] D. Shetlar. (2014) *Turfgrass Insect Ecosystems and Pest Management in Ohio*; research project Ohio State Univ.
[7] Shetlar, *Turf: Is it really a Green Desert?* http://landscapeontario.com/attach/1295274268.Biodiversity_in_Turf_-_Dr_David_Shetlar.pdf
[8] *Search Beneath Lawns Provides Insight Into Backyard Biodiversity,* Science Daily (13 August 2003)

Zirkle (2011)[9] cited the following estimates as the number of US residential lawns with associated lawn care practices as follows:

Practice	Number of Homes	Source
Minimal input management. Minimal input lawns are defined as mowing once a week without irrigation, fertilizer, or pesticide use	40 Million	Bruce Augustin The Scotts Miracle-Gro Company (2007)
Do-it-yourself management. Mowing once a week; 10% to 15% (3 to 4.5 million) irrigate; fertilizing 2-3 times per year; pesticide treatment 2 times per year	30 million	National Agriculture Statistics Service, 2002, 2004
Best management practices. This program is defined as mowing once per week, irrigating regularly when rainfall is insufficient for healthy grass growth, and fertilizing four times a year with pest prevention; typically performed by a lawn care service.	10 million	Augustin, 2007

From the table above, it is calculated that roughly 65 million home lawns (80 percent) are not irrigated.

While lots in adjoining developments were being covered with rock mulch to comply with the jurisdiction's turfgrass area limits, across the street there were acres of non-irrigated turfgrass serving open park space.

Presumably this turf was either native buffalo grass which has a low water demand (as low as 15 inches annually) or a drought resistant turfgrass, some of which can survive 60 summer days in Texas without any water[10] while preventing wind erosion and being ready to provide a full range of ecosystem services when precipitation is available.

Additional information about drought resistant turf is provided in this Alliance for Water Efficiency webinar, *Drought Tolerant Turf and Water Efficiency*

[9] Ibid.

[10] Chalmers et al. *Evaluation of Sixty-Day Drought Survival in San Antonio of Established Turfgrass species and Cultivars* (2008)

To address concerns with water use for turfgrass in arid climates, where there is no existing turf limitation ordinance, it is proposed that points for turf limitations be awarded only where annual precipitation averages 12 or less inches per year and that the use of a WBT be used to establish turf limits for sites that average more than 12 inches of precipitation per year. We also propose that the maximum points for a 100% turf limitation be equal to the points awarded for use of a WBT.

Proposed change:

503.5 Landscape plan. A plan for the lot is developed to limit water and energy use while preserving or enhancing the natural environment.	
	Points
(4) For sites receiving more than 12 inches of average annual precipitation the EPA WaterSense Water Budget Tool or equivalent is used when implementing the maximum percentage of turf areas.	~~2~~ 5
(5) For landscaped vegetated areas on sites receiving 12 or less inches of average annual precipitation, the maximum percentage of turf area is:	
(a) 0 percent	5
(b) Greater than 0 percent to less than 20 percent	4
(c) 20 percent to less than 40 percent	3
(d) 40 percent to 60 percent	2

LogID 6222

HEALTH IS A HUMAN RIGHT.

GREEN BUILDING CAN HELP.

A REPORT FROM

THE SUMMIT ON GREEN BUILDING & HUMAN HEALTH

JANUARY 2013

FOREWORD

We know these to be simple truths: Where we spend our time matters. Daylight matters. Good acoustics matter. Healthy materials matter. Fresh, clean air and water matter. Design that encourages movement matters. Access to local and healthy food matters.

Every corner of our built environment should provide these things to promote our health and well-being. It should be our baseline, but all too often it's our aspiration.

So how do we change that? How do we more clearly link the market transformation that the green building movement has inspired to its opportunity to create an equally transformational impact on human health?

That was the question that framed the Summit on Green Building & Human Health in January 2013. We knew this conversation was taking place at every point along the built environment continuum. From architects to engineers to product manufacturers to public health practitioners to financial institutions and government agencies-- a lot of people and organizations have been wrestling with this.

But we discovered early on that the conversation wasn't happening ***across*** the continuum. Architects weren't engaging public health physicians. Insurance companies weren't talking to contractors. Product manufacturers weren't sitting down with their upstream supply chain partners. We were all talking loudly to ourselves.

The U.S. Green Building Council learned a long time ago that there is no such thing as a paradigm baby step. It takes everyone having the same conversation to ignite real change in practice. We need a clear line of sight to what we know and what we need to know, and fundamental to any success is engaging the passion of a movement around an idea so powerful that action is a given and change is the outcome.

In the following pages, we summarize this first conversation, and then suggest a few next steps to keep us moving forward. Because there is one other thing we know to be true: If health is a human right, and green building can help, we've got a lot of work to do.

Rick Fedrizzi
President, CEO and Founding Chair
USGBC

Anthony Bernheim, FAIA, LEED Fellow
Vice-Chair
USGBC Board Working Group on
Green Building & Human Health

Gail Vittori, LEED Fellow
USGBC Board Working Group on
Green Building & Human Health

Howard Frumkin, MD, Dr.PH
Chair
USGBC Board Working Group on
Green Building & Human Health

Michael McCally, MD PhD.
USGBC Board Working Group on
Green Building & Human Health

TABLE OF CONTENTS

OVERVIEW 3

USGBC'S SUMMIT ON GREEN BUILDING & HUMAN HEALTH 4

- The Summit Process 4
- Summit Organization 5
- Opening Plenary 5
- Charrette Summaries 8
  - Charrette 1 8
  - Charrette 2 10
  - Charrette 3 14
  - Charrette Themes 17
- Closing thoughts from participants 17

WAS THE SUMMIT SUCCESSFUL? 19

WHERE DO WE GO FROM HERE? 20

CLOSING THOUGHTS 23

APPENDICES 26

- Appendix I: Summit Participants 26
- Appendix 2: USGBC Initiatives 30

OVERVIEW

Our nation is in the midst of a lively public policy debate on how best to enable individuals and communities to make healthier choices. In recent years, with the rapid advance of green building practices, the connection between green building and its promotion of human health has become increasingly clear: Done right, the built environment can have profound positive effects on health, both human and environmental.

At their worst, our building materials and designs, and our choices about location, building construction, operation and maintenance, contribute to some of the key public health concerns of modern society, from asthma to cancer to obesity. At their best, our buildings and communities can be powerful protectors and promoters of health and well-being.

We must shift practice such that our definitions of sustainable building include the well-being of the people in the buildings and the community around them as a matter of course – not an incidental byproduct. In the new paradigm, human performance must be seen as important as energy performance; health conservation equal to water conservation; health management on par with waste management. And we must ground our choices in data, using research and evidence to inform our approaches to healthy design, construction and maintenance. It's through this holistic approach that green building becomes not just a market transformation tool, but a human transformation tool as well.

As a leader in the green building movement, USGBC is committed to environmental sustainability and economic prosperity. Sharpening our focus on how green building can advance human health and well-being marks an important milestone in the history of our movement.

USGBC'S SUMMIT ON GREEN BUILDING & HUMAN HEALTH

USGBC initiated the Summit on Green Building & Human Health to assess and advance the state of the green building movement as it relates to human health concerns.

Our buildings and communities are habitat. Shelter. Assembly. Sanctuary. When we think about them this way, their ability to protect, to inspire, to promote health rather than compromise it seems to suggest an obvious need to incorporate this lens in how we plan, design, construct and maintain our built environment.

It is, of course, crucial that high-performing built environments use less energy and water and fewer virgin materials. The Summit sought to raise the intensity of the conversation around how human health factors can be woven into buildings. The meeting made clear that the industry is poised to give equal weight to decisions that are consequential to human health.

The Summit Process

After two years of consultative planning, led by USGBC, the Summit on Green Building & Human Health brought together thought leaders from diverse sectors to address three overarching goals:

- Assess the state of the green building movement relative to human health concerns, and identify pathways to build and reinforce **programs** in USGBC and across the industry that advance the human health aspects of green building.
- Strengthen and build the **knowledge base** on green building and human health.
- Support the robust international green building **movement** so that it more clearly connects human health to green building practice and promotes the value in doing so.

Participants at this invitational Summit included more than 100 experts from the public, private and NGO sectors in public health, health care delivery, research, architecture, design, construction, facility management, product manufacture, finance and real estate development. Many had never met.

Summit Organization

The Summit opened with a strong opening plenary laying out the importance of the work, and the equally important work of effectively communicating about this complex subject in a way that not only informs, but also inspires and challenges us to seek solutions and opportunities. The group then spent the next 1.5 days in three charrette sessions, each of which addressed one of the Summit goals. A few of the Summit participants were selected to "ignite" the conversations in the charrettes and introduced the topic for each session.

Each charrette was broken out into six smaller work groups to assure the groups were small enough to have meaningful discussion. All the participants addressed each topic, expanded the discussion and made observations and recommendations within their charrette groups.

The groups reconvened for a short debrief after each charrette before tackling the next topic. The event closed with a final summary session that collapsed 1.5 days of work and dozens of flip chart records into a set of proposed recommendations for further action.

While this white paper cannot reproduce all of the thinking, here is a brief summary of the sessions and their recommendations.

Opening Plenary

The Opening Plenary gave participants an opportunity to get to know each other a bit, to challenge their thinking for the session and to underscore the importance of the work.

Participants met the members of the USGBC Board Working Group for Green Building & Human Health and were treated to an inspiring call to action from USGBC CEO Rick Fedrizzi.

Communications strategist Kristin Shannon gave a short keynote about the neuroscience of communications and the importance of framing the issue of human health in green building in powerful and meaningful ways to encourage adoption and inspire action.

GB&HH Working Group Chair Dr. Howard Frumkin laid out the Summit work.

Voices *from the Opening Plenary*

LEED was a way to capture people's energy, imagination and focus. Health has always been there, but it was never in the front seat. It needs to be in an important way.

20 years later, we're convening this group, not because we didn't care over the past 20 years, but because we are now ready for this discussion. We're grown up now.

Health will be the biggest driver in the green building space in the next 20 years.

- Rick Fedrizzi

Voices *from the Opening Plenary*

We all carry around grammars that are unique to us but foreign to everyone else. We need a common grammar about green building and human health.

- Judith Webb

Green building has matured and it's now ready to grow beyond its environmental roots to embrace a human dimension.

Our goal is a safe, healthy, green, sustainable, economically viable, beautiful, inspiring, great places for people. We'll get there if we blend our individual visions.

- Howard Frumkin

CHARRETTE 1

How can we support a robust nationwide movement that promotes green building and human health?

CHALLENGE:

Industry groups, non-governmental organizations, professional associations representing both design and health professions, community groups, academia and government agencies are among the partners needed for true transformation. Because of the many co-benefits that may flow from green, healthy building, broad-based coalitions are necessary.

Questions Considered:

- What role should USGBC take in advancing green building and human health?
- Who has the resources to map and publish data on the organizations that are involved in and contributors to the movement?
- Who should take the lead in defining the metrics and standards for a healthy community for people?

Igniter Panel:

MODERATOR:

Michael McCally, MD, PhD
Clinical Professor of Preventive Medicine
Mount Sinai School of Medicine

PANELISTS:

Majora Carter
Founder of Sustainable South Bronx and President
Majora Carter Group

"It's all about the people. Whatever position you have, how can you use your position at the table to help those who are not?"

Rachel Gutter
Director
USGBC's Center for Green Schools

"Don't lobby, partner. Partner with people who want most to protect the status quo."

Tim Cole
Head of Sustainability
Forbo Industries

"Two things that cause change with product manufacturers: Cost and stakeholder demand."

Charlotte Brody
Associate Director, Health Initiatives
BlueGreen Alliance

"We must appeal to the humanity of the people who build and maintain our buildings."

Discussion Summary

Panelists stated that a nationwide movement that promotes green building and human health is primarily about people and neighborhoods, not just about the physical structures. They invited Summit conferees to focus less on blueprints and more on the people who use the buildings as homes, schools and workplaces. They emphasized specific communities of interest and recommended that we specifically examine their needs and find ways to measure the impact of improved practice. Groups include: children, the elderly, underserved communities and communities of color. They also noted the importance of partners with a focus on specific kinds of built environments, such as schools, homes and health care institutions.

Panelists also highlighted the impact on the workers who make building products, build and maintain facilities, neighborhoods and communities. There was a focus on fence-line communities (along material supply and disposal chains). Questions were raised about the global community and impact on future generations of today's decisions.

Product manufacturers rely on design standards and building codes as guidelines to develop and promote their products; the session included requests from product manufacturers to make guidelines more explicit and universal – thereby leveling the business playing field.

Charrette Session Summary

Participants concluded that there is a need to:

- Clearly define healthy communities, buildings and interiors (i.e. places that support healthy children and adults) with metrics, thresholds and applications, and to
    - Inform and inspire in areas where we have choices.
    - Create minimum acceptable standards in areas where we have no choices.
    - Invest in areas where long-standing inequities create health disparities.
- Use digital technology to map the universe of organizations connected to green building and human health. Form a network, find synergies and develop a common vision.
- Develop the language to communicate the message to different communities and interest groups.
- Continue to refine LEED and better communicate its requirements for improved human health.

CHARRETTE 2

How can we build the knowledge base on green building and human health?

CHALLENGES:

Information is one of the limits to realizing green, healthy buildings and communities for all. While we know a lot, there is much that needs to be established based on solid data to enable evidence-based design and valid metric-based measures of progress and success. This will call for research—not highly theoretical research, but "use-driven" research that aims to answer practical, human-oriented questions. It will also require that the information we have be effectively disseminated, from the level of students preparing for the design, construction, business and health professions, to the level of practicing professionals.

Questions Considered

- What are the most pressing research questions?
- How should research funding be enabled?
- Who should and how best to collect, organize and distribute the relevant research and building-oriented solutions?
- How should health-based design and outcomes information be disseminated?

Igniter Panel

MODERATOR:

Gail Vittori
LEED Fellow, Co-Director
Center for Maximum Potential Building Systems

"Identify the value of health and take the opportunity to take it to scale."

PANELISTS:

Matthew Trowbridge, MD, MPH
Assistant Professor and Associate Research Director
School of Medicine, University of Virginia
USGBC Ginsberg Fellow

"A healthier building, a healthier place has not yet been valuated as such in the marketplace and that's what we need to address."

Vivian Loftness
FAIA, LEED AP, Professor
School of Architecture, Carnegie Mellon University

"We're going to have to sit down as a group and decide: What health factors can we have the biggest impact on?"

Daniel Friedman, PhD
Professor and Former Dean
College of Built Environments, University of Washington

Discussion Summary

Two competing themes emerged from the presentations. The first was the need for additional research on human health in the built environment. We need examples of healthy environments (buildings and communities) with information on what works that can be translated and applied on future projects. The second theme was the urgent need to design, construct and operate the built environment in the present time—before all the data are in—to support improved human health. To support these research and action needs, there is an additional real-time need to improve the education for design and construction professionals to provide them with sustainable, health-based and action-oriented information and skills to supplement their traditional training.

Charrette Session Summary:

Participants concluded that there is a need to:

- Map the currently available research on health and the built environment.
- Use digital technology and robust data analytics to identify best practices and solutions.
- Disseminate the information in a usable form (i.e. translate the research for lay, academic and professional audiences).
- Identify what additional research is needed, cultivate funding prospects and pursue opportunities to partner/collaborate with other organizations around shared interests.
- Gather data from a wide range of disciplines.
- Provide USGBC support for the issue of green building and human health to spur support for additional research.
- Propose a "Healthy Indoor Air Act" to congressional leaders to spur action by federal agencies. This could also incentivize research funding at such groups as Environmental Protection Agency, National Institutes of Health and National Science Foundation.

Voices *from the Opening Plenary*

Personalizing knowledge forecloses on common sense.
Best example is training of architects.

154
architecture programs

5,700
full and part-time faculty teach in those facilities

3,200
assistant/ associate or full professors

28,000
full-time students and trending downwards

123
institutions

29%
of assistant/ associate or full professors are registered architects

15%
of assistant/ associate or full professors are PhDs

50%
of assistant/ associate or full professors are Masters

With respect to research: **no measurable, palpable culture of research exists in the architectural curriculum**.

- Daniel Friedman

Voices *from the Opening Plenary*

104,301
registered architects in the U.S

500,000
construction managers in the U.S

1 MILLION
carpenters

5 : 1
ratio of construction managers to architects

5.5 MILLION
people earn a living in the $1 trillion US construction industry, down 2.2 million from 2006

- Daniel Friedman

CHARRETTE 3

How can we build and reinforce programs in USGBC and across the industry that advance the postive impacts of green building on human health?

CHALLENGE:

USGBC plays a major role in the green building movement through LEED (Leadership in Energy and Environmental Design) and the corresponding training, credentialing and certification offered by the Green Building Certification Institute (GBCI). In addition, several other initiatives exist including other rating systems (e.g., Living Building Challenge, Earthcraft), voluntary product certifications and disclosures (e.g., the Health Product Declarations, Cradle-to-Cradle) and regulatory approaches. This session considered the way major programmatic initiatives to date have incorporated human health and identify future opportunities to expand their promotion of human health, preparing for the design, construction, business and health professions, to the level of practicing professionals.

Questions Considered

- Who should collaborate to build such tools as:
    - Health Impact Assessment Tool for buildings
    - Green Building Product Assessment Tool
- How could the USGBC partner with other organizations and the USGBC regional/local chapters to build programs, refine existing programs and deliver the healthy environment message to the community?
- How should USGBC clarify the relationship between LEED and human and environmental health?

Igniter Panel

MODERATOR: **Beth Heider**
AIA, LEED AP, Senior Vice President of Green Markets
Skanska

PANELISTS: **Robin Guenther**
FAIA, LEED AP, Principal
Perkins+Will

"If health is the yang, how does the mindset have to shift to a world of less harm to one of environments that heal?"

Anthony Bernheim

FAIA, LEED Fellow, Principal

Sustainable Built Environments

"How do we bring human health into the consciousness of the community and design and make human environments that are healthier for all of us?"

John Wargo

Tweedy Ordway Professor of Environmental Health and Politics

Yale University

"The opportunity to conduct research on buildings that you have certified is a way to research what works."

Brendan Owens

LEED Fellow, Vice President for LEED Technical Development

USGBC

"We have mechanisms that catalyze significant change. We provide evaluation that gives designers opportunity to make preferential selection. That signals the market. And that leads to innovation."

Discussion Summary

Professor David Orr's definition of sustainability was cited as a compelling touchstone:

> "The standard for ecological design is neither efficiency nor productivity but health, beginning with that of the soil and extending upward through plants, animals and people. It is impossible to impair health at any level without affecting it at other levels.[1]"

This implies that global and human well-being are fused, and that the built environment should support human thriving, healing and positive emotional being.

Building design decisions should be made with an understanding of integrated systems and building product trade-offs.

There are a number of initiatives and programs that are currently being used to support improved human health in the built environment including the California Indoor Air Quality Standard (now referenced in the new national green building codes), LEED, the Health Product Declaration, the Electronic Product Environmental Assessment Tool and others.

A range of environmental conditions, from climate change on a global scale, to air quality at the regional and even building scale, to toxic chemicals at the molecular scale, have implications for human health. Further research is needed both to understand these impacts, and to understand the role of the built environment in either aggravating or mitigating them.

1 Orr, David W., The Nature of Design, Ecology, Culture and Human Intervention, Oxford University Press, 2002.

LEED has evolved over the years to further recognize the importance of building and community design and operation for improved human health. USGBC seeks to translate research into solutions across the building life cycle, and to encourage the industry to adopt improved standards at a pace that fulfills sustainability objectives and practical business needs.

Charrette Session Summary:

Participants concluded that there is a need to:

- Develop a Health Impact Assessment tool for buildings.
- Develop a comprehensive explanation of how LEED credits support improved human health and refine future LEED versions based on new research.
- Develop a map of other related organizations and their work in this area and find ways to leverage capacities and expertise
- Build on existing initiatives and tools (e.g. Health Product Declarations, Environmental Product Declarations, Electronic Product Environmental Assessment Tool, California DCPH/EHLB/Standard Method V1.1, February 2010, etc.) based on health indices.
- Encourage product chemical content and volatile organic compound emissions transparency.
- Harness the efforts of USGBC local chapters to work on this issue in their communities. An example is the USGBC Northern California Chapter that has initiated a Healthy Communities Initiative.

Charrette Results and Themes from all Three Sesions:

NEW FORMS OF COLLABORATION AND NEW MEASURES OF WELL-BEING

A number of common themes were identified across the three sessions. It is useful to list them as they provide guidance on how the movement might move forward. Cross-cutting themes include:

- Cross-discipline collaboration is needed to facilitate improved health in the built environment.
- Metrics are needed to help establish what is considered a healthy environment for people.
- Mapping and sharing of data is needed. Data should include information on relevant professionals and organizations, currently available and future research needs and currently available healthy building solutions.
- There is a need to connect our understanding about human, physical and emotional health with building design choices.
- There was a concern that human health is a social equity issue and everyone should have access to healthy environments.
- While there needs to be thoughtful planning for the path forward, there is also an urgency to proceed quickly.

Closing Thoughts

FROM THE PARTICIPANTS

Based on the intense conversations during the charrettes, in the regroup sessions, during networking and at the closing event, Summit participants had strong recommendations about work that needs to be undertaken to keep this initiative moving forward. An informal survey of the Summit participants revealed the following list (in priority order)

1. Develop a "trail map" to build the movement and improve human health in the built environment utilizing the collective knowledge of the Summit participants.
2. Develop human health-based benchmarks and metrics for the built environment, and inclusive of the construction process, to help project teams that use LEED, specifically, and other standards, more broadly, to make more informed decisions.
3. Define health in the built environment and establish its value.
4. Develop the message appropriately for different audiences and facilitate a public relations informational campaign.

5. Compile and distribute research related to the built environment and human health; translate research into actionable design solutions that can be applied to city and community planning, and building design by planners and architects using LEED and other standards more broadly.

6. Recognize a shift in the definition of "sustainability" as it moves from Sustainability = energy, to Sustainability = zero net energy, water, & waste + improved human health (buildings and community) as it becomes intrinsic to standard practice.

WAS THE SUMMIT SUCCESSFUL?

In assessing the Summit's success, the organizing team noted the following outcomes:

- Identified recommendations and resources for continuing to evolve LEED to more fully embrace human health.
- Began to identify the research needed to better target positive building design targets for community health.
- Provided a lively collaborative forum for representatives from diverse sectors to identify issues and develop solutions. The Summit "sparked" a significant dialogue on green building and human health amongst health experts and designers who do not usually meet and collaborate.
- Energized participants to meet again, cooperate and continue collaborating to further develop the movement towards improved voluntary health standards.
- Identified additional people and organizations to contribute to information for standard setting; provided sources for relevant data to be made available through an accessible clearinghouse.
- Strengthened the resolve and enthusiasm within the green building movement and USGBC; in the words of a participant "restored the romance" of the movement for the next stage.
- Provided USGBC staff with resources, both experts and organizations, for future work in the space of human health in the built environment.
- Identified communications forums, processes and technologies (e.g. social media), to better communicate and focus the work going forward.
- Identified other thought leaders and experts who should participate in next steps.
- Generated measures of success and recommendations for next steps. The participants advocated the development of a "trail map" or plan to accelerate and integrate the various pieces that impact green building and human health.

WHERE DO WE GO FROM HERE?

The USGBC's mission and vision over the last two decades has been to transform the industry (design, construction and building operation) to improve the quality of life in the places where we live, learn, work, heal and play within a generation.

For many, however, "green building" is still translated simply as "energy efficiency." At The Summit on Green Building & Human Health contributors made clear that this is no longer sufficient; that the next stage must emphasize the role of the built environment in supporting human health. They concluded that it's now time to raise the profile of human health concerns as part of our measures of sustainability.

In recognition of its vision, mission, USGBC is committed to further identifying these connections and incorporating well-being into the practices and policies it promotes by incorporating this charge into its 2013-2015 Strategic Plan:

"While green building has strong roots in economic and environmental performance, it offers vitally important benefits for human health and well-being. Designing for these benefits, 'human-based design' can promote health and well-being in many ways, from reduced exposure to toxic chemicals to enhanced access to natural light, from routine physical activity to improved indoor and ambient air quality, from injury prevention to increased mobility."

"USGBC will pursue a range of strategies to understand, document, implement and disseminate the health benefits of green building including a healthier climate, healthier environment and healthier individuals."

"Strategies:

- *Continue to evolve the LEED rating system and other certification standards to incorporate health and well-being parameters;*
- *Build the knowledge base on the health benefits of green building, including the health benefits of LEED, by supporting research initiated by USGBC and others;*
- *Educate our communities, the public, and the building professions about the health benefits of green building, including the health benefits of LEED; and*
- *Take a lead role in strengthening the healthy building movement through partnership and collaboration."*

The Summit was one of the key initiatives we teed up as a way to capture community input about what our scope should be in addressing these strategies. Following is a brief synopsis of work that is currently underway to support these strategies[2].

2 A longer list of initiatives underway to address these strategies is attached in Appendix 2: USGBC Initiatives. Many grew out of the work undertaken at the Summit.

Building the Movement:

- Offering a webcast in August 2013 to brief our community on this report, continue the conversation begun at the Summit and discuss future initiatives.
- Establishing a web-based community via Yammer and usgbc.org that can provide a place for information exchange and collaboration.
- Developing and circulating for community ratification a set of basic guiding principles that can be used as a point of reference by USGBC chapters and members of our extended communities.
- Using Greenbuild 2013 as a platform by:
    - Identifying key health-related education programs so attendees can build a track that focuses on green building and human health.
    - Convening a two-hour Master Speaker and Panel Session, featuring Dr. Dick Jackson, UCLA.
    - Considering a Materials and Human Health pre-event Summit that includes convening product manufacturers and designers to learn about LEED and the Materials credits.
- Partnering with key organizations in various sectors to leverage strengths and build the movement by continuing to convene a dialogue around green building and human health, act as a broker for establishing partnerships that advance this work and facilitate communications between and across our diverse communities.

Building the Knowledge Base:

- **Green Building & Public Health Metrics** development across LEED rating systems is underway (supported by a 2-year, $300K grant from Robert Wood Johnson Foundation. The metrics will become part of the Green Building Information Gateway platform (GBIG).
- **Health-related Resilience Research (on-going through academic collaborations), including** temperature impacts on vulnerable populations; a case study for resilient health care facilities and the development of a LEED credit screening tool.
- Several additional written resources to address various points of intersection between green buildings and human health with partners including the McGraw Hill Research Foundation, the Center for the Built Environment at Colorado State University and the National Collaborative on Childhood Obesity Research (NCCOR).
- **Materials in LEED (supported by a grant from Google):**
    - Engaging three Senior Research Fellows.
    - Working on creating a harmonized approach to hazard assessment across the globally harmonized system (GHS), Cradle to Cradle (C2C), Health Product Declarations (HPDs) and GreenScreen.

- Identifying research opportunities through the building materials research heat map (supported by BuildingGreen and Cradle to Cradle).
- Preparing communications calendar for USGBC.gov and GBIG Insight, to include technical social media, white papers and peer-reviewed analysis and synthesis.
- Reducing barriers to reporting and disclosure around building materials by supporting the Health Product Declaration Collaborative (HPDC).
- Leveraging the grant work to increase the availability of products compliant with Health Product Declaration, GreenScreen and Cradle to Cradle requirements to scale up the market by working directly with manufacturers to speed adoption of the programs referenced in the LEED v4 Material Ingredients credit.

Programmatic Initiatives:

- **LEED**
  - A number of changes made to **LEED v4** reflect an ehanced focus on human health. Our Technical Advisory Groups worked across BD&C and O&M credit categories to make the health impacts of v4 more specific.
  - Use of the Pilot Credit library has been a helpful way to advance the consideration of new credit language that has health impact, including Walkable project sites; Clean Construction; Ergonomics strategy; Enhanced acoustical performance – exterior noise control; Indoor air quality procedure(s) – alternative compliance path; and Design for Active Occupants.
  - A key Summit outcome has been to start working with the National Institute of Occupational Safety and Health (NIOSH) on the development of a Worker Safety pilot credit as well.

CLOSING THOUGHTS

"When in doubt, do something."

In many ways, our inspiration for convening this Summit was just that simple. We knew if our next effort to change the world was to be successful, we needed to use the power of USGBC's big tent to gather the passion around our core idea and focus our collective energy into a framework for action.

The Summit report has been drafted concurrent to a number of initiatives that are already underway. Others were in response to Summit ideas. But it's just a first step.

In a separate email to be sent, we're providing for your consideration the first draft of some proposed Statement of Principles for human health in the built environment[3]. We need your help to refine, finalize and ratify these principles. You'll find in the email a link to the Green Building & Human Health Yammer Community, where the principles are posted individually for your comment. Our goal is to get input from our Summit participants on this first draft by July 30, 2013. We'll use your comments to refine, and then repost for input from others who have expressed interest in being part of this initiative. We'll also host a Webex Town Hall to offer an additional venue for keeping the conversation going and reporting on our progress to date.

We're grateful beyond measure for the time and effort of every individual who has lent his or her time and thinking to this effort.

But the time for talking is done.

If human health needs to be a much stronger outcome of green building, we need to get to work.

---

3 Special thanks to Tom Lent, of the Healthy Building Network, for inspiring our initial thoughts.

SUMMIT ORGANIZERS AND AKNOWLEDGEMENTS

Summit Organizers

USGBC Board of Directors Working Group on Green Building and Human Health:

Dr. Howard Frumkin, MD, Dr.PH (Chair)

Anthony Bernheim, FAIA, LEED Fellow

Michael McCally, MD PhD.

Gail Vittori, LEED Fellow

Consultation and Facilitation

Nadav Malin, BuildingGreen

Staff

Judith Webb, APR

Melissa Gallagher-Rogers, LEED AP BD&C

Selina Williams, LEED Green Associate

Keynote Speaker and Event support:

Kristen Shannon, Chair CIAO: "*Minds, Memes & Smart Messages*"

Adrian Segar, Facilitator

Summit Moderators:

Charrette 1: Michael McCally, MD, PhD.

Charrette 2: Gail Vittori, LEED Fellow

Charrette 3: Elizabeth Heider, AIA, LEED AP

Summit Igniter Panelists:

Charrette 1

Majora Carter, Founder of Sustainable South Bronx and President, Majora Carter Group

Rachel Gutter, Director, USGBC's Center for Green Schools

Tim Cole, Head of Sustainability, Forbo Industries

Charlotte Brody, Associate Director, Health Initiatives, BlueGreen Alliance

Charrette 2

Matthew Trowbridge, MD, MPH, Assistant Professor and Associate, Research Director, School of Medicine, University of Virginia

Vivian Loftness, FAIA, LEED AP, Professor, School of Architecture, Carnegie Mellon University

Daniel Friedman, PhD, FAIA, Professor and Former Dean, College of Built Environments, University of Washington

Charrette 3

Robin Guenther, FAIA, LEED AP, Principal, Perkins+Will

Anthony Bernheim, FAIA, LEED Fellow, Prinicpal, Sustainable Built Environments

John Wargo, Tweedy Ordway Professor of Environmental Health and Politics, Yale University

Brendan Owens, LEED Fellow, Vice President for LEED Technical Development, USGBC

USGBC Summit Facilitator and Recording Teams

Kristin Ritchie and Sara Cederberg

Whitney Austin Gray and Mika Kania/Jeremy Sigmon

Chris Pyke and Casey Studhalter

Dan Geiger and Asa Foss

Lindsay Baker and Elle Olszewski/Melissa Gallagher-Rogers

Brendan Owens and Emily Alvarez

Mara Baum and Emily Loquidis/Nate Allen

For more information:

U.S. Green Building Council

2101 L St. NW, Suite 500

Washington, D.C. 20037

202.828.7422

APPENDIX I: SUMMIT ATTENDEES

First Name	Last Name	Company Name
Paula	Olsiewski Miller	Alfred P Sloan Foundation
Kristin	Durazo	American Heart Association
Nick	Kushner	American Planning Association
Anna	Ricklin	American Planning Association
Douglas	Brown	BASF
Adele	Houghton	Biositu, LLC
Charlotte	Brody	BlueGreen Alliance
Emily	Naden	BOMA International
Naday	Malin	BuildingGreen
Elizabeth	Whalen	CalAg
Vivian	Loftness	Carnegie Mellon University
Arthur	Wendell	Center for Disease Control & Pervention
Mark	Rossi	Clean Production Action
Lauren	Heine	Clean Production Action, Lauren Heine Group LLC
Gail V	Vittori	CMPBS
Eden	Brukman	Concenter Solutions, LLC
Sarah	Lewis	Congress for New Urbanism
Howard	Williams	Construction Specialties
Whitney	Gray	Consultant
Carmen	Brick	Council of Large Public Housing Authorities
Sunia	Zaterman	Council of Large Public Housing Authorities
Stacy	Glass	Cradle to Cradle Products Innovation Institute
Lorraine	Doo	DooConsulting
Peter	Doo	DooConsulting
Penny	Bonda	Ecoimpact Consulting
Robert	Watson	EcoTech International
Thomas	Osdoba	Enterprise Community Partners, Inc.
Yianice	Hernandez	Enterprise Community Partners, Inc.
Tim	Cole	Forbo Flooring Systems
Kristen	Ritchie	Gensler
Charlene	Bayer	Georgia Institute of Technology
Nisha	Botchwey	Georgia Institute of Technology
Jean	Carroon	Goody Clancy
Michelle	Hatzis	Google, Inc.

Summit Attendees (continued)

First Name	Last Name	Company Name
Lacy	Caruthers	Google, Inc.
Anthony	Ravitz	Google, Inc.
Veena	Singla	Green Science Policy Institute
Aaron (Ari)	Bernstein	Harvard School of Public Health, Center for Health and the Global Environment
Robert	Phinney	HDR Architecture, Inc.
Jean	Hansen	HDR Architecture, Inc.
Tom	Lent	Healthy Building Network
Bill	Walsh	Healthy Building Network
Claire	Barnett	Healthy Schools Network
Ihab	Elzevadi	High Performance Environments Lab, University of Oregon
Mara	Baum	HOK
Mary Ann	Lazarus	HOK
Mikhail	Davis	Interface
Richard	Graves	International Living Futue Institute
Amanda	Sturgeon	International Living Future Institute
Joel	Todd	Joel Ann Todd Consulting
Joyce	Lee	Joyce Lee, FAIA, LEED AP
Dana	Bourland	JPB Foundation
Travis	English	Kaiser Permanente
Majora	Carter	Majora Carter Group
Lindsay	Baker	Mary Davidge Associates
Anne	Less	Mary Davidge Associates
Michael	McCally	Mt. Sinai School of Medicine
Rebecca	Morley	National Center for Healthy Housing
Christine	Branche	National Institute for Occupational Safety and Health
Charles	Blumberg	National Institutes of Health
Susan	Hinton	National Institutes of Health
Kenny	Floyd	National Institutes of Health
Matt	Gillen	NIOSH/CDC
Carlos	Santos-Burgoa	Pan American Health Organization/World Health Organization
Robin	Guenther	Perkins+Will
Elaine	Arkin	Robert Wood Johnson Foundation
Vikas	Ahuia	SCS Global Services

Summit Attendees (continued)

First Name	Last Name	Company Name
Beth	Heider	Skanska
Geoff	Anderson	Smart Growth America
Russell	Perry	SmithGroup
Jennifer	Foskey	Social Green
Randal	Carter	Steelcase
Anthony	Bernheim	Sustainable Built Environments
William	Browning	Terrapin Bright Green
Suzanna	Wight Kelley	American Institute of Architects
Brooks	Rainwater	American Institute of Architects
Amanda	Kaminsky	The Durst Organization
Margaret	Whittaker	ToxServices LLC
Jonathan	Herz	U.S. Department of Health & Human Services
Kevin	Teichman	U.S. Environmental Protection Agency
Bob	Thompson	U.S. Environmental Protection Agency
Tracy	Enger	U.S. Environmental Protection Agency
Michele	Curreri	U.S. EPA Indoor Environments Division
Emily	Alvarez	U.S. Green Building Council
Sarah	Buffaloe	U.S. Green Building Council
Sara	Cederberg	U.S. Green Building Council
Rick	Fedrizzi	U.S. Green Building Council
Asa	Foss	U.S. Green Building Council
Melissa	Gallagher-Rogers	U.S. Green Building Council
Selina	Holmes	U.S. Green Building Council
Scot	Horst	U.S. Green Building Council
Mahesh	Ramanujam	U.S. Green Building Council
Casey	Studhalter	U.S. Green Building Council
Judith	Webb	U.S. Green Building Council
Rachel	Gutter	U.S. Green Building Council
Brendan	Owens	U.S. Green Building Council
Chris	Pyke	U.S. Green Building Council
Mark	Rossolo	UL
Tony	Worthan	UL
Eve	Edelstein	University of Arizona, College of Architecture, Planning & Landscape Architecture

Summit Attendees (continued)

First Name	Last Name	Company Name
Esther	Sternberg	University of Arizona College of Medicine
Rachel	Ballard-Barbas	NIH - National Cancer Institute
Matthew	Trowbridge	University of Virginia School of Medicine
Daniel	Friedman	University of Washington
Andrea	Falken	U.S. Department of Education
Judith	Heerwagen	U.S. General Services Administration
Dan	Geiger	USGBC - Northern California Chapter
Howard	Frumkin	University of Washington School of Public Health
Steven	Davis	WMDO Architects
Pauline	Souza	WRNS Studio
John	Wargo	Yale University

APPENDIX II: USGBC INITIATIVES

The following provides additional detail about some initiatives underway and planned across USGBC.

BUILDING THE MOVEMENT

Currently Underway:

- Offering a webcast to brief our community on this report and future initiatives.
- Establishing a web-based community via Yammer that can provide a place for information exchange and collaboration.
- Developing and circulating for community ratification via Yammer a set of basic guiding principles that can be used as a point of reference by any member of our extended communities.
- Setting up a GB&HH digest that can be subscribed to via usgbc.org that provides periodic email summaries of initiatives and activities.
- Using Greenbuild as a platform by:
    - Identifying key health-related education programs so attendees can build a track.
    - Convening a two-hour Master Speaker and Panel Session.
    - Organizing the Women in Green Power Breakfast around a green building and human health theme.
    - Supporting the Materials and Human Health pre-event Summit which includes Convening product manufacturers and designers to learn about LEED and the Materials credits.
    - Expo Hall program: Building Products and LEED v4 – Session highlighting product manufacturers with products that can qualify for LEED v4 points in the Material Ingredients credit.
    - USGBC Update session: Optimization Through Life Cycle Analysis and Environmental Product Declarations – Session about how life cycle analysis has informed optimization of manufacturing practices and how to apply this practice to analyzing an entire building.

Under Planning and Review

- Centralize information about green building and human health at usgbc.org that allows for community

- Develop a robust plan for media outreach to help raise awareness of USGBC activities as well as draw attention to key efforts being undertaken by other partners.
- Establish a Center for Health and the Built Environment @ USGBC with appropriate staffing and resource support.
- Provide annual progress reporting to the community.
- Continue to partner with key organizations in various sectors to leverage strengths and build the movement. Some key examples include:
    - **Schools:**
        - Convened Research Summit on Childhood Health and School Buildings.
        - Published "The Impact of School Buildings on Student Health and Performance" with McGraw Hill Research Foundation.
        - Partnered with National Collaborative on Childhood Obesity Research (NCCOR) to host Green Health: Building Sustainable Schools for Healthy Kids Summit; Co-published summary report, "Green Health: Building Sustainable Schools for Healthy Kids."
        - Recruited leading children's health organizations to participate on the Executive Committee of the Coalition for Green Schools including the American Lung Association, the Healthy Schools Campaign and the National Association for School Nurses.
        - Provided start-up funding to Ohio Facilities Commission and USGBC Ohio chapters for the creation of a Green Schools Compendium. The Compendium will quantitatively define the economic and occupant-related impacts of LEED certification for school facilities. The Central Ohio Chapter has hired a Green Schools Research Fellow to compile data including test scores and attendance records on the more than 300 LEED registered and more than 60 LEED Certified schools, as well as non-LEED schools across the state.
        - Hosting regular opportunities for key stakeholders to convene on the theme of LEED v4 Occupant Health & Schools (to date this includes one in-person meeting and 3 webcasts.
        - In partnership with the Healthy Schools Campaign, currently developing resources and trainings on improving healthy food options and food service efficiency in schools.
        - Collaborated with leading school health organizations including the National Association of School Nurses, Asthma and Allergy Foundation of America, the Merck Childhood Asthma Network and the American Lung Association to develop a joint-statement outlining best practices and proven, effective strategies for a comprehensive approach to asthma management in schools.
        - Explore more substantive, long-term opportunities for collaboration with NCCOR.

- **Professional and Trade Organizations**
    - Working with American Institute of Architects (AIA) to complete an environmental scan especially related to the Design + Health leadership group and other activities especially related to the Design + Health leadership group and other activities.
    - Working with International Interior Design Association (IIDA) to find ways to more closely align Commercial Interiors community with health.
    - Working with International Living Future Institute (ILFI) to collaborate on ways to further the green building and human health conversation.
    - Working with National Institute for Occupational Safety and Health (NIOSH) to begin to raise awareness of worker safety as part of the green building and human health conversation.
- **Affordable Housing**
    - Working with the Council of Large Public Housing Authorities (CLPHA) to find ways to advance policies that align green affordable housing and its human health impacts.
    - Working with the National Healthy Housing Network to potentially convene affordable housing developers on green building and human health.

BUILDING THE KNOWLEDGE BASE

Currently Underway:

- Green Building & Public Health Metrics (supported by a 2-year, $300K grant from Robert Wood Johnson Foundation)
    - Health metrics across existing LEED rating systems.
    - Identify opportunities to align green building credits with public health metrics and surveillance systems.
    - Display existing and new health metrics in GBIG.
- Health-Related Reislience Research (on-going through academic collaborations)
    - Temperature impacts on vulnerable populations (intern: Adele Houghton, John Hopkins School of Public Health).
    - Case study for resilient health care facilities (intern: Aubrey Chamberlain, Tulane University).
    - LEED credit screening tool, a Microsoft Excel workbook (intern: JP Jaudel, George Washington University, Sustainable Urban Planning Program).

Under Planning and Review:

- **Schools**
    - Produce several additional written resources to address various points of intersection between green buildings and human health with partners including the McGraw Hill Research Foundation, the Center for the Built Environment at Colorado State University and the National Collaborative on Childhood Obesity Research (NCCOR)Identify opportunities to align green building credits with public health metrics and surveillance systems.
    - Advance new research efforts to qualify and quantify the health-related benefits of green schools.

SIGNIFICANT INITIATIVE

- **Materials in LEED (supported by a grant from Google)**
    - Objectives
        - Improve the indoor environment from a human health perspective.
        - Reduce barriers to materials transparency.
        - Improve the understanding of health impacts of building materials.
        - Bring materials transparency and product optimization into the mainstream.
    - Key Outcomes
        - Harmonization of product transparency and optimization programs: emphasis will be placed upon increased collaboration between USGBC, Healthy Building Network, Cradle to Cradle Products Innovation Institute and Clean Production Action.
        - Greater industry and public understanding of the importance of materials transparency and product optimization.
        - Increased availability of products with publicly disclosed ingredient profiles and demonstrated track records of product improvement. This outcome will be verified by tracking product specification statistics and LEED credit achievement.
        - Market-based tools that dramatically streamline the process of specifying healthy building products.

Currently Underway

- Engage experienced thought leaders in the material science and public health realm as Senior Research Fellows. Two fellows (three individuals) secured, with contract negotiations in progress with selection of third and final fellow (for 2103) in progress.

- Hire a post doctorate in material science to expand USGBC in-house capacity.
- Create a harmonized approach to hazard assessment across the globally harmonized system (GHS), Cradle to Cradle, HPDs and GreenScreen.
- Identify the top research opportunities for funding through the building materials research heat map (supported by BuildingGreen and Cradle to Cradle). Final design of "beta" survey to identify research gaps will be followed by survey test run.
- Translate current material science and green chemistry to lay people through the Insight series and our Senior Research Fellows. Preparing communications calendar for USGBC.gov and GBIG Insight, to include technical social media, white papers and peer-reviewed analysis and synthesis.
- Streamline the material design and selection process with market-based tools.
- Reduce barriers to reporting and disclosure around building materials by supporting the Health Product Declaration Collaborative (HPDC).

In Planning and Review

- In the future, work directly with manufacturers to speed adoption of the programs referenced in the LEED v4 Material Ingredients credit to hasten the availability of products. That is, leveraging the grant work to increase the availability of products compliant with Health Product Declaration, GreenScreen and Cradle to Cradle requirements to scale up the market.
- Preparing scope of work for an information strategies "back-casting" workshop (in collaboration with SERA Architects).
- Materials Data Hackathon: Evaluating "Data Jam+Data Palooza" strategy, potentially with White House/Office of Science and Technology Policy (OSTP) engagement.

PROGRAMMATIC INITIATIVES

LEED

- Part of our long term plan has been to use research work to directly impact how we prioritize issues for emphasis in LEED, and how we structure measurement and verification protocols for the ideas we develop.
- Changes made to **LEED v4** relative to health indicate that the system goals were effective in getting the Technical Advisory Groups to focus their proposed changes to LEED:
    - **BD+C**
        - **Bicycle facilities (LTc6) –** Includes a new requirement to connect to a bicycle network.

- Open space (SSc3) – New credit – “To create exterior open space that encourages interaction with the environment, social interaction, passive recreation and physical activities.”
- **Minimum energy performance (EAp2)** – Higher thresholds = more efficient buildings = less coal burning and less climate change.
- **Demand response (EAc4)** – New concept in LEED – More efficient energy generation and distribution systems = less coal burning and less climate change.
- **Building product disclosure and optimization – material ingredients (MRc4)** – new concept in LEED. Intent:
    - To encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically and socially preferable life-cycle impacts. To reward project teams for selecting products for which the chemical ingredients in the product are inventoried using an accepted methodology and for selecting products verified to minimize the use and generation of harmful substances. To reward raw material manufacturers who produce products verified to have improved life-cycle impacts.
- **Minimum indoor air quality performance (EQp1)** – Major update to natural ventilation requirements: climate and regional air quality taken into account.
- **Environmental tobacco smoke control (EQp2)** – No smoking in any LEED building except for private residences, where smoking areas must be compartmentalized.
- **Low-emitting materials (EQc2)** – Shift from content to emissions testing requirements means more accurate prediction and understanding all of the off-gassing from a product, not just regulated VOC content.
- **Indoor air quality assessment (EQc4)** – Higher weighting for air quality testing, and expanded scope of testing that is closely tied to the low emitting material requirements.
- **Interior lighting (EQc6)** – New concept in LEED – “To promote occupants’ productivity, comfort and well-being by providing high-quality lighting.”
- **Quality views (EQc8)** – A view of a brick wall no longer counts as an exterior view; you have to be able to see flora, fauna or sky, movement, and/or objects at least 25’ from the building exterior.
- **Acoustic performance (EQc9)** – New concept in more D+C rating systems; the only Indoor Environmental Quality (IEQ) category where green buildings underperform when compared to standard office design. “To provide workspaces and classrooms that promote occupants’ well-being, productivity, and communications through effective acoustic design.”

- **O+M**
  - **Demand Response (EAc6)** – New concept in LEED – More efficient energy generation and distribution systems = less coal burning and less climate change.
  - **Minimum indoor air quality performance (EQp1)** – Added section 4 from ASHRAE 62.1 requirements (outdoor air quality).
  - **Environmental tobacco smoke control (EQp2)** – No smoking in any LEED building except for private residences, where smoking areas must be compartmentalized.
  - **Green cleaning policy (EQp3)** – Prerequisite to implement your green cleaning policy.
  - **Interior lighting (EQc4)** – New concept in LEED – "To promote occupants' productivity, comfort, and well-being by providing high-quality lighting."
- **PILOT CREDITS**
  - Existing:
    - **Walkable project site (SSpc14)** – "To promote walking, biking, and other non-motorized transportation that results in reduced vehicle miles traveled (VMT), increased public health, and enhanced community participation."
    - **Clean Construction (SSpc75)** – "To minimize the health and climate impacts to local communities from diesel engine emissions associated with construction activities."
    - **Ergonomics strategy (EQpc44)** – "To promote healthy, comfortable, and productive work by designing the workplace to accommodate its users."
    - **Enhanced acoustical performance – exterior noise control (EQpc57)** – "Improve or have no negative impacts on the outdoor acoustical environment as a result of new or major renovation building construction."
    - **Indoor air quality procedure – alternative compliance path (EQpc68):** A performance path to the minimum indoor air quality prerequisite for rating systems prior to LEED v4.
    - **Design for Active Occupants (EQpc78)** – "Improve the health of building users through physical activity while reducing environmental impacts."
  - In Development:
    - **NIOSH -- Worker Safety** (due in June).
      - Discussions with the Occupational Safety and Health Administration (OSHA) progressing – outcomes unclear at the moment.
    - **Indoor Plants**

- **SUPPLY CHAIN OPTIMIZATION WORKING GROUP**
    - Standing up a working group (to report to the Materials and Resources Technical Advisory Group) tasked with figuring out if/how we can operationalize the supply chain optimization path in the **Building product disclosure and optimization – material ingredients (MRc4)** credit. Applicants received in April; vetting/selection in progress.

DRAFT

ORDINANCE NO. XX-2016

AN ORDINANCE OF THE CITY OF FREMONT ADOPTING AND AMENDING BY REFERENCE THE 2016 CALIFORNIA BUILDING, MECHANICAL, PLUMBING, ELECTRICAL, EXISTING BUILDING, HISTORICAL BUILDING, ENERGY, RESIDENTIAL BUILDING, GREEN STANDARDS BUILDING, 2015 INTERNATIONAL POOL AND SPA CODE, AND THE 2015 INTERNATIONAL PROPERTY MAINTENANCE CODE; AND AMENDING FREMONT MUNICIPAL CODE TITLE 15 BUILDINGS AND CONSTRUCTION DIVISION 1 FREMONT BUILDING STANDARDS CODE

NOW, THEREFORE, THE CITY COUNCIL OF THE CITY OF FREMONT DOES ORDAIN AS FOLLOWS:

SECTION 1. DRAFTING SYNTAX

The Fremont Municipal Code (FMC) text adopting the local modification is italicized in this ordinance to assist the reader in distinguishing between City of Fremont modifications to the California Building Standards Code and the FMC section text adopting the modifications.

Each section of the California Building Standards Code that is modified by the City of Fremont is listed. However, whole subsections may not be modified and those unmodified subsections are indicated by the subsection number followed by "{CBC text not modified}" with the appropriate acronym for the specific Building Standards Code. The unmodified subsections are to be codified as written in the California Code. Each subsection that is deleted in its entirety by the City of Fremont is indicated by the subsection number followed by "deleted".

SECTION 2. FMC CHAPTER 15.05 REPEALED AND REPLACED

Chapter 15.05 (General Provisions) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.05.010 Title.

This division shall be known and may be cited as the "Fremont building standards code" or "FBSC." The Fremont building standards code consists of the California Building Standards Code, as codified in Title 24 of the California Code of Regulations, and as amended by this division.

Sec. 15.05.020 Administration & Enforcement.

(a) The building and safety division is responsible for the administration and enforcement of the provisions of Title 15, Division 1, Chapters 15.05 through 15.30 and Chapters

15.40 through 15.49 of this code. “Building official” as referenced in this code means the Building official.

(b) The fire prevention bureau, under the direction of the fire chief, is responsible for the administration and enforcement of the provisions of Chapter 15.35. “Fire marshal” as referenced in this division means the individual specified by the fire chief under Section 15.35.020(b).

Sec. 15.05.030 Permit Applications Pending as of December 31, 2016.

The provisions of this division shall take effect on January 1, 2017 except that where complete working drawings, plans, structural designs and specifications for buildings have been filed for building permits before this date, permits may be issued based on the previous ordinances and codes effective at the time of filing, and the applicant may proceed with the construction, provided physical construction is started within 180 days from the date of issuing the permit and continued to completion. Where construction has not commenced within 180 days of the issuance of a building permit which has been issued under any previous ordinance, no renewal or extension of such building permit shall be granted unless all of the requirements of the 2016 California Building Standards Code, as amended by the city of Fremont, are met.

Sec. 15.05.040 Findings.

The city council has adopted updated findings by resolution under Health and Safety Code Section 17958.7 for local modifications to the building standards contained in the 2016 California Building Standards Code based on local climatic, geological and topographical conditions as required by Health and Safety Code Sections 18941.5 and 17958.5.

Sec. 15.05.050 Violations.

A violation of any provision or failure to comply with any mandatory requirement of this division shall constitute an offense as set forth in Section 1.15.010. Each person, firm or corporation shall be charged with a separate offense for each and every day during any portion of which any violation of this division is committed, continued, or permitted by the person, firm or corporation and shall, upon conviction, be punished as set forth in Section 1.15.020.
It is hereby declared that any violation of this division constitutes a public nuisance, and in addition to any other remedies provided by this division for the enforcement of this division, the Fremont city attorney may bring a civil or criminal action to enjoin the violation of any provision of this division or pursue any other legal remedy.

The remedies described in this division are cumulative and in addition to any other remedies available for a violation of this division

Sec. 15.05.060 Appeals.

(a) Where the provisions of this title allow for a board of appeals, the board shall be an administrative hearing officer appointed by the city manager. The appeal shall follow the process and procedures of FMC Sections 8.60.120 through 8.60.150. The decisions of the hearing officer are final as to the city. The hearing officer shall have no authority relative to interpretation of the administrative provisions of this title nor shall the hearing officer be empowered to waive requirements of this title.

(b) An application for appeal shall be based on a claim that the true intent of this code has been incorrectly interpreted, the provisions of this code do not fully apply or an alternative provides at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

SECTION 3. FMC CHAPTER 15.10 REPEALED AND REPLACED

Chapter 15.10 (Fremont Building Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.10.010 Title.

This chapter shall be known and may be cited as the “Fremont building code” or “FBC” and will be referred to in this chapter as “this code.”

Sec. 15.10.020 Adoption of the 2016 CBC with Amendments.

The 2016 edition of the California Building Code (“CBC”)as published by the International Code Council is adopted as the Building Code of the city of Fremont, California, as if fully set out in this chapter and is amended as provided in this chapter. A copy of the 2016 CBC shall be maintained on file in the office of the city clerk.

Sec. 15.10.030 Adoption of Certain 2016 CBC Appendix Chapters.

The following Appendix Chapters of the 2016 California Building Code are adopted by the city of Fremont. The remaining Appendix Chapters are not adopted.

(a) Appendix Chapter C (Agricultural Buildings).

(b) Appendix Chapter F (Rodent Proofing of Dwellings).

(c) Appendix Chapter I (Patio Covers).

Sec. 15.10.040 Adoption of 2016 CBC Chapter 1, Division II.

Chapter 1, Division II of the 2016 California Building Code is adopted by the city of Fremont and made a part of the Fremont Building Code, unless amended in this section. References to model codes in the adopted sections shall mean the corresponding California Codes as adopted by the city of Fremont.

Sec. 15.10.050 Amendment of 2016 CBC Section 101 (General).

Section 101 of the 2016 California Building Code is amended as follows:

101.4 Referenced codes. The other codes listed in Sections 101.4.1 through 101.4.11 and referenced elsewhere in this code shall be considered part of the requirements of this code to the prescribed extent of each such reference.

101.4.1 Gas. The provisions of the 2016 California Mechanical Code and California Plumbing Code shall apply to the installation of gas piping.

101.4.2 Mechanical. The provisions of the 2016 California Mechanical Code shall apply to installation, alterations, repairs and replacement of mechanical systems.

101.4.3 Plumbing. The provisions of the 2016 California Plumbing Code shall apply to installation, alternation, repairs and replacement of plumbing systems.

101.4.4 Property Maintenance. The provisions of the 2016 California Building, Residential, Mechanical, Electrical, Plumbing, Fire Code, and the 2015 International Property Maintenance Code shall apply to existing structures and premises; equipment and facilities; light, ventilation, space heating, sanitation, life and fire safety hazards; responsibilities of owners, operators and occupants and occupancy of existing premises and structures.

101.4.5 Fire Prevention. The provisions of the 2016 California Fire Code, shall apply to matters affecting or relating to fire hazards.

101.4.6 Energy. The provisions of the 2016 California Energy Code, Title 24, Part 6, shall apply to all matters governing the design and construction of building for energy.

101.4.7 Existing buildings. The provisions of the 2016 California Existing Building Code shall apply to all matters governing the repair, alteration, change of occupancy, addition to and relocation of existing buildings.

101.4.8 Green Building Standards. The provisions of the 2016 California Green Building Standards Code shall apply to all matters governing the "green building" related planning, design construction, operation, use and occupancy of newly constructed buildings.

101.4.9 Residential Buildings. The provisions of the 2016 California Residential Code shall apply to all matters governing the design and construction of detached, one- and two-family dwellings, townhouses not more than three stories and separate means of egress, and structural accessory thereto.

101.4.10 Electrical. The provisions of the 2016 California Electrical Code shall apply to the installation of electrical systems, including alterations, repairs, replacement, equipment, appliances, fixtures, fittings and appurtenances thereto.

101.4.11 Historical Buildings. The provisions of the 2016 California Historical Code shall apply to the alteration, addition, and relocation to qualified historical buildings or properties.

Sec. 15.10.060 Amendment of 2016 CBC Section 104 (Duties and Powers of the Building Official).

Section 104 of the 2016 California Building Code is adopted as follows:

104.1-104.11.2 {CBC text not modified}

104.12 Authority to condemn building service equipment. Whenever the Building Official ascertains that any building service equipment regulated in the technical codes has become hazardous to life, health, property, or becomes unsanitary, he or she shall order in writing that such equipment either be removed or restored to a safe or sanitary condition, whichever is appropriate. The written notice itself shall fix a time limit for compliance with such order. No person shall use or maintain defective building service equipment after receiving such notice.

When such equipment or installation is to be disconnected, a written notice of the disconnection and causes therefore shall be given within 24 hours to the serving utility, the owner and occupant of such building, structure or premises.

When any building or the associated service equipment is maintained in violation of the technical codes and in violation of any notice issued pursuant to the provisions of this section, the Building Official may institute any appropriate action to prevent, restrain, correct or abate the violation. The Building Official shall be authorized to affix an approved placard to said building or equipment stating the date, corrections required, address and allowable time for repairs if any. Damage or removal of said placard shall be a violation of this code.

104.13 Connection after order to disconnect. No person shall make connections from any energy, fuel or power supply nor supply energy or fuel to any building service equipment which has been disconnected or ordered to be disconnected by the Building Official or the use of which has been ordered to be discontinued by the Building Official until the Building Official authorizes the reconnection and use of the equipment.

104.14 Authority having jurisdiction. Whenever the term "Authority Having Jurisdiction" is used, it shall be construed to mean the Building Official or his or her authorized representative.

104.15 Limits on repair/remodel for R-3 and U occupancies. When the scope of work for R-3 and U occupancies involves the removal or replacement of 50 percent or greater of the linear length of the walls of the building (exterior plus interior) and 50 percent of the roof within a one-year period, the project shall be considered as new construction; and the entire building shall comply with all current codes including local ordinances. For automatic fire extinguishing system requirements, see FMC Section 15.35.140.

Sec. 15.10.070 Amendment of 2016 CBC Section 105 (Permits).

Section 105 of the 2016 California Building Code is amended as follows:

105.1 {CBC text not modified}

105.1.1 - 105.1.2 - deleted

105.2 Work exempt from permit {CBC text not modified}

Building:

1. {CBC text not modified}

2. Wood fences not over 7 feet (2134 mm) high or concrete or masonry wall not over 4 feet (1219 mm) high when not subject to specific city of Fremont planning and zoning regulations.

3. {CBC text not modified}

4. deleted

5. {CBC text not modified}

6. Sidewalks and driveways not more than 30 inches (762 mm) above adjacent grade and not over any basement or story below and are not part of an accessible route, accessible parking spaces, or required exits.

7. - 8 {CBC text not modified}

9. Prefabricated swimming pools accessory to a Group R-3 occupancy that are less than 18 inches deep, do not exceed 5,000 gallons and are installed entirely above ground.

10. {CBC text not modified}

11. Swings and other playground equipment accessory to single detached one- and two-family dwellings and not considered a public playground.

12. Window awnings supported by an exterior wall that do not project more than 54 inches (1,372 mm) from the exterior wall and do not require additional support of Group R-3 and U occupancies.

13. {CBC text not modified}

14. Wood decks not over 30 inches above surrounding grade or finishes, not attached to a structure, or serving any part of the means of egress.

Electrical {CBC text not modified}

1. Portable motors or other portable appliances energized by means of a cord or cable having an attachment plug end to be connected to an approved receptacle when that cord or cable is permitted by the Electrical Code.

2. Repair or replacement of motors, transformers and controls within fixed approved appliances of the same type and rating in the same location.

3. Temporary decorative lighting for residential dwellings.

4. Repair or replacement of current-carrying parts of any switch, contactor or control device.

5. Reinstallation of attachment plug receptacles, but not the outlets thereof.

6. Replacement of any overcurrent device less than 1,200 amps of the same capacity in the same location.

7. Repair or replacement of electrodes or transformers of the same size and capacity for signs or gas tube systems.

8. Removal of electrical wiring.

9. Temporary wiring for experimental purposes in suitable experimental laboratories.

10. The wiring for temporary theatre, motion picture or television stage sets.

11. Electrical wiring, devices, appliances, apparatus or equipment operating at less than 25 volts and not capable of supplying more than 50 watts of energy.

12. Low-energy power, control and signal circuits of Classes II and III as defined in the Electrical Code.

13. A permit shall not be required for the installation, alteration or repair of electrical wiring, apparatus or equipment or the generation, transmission, distribution or metering of electrical energy or in the operation of signals or the transmission of intelligence by a public or private utility in the exercise of its function as a serving utility.

Gas {CBC text not modified}

Mechanical {CBC text not modified}

Plumbing {CBC text not modified}

Exemption from the permit requirements of this code shall not be deemed to grant authorization for any work to be done in any manner in violation of the provisions of this code or any other laws which are enforced by the city of Fremont

105.2.1 – 105.3.1 {CBC text not modified}

105.3.2 Time limitation of application. An application for a permit for any proposed work shall be deemed to have been abandoned 180 days after the date of filing unless such application has been pursued in good faith or a permit has been issued; except that the Building Official is authorized to grant one extension of time for an additional period not exceeding 180 days. The extension shall be requested in writing and justifiable cause demonstrated and accepted by the Building Official.

105.3.3 Who may be issued a permit. Permits shall be issued only to State licensed contractors or their respective authorized representative but only to the extent and to the work the person is licensed by the State of California to do so.

Exception: Permits may be issued to owners certifying proof of exemption under the exemptions specified in California Business and Professions Code Section 7044.

105.3.4 Withhold permit. The Building Official may withhold the issuance of a permit if the proposed work is in conjunction with construction requiring the issuance of a building permit where no building permit has been issued.

105.4 {CBC text not modified}

105.5 Expiration. Every permit issued by the Building Official under the provisions of this code shall expire by limitation and become null and void if the building or work authorized by such permit is not commenced within 180 days from the date of such permit, or if the building or work authorized by such permit is suspended or abandoned at any time after the work is commenced for a period of 180 days. The construction is deemed suspended or abandoned unless an inspection indicating substantial progress in construction has been requested every 180 days or sooner. Before work may resume on a construction project declared suspended or abandoned, a new permit must first be obtained. Where suspension or abandonment has not exceeded one year and no changes have been made or will be made to the original plans and specifications for the work, the renewal fee shall be one half the amount required for a new permit for the work otherwise, the renewal fee shall be the full amount required for a new permit.

Any permittee holding an unexpired permit may apply for an extension of the time within which work may commence under that permit when the permittee is unable to perform work within the time required by this section for good and satisfactory reasons. The Building Official may extend the time for action by the permittee for a period not exceeding 180 days on written request by the permittee showing that circumstances beyond the control of the permittee have prevented action from being taken.

105.6 {CBC text not modified}

105.7 Placement of Permit. The building permit, along with all plans and documentation approved by the building official, shall be kept on the site of the work until final approval has been granted by the building official.

105.8 Change of contractor or of ownership. A permit issued hereunder shall expire upon a change of ownership or a change of contractor regarding the building, structure or grading for which said permit was issued if the work thereon has not been completed, and a new permit shall be required for the completion of the work. If no changes have been made to the plans and specifications last submitted to the Building Official, no charge, other than the permit issuance fee and applicable State fees, shall be made for the issuance of the new permit under such circumstances. If, however, changes have been made to the plans and specifications last submitted to the Building Official, a permit fee based upon the proposed changes may be levied.

105.9 Surrender of permit. If no portion of the work or construction covered by the issued permit has commenced, the permit holder may deliver such permit and approved documents to the Chief Building Official with written request that such permit is to be canceled. The Chief Building Official shall make note on the permit with or with like wording "Canceled at the request of the Permit holder." Thereupon the permit and documents shall become null and void.

Sec.15.10.080 Amendment of 2016 CBC Section 107 (Submittal Documents).

Section 107 of the 2016 California Building Code is amended as follows:

107.1 – 107.2.6 {CBC text not modified}

107.2.7 Required plat of survey. Any person, firm or corporation applying for a permit for the erection or construction of a building or structure, or moving an existing building to a new location shall, when required by the Building Official, file with the set of plans and specifications required by the foregoing provisions of this section a minimum of three (3) copies of a plat of a survey of the property proposed to be improved by said building or structure, on which plat shall be delineated the accurate location of said proposed improvement and the grades at which it is to be constructed, the location of every existing building on the lot, the location of existing curbs, sidewalks, and main sewers and the location of waterways, storm drains, inlets, and culverts affecting the lot. Said plat shall be drawn to a scale of not smaller than twenty (20) feet to one (1) inch, unless authorized by the Building Official, and shall show the contours at one (1) foot intervals for predominant ground slopes between level and four (4) percent and five (5) foot contours for predominant ground slopes over four (4) percent which contours shall extend to the center of the street when said street is unimproved, or to the curb line when the street is improved. All grades and contours shall be based on United States Coast and Geodetic Survey datum (mean sea level) except when authorized otherwise by the Building Official. The survey shall have been made by a licensed land surveyor or registered civil engineer in the State of California and the map of said survey shall be signed and certified with their license or certificate number, and the property shall be located thereon by map or deed distance to the nearest street intersection. The exterior boundaries of said property shall be clearly outlined on the ground by appropriate permanent stakes or monuments. The location of said stakes or monuments shall be shown on the survey map with elevations thereon.

107.3 {CBC text not modified}

107.3.1. Approval of construction documents. When the Building Official issues a permit, the construction documents shall be approved, in writing or by stamp, as *"Approved"*. One set of construction documents so reviewed shall be retained by the

Building Official. The other set shall be returned to the applicant, shall be kept at the site of work and shall be open to inspection by the Building Official or a duly authorized representative.

107.3.2 – 107.5 {CBC text not modified}

Sec. 15.10.090 Amendment of 2016 CBC Section 109 (Fees).

Section 109 of the 2016 California Building Code is adopted as follows:

109.1 {CBC text not modified}

109.2 Schedule of permit fees. On buildings, structures, electrical, gas, mechanical, and plumbing systems or alterations requiring a permit, a fee for each permit shall be paid as required, in accordance with the schedule of fees established by resolution of the Fremont city council. Where issuance of a permit for the construction of part of a building or structure has been approved, the fees shall be established by a city of Fremont Fee Resolution as adopted by the city council.

109.3 Building permit valuation. The value to be used in computing the building permit and building plan review fees shall be the total value of all construction work for which the permit is issued, including materials and labor, as well as all, roofing, electrical, plumbing, heating, air conditioning, elevators, fire-extinguishing systems and any other permanent equipment . If in the opinion of the Building Official, the valuation is underestimated on the application, the permit shall be denied, unless the applicant can show detailed estimates to meet the approval of the Building Official. Final building permit valuation shall be set by the Building Official.

109.3.1 Plan review fees. When submittal documents are required by Section 107 a plan review fee shall be paid at the time of submitting the documents for plan review. Said plan review fee shall be as established by resolution of the city council.

The plan review fees specified in this section are separate fees from the permit fees specified in Section 109.2 and are in addition to the permit fees.

When submittal documents are incomplete or changed so as to require additional plan review or when the project involves deferred submittal items as defined in Section 107.3.4.1, an additional plan review fee shall be charged at the rate established by resolution of the city council.

109.4 Work commencing before permit issuance. Whenever any work for which a permit is required by this code has been commenced without first obtaining said permit, the fee for necessary permits shall be double the fee established by resolution of the city council.

109.4.1 An investigation fee, in addition to the permit fee, shall be collected whether or not a permit is then or subsequently issued. The investigation fee shall be equal to the amount of the permit fee required by this code. The payment of such investigation fee shall not exempt any person from compliance with all other provisions of this code nor from any penalty prescribed by law.

109.5. Related fees. The payment of the fee for the construction, alteration, removal of demolition for work done in connection to or concurrently with the work authorized by a building permit shall not relieve the applicant or holder of the permit from the payment of other fees that are established by resolution of the city council.

109.6 Refunds. The Building Official is authorized to establish a refund policy. As part of the policy, the Building Official may authorize refunding a portion of the fee equal to 80 percent of the permit fee paid less the application fee when no work has been done under a permit issued in accordance with this code.

109.7 Additional plan review fees. Where plans are incomplete or changed so as to require additional plan checking, an additional plan checking fee shall be paid to the Building Official based upon the value of construction of the proposed change or redesign. In establishing said fee, no allowance for a decreased valuation shall be permitted due to the replacement, omission or lessening of any member or portion of the building shown in the original plans. Said fee may be waived when in the opinion of the Building Official the additional fee is not warranted. No additional fees shall be charged for checking corrections required by the Building Official; except where excessive plan reviews are performed, additional fees may be levied as established by city council.

Sec. 15.10.100 Amendment to 2016 CBC Section 110 (Inspections).

Section 110 of the 2016 California Building Code is adopted as follows:

110.1 – 110.6 {CBC text not modified}

110.6.1 Gas or electrical utilities. There shall be no clearance for connection of gas or electrical utilities until final building, electrical, plumbing, heating, air conditioning, security and zoning inspections are made and approval has been given on any building sought to be connected to such utilities unless approval has first been obtained from the Building Official, as provided by the Temporary Certificate of Occupancy in Section 111.3.

110.7 Re-inspection fee. When re-inspection is required, an additional inspection fee shall be charged at the fee rate established by resolution of the city council.

110.8 Inspection Card. Work requiring a permit shall not be commenced until the permit holder or an agent of the permit holder has posted or otherwise made available the inspection record card issued by the building official such as to allow the building official to conveniently make the required entries thereon regarding inspection of the work. This card shall be maintained and available by the permit holder until final approval has been granted by the building official.

Sec. 15.10.110 Amendment of 2016 CBC Section 111 (Certificate of Occupancy).

Section 111 of the 2016 California Building Code is amended as follows:

111.1 Use and occupancy. No building or structure shall be used or occupied, and no change in the existing use or occupancy classification of a building or structure or portion thereof shall be made until the Building Official has issued a certificate of occupancy therefore as provided herein.

Exception: Single-family homes, townhomes, and U occupancies.

Issuance of a certificate of occupancy shall not be construed as an approval of a violation of the provisions of the codes or of other ordinances of the jurisdiction. Certificates presuming to give authority to violate or cancel the provisions of the codes or other ordinances of the jurisdiction shall not be valid.

111.1.1 Change in Use. Where a change of occupancy and use is proposed and approved by the Building Official, an inspection of the premises by the Building Official to determine that the provisions of Section 111.1 are met before issuance of said certificate. Said certificate of occupancy shall be obtained from the Building Official upon completion of an application for the certificate and the payment of a fee as established by resolution of the city council.

111.2 Certificate issued. After final inspection when it is found that the building or structure complies with the provisions of this code and other laws which are enforced by the city of Fremont, and, when required by the Building Official, the engineer or architect of record shall state, in writing, that based on field observation conducted by him or her, or his or her designee, the building or structure is in general conformance with the approved plan, then the Building Official shall issue a certificate of occupancy which shall contain the following:

1. The building permit number.

2. The address of the building.

3. The name and address of the owner.

4. A description of that portion of the building for which the certificate is issued.

5. A statement that the described portion of the building complies with the requirements of this code for the group and division of occupancy and the use for which the proposed occupancy is classified.

6. The name of the Building Official.

7. The use and occupancy.

8. The type of construction.

9. The design occupant load.

10. Automatic sprinkler system if provided, whether the sprinkler system is required.

11. The edition of the code under which the permit was issued.

12. . Any special stipulations and conditions of the building permit.

111.3 {CBC text not modified}

111.3.1 Limitations. An application for temporary certificate of occupancy must be obtained for connection of gas and electrical utilities. The required fees as established in the city of Fremont Fee Resolution shall be paid before the temporary certificate of occupancy is issued.

111.3.2 Discontinuance of temporary occupancy. In the event the building is not completed and ready for final inspection in the time prescribed by the Building Official, the building shall be vacated and the utilities disconnected until such time as the building is completed and final inspection is made and a certificate of occupancy is issued as set forth above.

111.4 {CBC text not modified}

Sec. 15.10.120 Amendment of 2016 CBC Section 112 (Service Utilities).

Section 112 of the 2016 California Building Code is amended as follows:

112.1 Connection of utility service. No person shall make a connection from a source of electrical energy or fuel gas to any electric wiring system, gas piping system, device, appliance or equipment for the installation of which a permit is required, unless such wiring system, gas piping system, devices, appliance or equipment has first been inspected by the building official and found to comply with all applicable codes and ordinances of the city.

112.2 Temporary Connection. The Building Official shall have the authority to authorize the temporary connection to any electric wiring system, gas piping system, device, appliance or equipment to the utility source of energy, fuel or power.

112.3 Authority to disconnect utilities. The Building Official or his or her authorized representative shall have the authority to disconnect any utility service or energy supplied to the building, structure or building service equipment therein regulated by this code or the technical codes in case of emergency where necessary to eliminate an immediate hazard to life or property. The Building Official shall whenever reasonably possible notify the serving utility, the owner and occupant of the building, structure or building service equipment of the decision to disconnect prior to taking such action, and shall notify such serving utility, owner and occupant of the building, structure or building service equipment, in writing, of such disconnection immediately thereafter.

112.4 All utility connections in areas prone to liquefaction shall be flexible and designed for differential settlement.

Sec. 15.10.130 Amendments of 2016 CBC Section 113 (Appeals) and 114 (Violations).

Sections 113 and 114 of the 2016 California Building Code are deleted.

Sec. 15.10.140 Amendment to 2016 CBC Section 302 (Classification).

Section 302 of the 2016 California Building Code is amended as follows:

302.1 Classification. Structures or portions of structures shall be classified with respect to occupancy in one or more of the groups listed in this section. A room or space that is intended to be occupied at different times for different purposes shall comply with all of the requirements that are applicable to each of the purposes for which the room or space will be occupied. Structures with multiple occupancies or uses shall comply with Section 508. Where a structure is proposed for a purpose that is not specifically provided for in this code or about which there is any question, such structure shall be classified, as determined by the Building Official, in the group that the occupancy most nearly resembles, according to the fire safety and relative hazard involved.

Sec. 15.10.150 Amendment to 2016 CBC Section 402 (Covered mall and open mall buildings).

Section 402 of the 2016 California Building Code is amended as follows:

402.1-402.4.3.1 {CBC text not modified}

402.5 {CBC text not modified}. Exception deleted

402.6-402.8.8 {CBC text not modified}

Sec. 15.10.160 Amendment to 2016 CBC Section 403 (High-Rise buildings and group I-2 occupancies having occupied floors located more than 75 feet above the lowest level of fire department vehicle access).

Section 403 of the 2016 California Building Code is amended as follows:

403.1-403.2.4 {CBC text not modified}

403.3 {CBC text not modified}. Exception: deleted

403.3.1-403.7 {CBC text not modified}

Sec. 15.10.170 Amendment to 2016 CBC Section 404 (Atriums).

Section 404 of the 2016 California Building Code is amended as follows:

404.1 - 404.2 {CBC text not modified}

404.3 {CBC text not modified}. Exceptions: deleted.

404.4 - 404.11 {CBC text not modified}

Sec. 15.10.180 Amendment to 2016 CBC Section 406 (Motor Vehicle Related Occupancies).

Section 406 of the 2016 California Building Code is amended as follows:

406.1 – 406.3.3 {CBC text not modified}

406.3.4 {CBC text not modified}

406.3.4.1 Dwelling unit separation. The private garage shall be separated from the dwelling unit and its attic area by means of gypsum board, not less than 5/8-inch (15.9 mm) thick Type X, or equivalent applied to the garage side. Garages beneath habitable rooms shall be separated from all habitable rooms above by not less than a 5/8-inch (15.9 mm) Type X gypsum board or equivalent. Door openings between a private garage and the dwelling unit shall be equipped with either solid wood doors or solid or honeycomb core steel doors not less than 1 3/8 inches (34.9 mm) thick, or doors in compliance with Section 716.5.3 with a fire protection rating of not less than 20 minutes. Doors shall be self-closing and self-latching.

406.3.4.2 – 406.3.6 {CBC text not modified}

406.3.7 Garage flammable vapor ventilation. In enclosed private garages attached to R occupancies, provide 1 square foot of ventilation area located at the lower 12" of garage wall. Said ventilation areas shall be directly communicated with the exterior, but shall not be installed where protection of openings is required.

406.4 – 406.9.3 {CBC text not modified}

Sec. 15.10.190 Amendment to 2016 CBC Section 602 (Construction Classification).

Section 602, Table 602, footnote b. of the 2016 California Building Code is amended as follows. All other subsections and tables within Section 602 are not modified.

b. Except in high-rise buildings, Group A, E, F-1, H, I, L, M, R-1, R-2, and S-1 occupancies, fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. For Group A, E, I, L, R-1, and R-2 occupancies and other applications listed in Section 111 regulated by the Office of the State Fire Marshal, fire protection of members other than the structural frame shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

Sec. 15.10.200 Amendment to 2016 CBC Section 708 (Fire Partitions).

Section 708 of the 2016 California Building Code is amended as follows:

708.1 – 708.2 {CBC text not modified}

708.3 {CBC text not modified}

Exceptions:

1. {CBC text not modified}

2. deleted

3. {CBC text not modified}

708.4 – 708.9 {CBC text not modified}

Sec. 15.10.210 Amendment to 2016 CBC Section 711 (Horizontal Assemblies).

Section 711 of the 2016 California Building Code is amended as follows:

711.1 – 711.2.4.2 {CBC text not modified}

711.2.4. {CBC text not modified}

Exception: deleted

711.2.4.4 -711.3.2. {CBC text not modified}

Sec. 15.10.220 Amendment to 2016 CBC Section 701A (Scope, Purpose and Application).

Section 701A of the 2016 California Building Code is amended as follows:

701A.1 Scope: This chapter applies to building materials, systems and/or assemblies used in the exterior design and construction of new and existing buildings or structures erected, constructed, altered, or moved within a Wildland-Urban Interface Fire Area as defined in Section 702A.

701A.2 {CBC text not modified}

701A.3 Application. New or existing buildings or structures erected, constructed, altered, or moved in any Fire Hazard Severity Zone or any Wildland-Urban Interface Fire Area designated by the enforcing agency constructed after the application date shall comply with the provisions of this chapter.

Exceptions:

1. – 3. {CBC text not modified}

4. deleted.

701A.3.1 – 701A.5 {CBC text not modified}

Sec. 15.10.230 Amendment to 2016 CBC Section 702A (Definitions).

Section 702A of the 2016 California Building Code is amended by modifying the following definitions. The remaining definitions are not modified.

LOCAL AGENCY VERY HIGH FIRE HAZARD SEVERITY ZONE means those areas designated by the city of Fremont as Very High Fire Hazard Severity Zones in Fremont Municipal Code Title 15, Chapter 15.65.

WILDLAND-URBAN INTERFACE FIRE AREA is a geographical area identified by the state as a “Fire Hazard Severity Zone” in accordance with Public Resources Code Sections 4201 through 4204 and Government Code Sections 51175 through 51189, and includes those areas designated by the city of Fremont as Very High Fire Hazard Severity Zones in Fremont Municipal Code Title 15, Chapter 15.65.

Sec. 15.10.240 Amendment to 2016 CBC Section 705A (Roofing).

Section 705A of the 2016 California Building Code is amended as follows:

705A.1 – 705A.2 {CBC text not modified}

705A.2.1 Wildland Urban-Interface Fire Area. The roof covering of any new structure or the re-roofing of any existing building within Wildland-Urban Interface Fire Area, regardless of the type of construction or occupancy classification, shall be a fire-retardant roof covering that is at least Class A. All alteration, repair, replacement or reroofing shall conform to the applicable provisions of the 2016 California Building Code Section 1604 “General Design Requirements” and any other applicable engineering requirements, including Chapter 15, “Roof Assemblies and Rooftop Structures” of this code.

705A.3 – 705A.4 {CBC text not modified}

Sec. 15.10.250 Amendment to 2016 CBC Section 707A (Exterior Covering).

Section 707A of the 2016 California Building Code is amended as follows:

707A.1 – 707A.3.1 {CBC text not modified}

707A.3.1.2 Exterior wall covering. All exterior faces of the exterior walls shall be of an assembly qualified for exterior face of recognized one-hour fire resistive assemblies. All exterior wall coverings shall meet a Class I flame spread requirement and be installed over materials approved for one-hour fire-resistive construction.

Exception: Class I flame spread requirement may be waived for additions not to exceed 50%, cumulatively over the life of the structure, of the existing structure, including garage areas with 1-hour fire resistive exterior wall assembly.

707A.4 – 707A.9 {CBC text not modified}

707A.10 Utilities. Utilities, pipes, furnaces, water heaters or other mechanical devices located in an exposed under-floor area of a building or structure shall be enclosed with material as required for exterior, one-hour, fire-resistive construction. Adequate covered access opening for servicing such utilities shall be provided as required by appropriate codes.

707A.11 Historical buildings. Repairs, alterations and additions necessary for the preservation, restoration, rehabilitation or continued use of a building or structure may be made without conformance to all the requirements of this code when authorized by the Building Official, provided:

1. The building or structure conforms to Part 8, Title 24, of the California Code of Regulations; and

2. A fire protection plan is implemented so that the building or structure will be no more of a fire hazard than any new building. The plan must be prepared and signed by a registered Fire Protection Engineer. The plan must be approved by the Building Official and fire chief prior to the commencement of any work.

Sec. 15.10.260 Amendment to 2016 CBC Section 902 (Definitions).

Section 902 of 2016 California Building Code is amended by adding additional definitions to Section 902.1 as follows. The remaining definitions are not modified.

CURRENT CODE means the edition of the California Building Standards Code published by the International Code Council (ICC) as adopted by the city of Fremont under Health and Safety Code Section 18941.5. The edition to be applied shall be that edition in effect at the time damage occurs.

ENGINEERING EVALUATION means an evaluation of a suspected damaged building or structure, performed under the direction of a fire protection engineer, structural engineer, civil engineer or architect retained by the owner of the building or structure. Engineering evaluations shall, at a minimum, contain recommendations for repair with an appropriate estimate of the construction cost for those repairs.

ESSENTIAL SERVICE FACILITY means that building or structure which has been designated by the city council to house facilities which are necessary for emergency operations.

FIRE PROTECTION ENGINEER means an individual registered by the State of California to practice fire protection engineering and to use the title, Fire Protection Engineer, as defined in the State of California Business and Professions Code.

HAZARDOUS FIRE AREA means the “Wildland-Urban Interface Fire Area” as defined in Section 702A as amended by the city of Fremont.

HISTORIC BUILDING OR STRUCTURE means as defined in the Section 8-201, Chapter 2, Part 8, 2010 California Historical Building Code, Title 24 of the California Codes of Regulations.

REPLACEMENT VALUE is the dollar value, as determined by the Building Official based upon the square footage and the guidelines used in establishing the valuation of new construction, of replacing the damaged structure with a new structure of the same size, construction material and occupancy on the same site.

VALUE OF REPAIR is the dollar value, as determined by the Building Official, of making the necessary repairs to a damaged structure.

Sec. 15.10.270 Amendment to 2016 CBC Section 903 (Automatic Sprinkler System).

Section 903 of the 2016 California Building Code is amended as follows:

903.1 General. Automatic sprinkler systems shall be provided as set forth in Section 903 of the California Fire Code as adopted and amended by FMC Section 15.35.140.

903.1.1 – 903.5 deleted

Sec. 15.10.280 Amendment to the 2016 CBC Section 1020 (Corridors).

Table 1020.1 of the 2016 California Building Code is amended by modifying the third row below the header to read as follows. The remainder of Table 1020.1 is unchanged.

Occupancy	Occupant Load Served by Corridor	Required Fire-Resistance Rating (Hours) – Without Sprinkler System	Required Fire-Resistance Rating (Hours) – With Sprinkler System
A[e]	Greater than 30	1	1
B, F, M, S, U	Greater than 30	1	0

Sec. 15.10.290 Amendment to 2016 CBC Section 1507 (Requirement for Roof Covering).

Section 1507 of the 2016 California Building Code is amended as follows:

1507.1 {CBC text not modified}

1507.1.1 Certification. The installer of the roof covering shall provide certification of the roof covering classification to the building owner and to the city when roof covering installation is subject to the 2016 CBC Chapter 7A.

Exceptions:

1. The certification requirements of this section shall not apply to any building which is subject to addition, repair, alterations, roof installation, or replacement of less than 50% of the existing building's roof area over the life of the building commencing on or after the effective date of February 15, 1991.

2. For accessory building, refer to Section 105.2, Exception 1.

1507.2 – 1507.3 {CBC text not modified}

1507.3.1 Deck requirements. Concrete and clay tile shall be installed only over solid structural sheathing boards.

1507.3.3.2 – 1507.17.8 {CBC text not modified}

Sec. 15.10.300 Amendment to the 2016 CBC Section 1612 (Flood Loads).

Section 1612 of the 2016 California Building Code is amended as follows:

1612.1 – 1612.2 {CBC text not modified}

1612.3 Establishment of flood hazard areas. To establish flood hazard areas, the governing body shall adopt a flood hazard map and supporting data. The flood hazard map shall include, at a minimum, areas of special flood hazard as identified by the Federal Emergency Management Agency in an engineering report entitled "The Flood Insurance Study for Alameda County, California", revision dated August 3, 2009, as amended, with the accompanying Flood Insurance Rate Map (FIRM) and related supporting data along with any revisions thereto. The adopted flood hazard map and supporting data are hereby adopted by reference and declared to be part of this section.

Exception: {CBC text not modified}

1612.3.1. – 1612.5 {CBC text not modified}

Sec. 15.10.310 Amendment to 2016 CBC Section 1613 (Earthquake Load).

Section 1613 of the 2016 California Building Code is amended as follows:

1613.1 – 1613.5.1 {CBC text not modified}

1613.5.2 Minimum distance for structural separation. ASCE-7 Equation 12.12-1 is amended as shown

(Equation 12.12-1)

$$\delta_M = \frac{C_d \delta_{max}}{\cancel{I}}$$

where:

C_d = Deflection amplification factor in Table 12.2-1 of ASCE 7.
δ_{max} = Maximum displacement defined in Section 12.8.4.3 of ASCE 7.

1613.5.3 Modified ASCE 7, 12.2.3.1, Exception 3. ASCE 7 Section 12.2.3.1

Exception 3 is amended as follows:

3. Detached one- and two-family dwellings up to two stories in height of light frame construction.

1613.5.4 Wood Diaphragm. Modify ASCE 7 Section 12.11.2.2.3 as follows.

12.11.2.2.3 Wood Diaphragms. In wood diaphragms, the continuous ties shall be in addition to the diaphragm sheathing. Anchorage shall not be accomplished by use of toe nails or nails subject to withdrawal nor shall wood ledgers or framing be used in cross-grain bending or cross-grain tension. The diaphragm sheathing shall not be considered effective as providing ties or struts required by this section.

For structures assigned to Seismic Design Category D, E, and F, wood diaphragms supporting concrete or masonry walls shall comply with the following:

1. The spacing of continuous ties shall not exceed 40 feet. Added chords of diaphragm may be used to form sub-diaphragm to transmit the anchorage forces to the main continuous crossties.

2. The maximum diaphragm shear used to determine the depth of the sub-diaphragm shall not exceed 75% of the maximum diaphragm shear.

1613.5.5 Maximum S_{DS} Value in Determination of C_S and E_V. Modify ASCE 7 Section 12.8.1.3 as follows.

12.8.1.3 Maximum SDS Value in Determination of Cs and Ev. The value of Cs and Ev are permitted to be calculated using a value of S_{DS} equal to 10 but not less than 70% of S_{DS} as defined in Section 11.4.4 provided that all of the following criteria are met:

1. The structure does not have irregularities, as defined in Section 12.3.2;

2. The structure does not exceed five stories above the lower of the base or grade plane as defined in Section 11.2, and, where present, each mezzanine level shall be considered a story for the purpose of this limit;

3. The structure has a fundamental period, T, that does not exceed 0.5 seconds, as determined using Section 12.8.2;

4. The structure meets the requirements necessary for the redundancy factor, p, to be permitted to be taken as 1.0, in accordance with Section 12.3.4.2;

5. The site soil properties are not classified as Site Classes E or F, as defined in Section 11.4.2; and

6. The structure is classified as Risk Category I or II, as defined in Section 1.5.1.

1613.6 {CBC text not modified}

1613.7 Suspended Ceilings. Minimum design and installation standards for suspended ceilings shall be determined in accordance with the requirements of Section 2506.2.1 of this code and this subsection.

1613.7.1 Scope. This part contains special requirements for suspended ceilings and lighting systems. Provisions of Section 13.5.6 of ASCE 7-10 shall apply except as modified herein.

1613.7.2 General. The suspended ceilings and lighting systems shall be limited to 6 feet (1828 mm) below the structural deck unless the lateral bracing is designed by a licensed engineer or architect.

1613.7.3 Sprinkler Heads. All sprinkler heads (drops) except fire-resistance-rated floor/ceiling or roof/ceiling assemblies, shall be designed to allow for free movement of the sprinkler pipes with oversize rings, sleeves or adaptors through the ceiling tile. Sprinkler heads and other penetrations shall have a 2 inch (50mm) oversize ring, sleeve, or adapter through the ceiling tile to allow for free movement of at least 1 inch (25mm) in all horizontal directions. Alternatively, a swing joint that can accommodate 1 inch (25mm) of ceiling movement in all horizontal directions is permitted to be provided at the top of the sprinkler head extension.

Sprinkler heads penetrating fire-resistance-rated floor/ceiling or roof/ceiling assemblies shall comply with Section 714 of this code.

1613.7.4 Special Requirements for Means of Egress. Suspended ceiling assemblies located along means of egress serving an occupant load of 30 or more shall comply with the following provisions.

1613.7.4.1 General. Ceiling suspension systems shall be connected and braced with vertical hangers attached directly to the structural deck along the means of egress serving an occupant load of 30 or more and at lobbies accessory to Group A occupancies. Spacing of vertical hangers shall not exceed 2 feet (610 mm) on center along the entire length of the suspended ceiling assembly located along the means of egress or at the lobby.

1613.7.4.2 Assembly Device. All lay-in panels shall be secured to the suspension ceiling assembly with two hold-down clips minimum for each tile within a 4-foot (1219 mm) radius of the exit lights and exit signs.

1613.7.4.3 Emergency Systems. Independent supports and braces shall be provided for light fixtures required for exit illumination. Power supply for exit illumination shall comply with the requirements of Section 1008.3 of this code.

1613.7.4.4 Supports for Appendage. Separate support from the structural deck shall be provided for all appendages such as light fixtures, air diffusers, exit signs, and similar elements.

Sec. 15.10.320 Amendment to 2016 CBC Section 1704 (Special Inspections and Tests, Contractor Responsibility and Structural observations).

Section 1704 of the 2016 California Building Code is amended as follows:

1704.1 - 1704.5 {CBC text not modified}

1704.6 Structural observations. Where required by the provisions of Section 1704.6.1 and 1704.6.2, the owner or the owner's authorized agent shall employ a structural observer to perform structural observations. Structural observation does not include or waive the responsibility of the inspections or special inspections in Section 1705 or other sections of this code. The structural observer shall be one of the following individuals:

1. The registered design professional responsible for the structural design, or

2. A registered design professional designated by the registered design professional responsible for the structural design.

Prior to the commencement of observations, the structural observer shall submit to the Building Official a written statement identifying the frequency and extent of structural observations.

The owner or owner's representative shall coordinate and call a preconstruction meeting between the structural observer, contractors, affected subcontractors and special inspectors. The structural observer shall preside over the meeting. The purpose of the meeting shall be to identify the major structural elements and connections that affect the vertical and lateral load resisting systems of the structure and to review scheduling of the required observations. A record of the meeting shall be included in the report submitted to the Building Official.

Observed deficiencies shall be reported in writing to the owner or owner's representative, special inspector, contractor and the Building Official. Upon the form prescribed by the Building Official, the structural observer shall submit to the Building Official a written statement at each significant construction stage stating that the site visits have been made and identifying any reported deficiencies which, to the best of the structural observer's knowledge, have not been resolved. A final report by the structural observer which states that all observed deficiencies have been resolved is required before acceptance of the work by the Building Official.

1704.6.1 Structural observation for seismic resistance. Structural observations shall be provided for those structures to Seismic Design Category D, E, or F, where one or more of the following conditions exist:

1. The structure is classified as Risk Category III or IV in accordance with Table 1604.5.

2. The height of the structure is greater than 75 feet (22860 mm) above the base.

3. The structure is classified as Risk Category I or II in accordance with Table 1604.5, and lateral design is required for the structure or portion thereof.

Exception: One-story wood framed Group R-3 and U Occupancies less than 2,000 square feet in area, provided the adjacent grade is not steeper than 1 unit vertical in 10 units horizontal (10% sloped), assigned to Seismic Category D

4. When so designated by the registered design professional responsible for the structural design.

5. When such observation is specifically required by the building official.

1704.6.2 {CBC text not modified}

Sec. 15.10.330 Amendment to 2016 CBC Section 1705 (Required Verification and Inspection).

Section 1705 of the 2016 California Building Code is amended as follows:

1705.1 – 1705.2. 4 {CBC text not modified}

1705.3 Concrete Construction**.** The special inspections and verifications for concrete construction shall be as required by this section and Table 1705.3.

Exceptions: Special inspection and tests shall not be required for:

1. Isolated spread concrete footings of buildings three stories or less above grade plane that are fully supported on earth or rock, where the structural design of the footing is based on a specified compressive strength, f'_c, no greater than 2,500 pounds per square inch (psi) (17.2 Mpa).

2. Continuous concrete footings supporting walls of buildings three stories or less in height that are fully supported on earth or rock where:

2.1. The footings support walls of light-frame construction;

2.2. The footings are designed in accordance with Table 1809.7; or

2.3. The structural design of the footing is based on a specified compressive strength, f'_c, no greater than 2,500 pounds per square inch (psi) (17.2 Mpa), regardless of the compressive strength specified in the construction documents or used in the footing construction.

3. Nonstructural concrete slabs supported directly on the ground, including prestressed slabs on grade, where the effective prestress in the concrete is less than 150 psi (1.03 Mpa).

4. deleted

5. Concrete patios, driveways and sidewalks, on grade.

1705.3.1-1705.11.3 {CBC text not modified}

1705.12 Special inspections for seismic resistance. Special inspections for seismic resistance shall be required as specified in Sections 1705.12.1 through 1705.12.9, unless exempted by the exceptions of Section 1704.2.

Exception: The special inspections specified in Sections 1705.12.1 through 1705.12.9 are not required for structures designed and constructed in accordance with one of the following:

1. The structure consists of light-frame construction; the design spectral response acceleration at short periods, S_{DS}, as determined in Section 1613.3.4, does not exceed 0.5; and the building height of the structure does not exceed 35 feet (10 668 mm).

2. The seismic force-resisting system of the structure consists of reinforced masonry or reinforced concrete; the design spectral response acceleration at short periods, S_{DS}, as determined in Section 1613.3.4, does not exceed 0.5; and the building height of the structure does not exceed 25 feet (7620 mm).

3. The structure is a detached one- or two-family dwelling not exceeding two stories above grade plane, is not assigned to Seismic Design Category D, E or F and does not have any of the following horizontal or vertical irregularities in accordance with Section 12.3 of ASCE 7:

3.1 Torsional or extreme torsional irregularity.

3.2 Nonparallel systems irregularity.

3.3 Stiffness-soft story or stiffness-extreme soft story irregularity.

3.4 Discontinuity in lateral strength-weak story irregularity.

1705.12.1 – 1705.18.2 {CBC text not modified}

Sec. 15.10.340 Amendment to 2016 CBC Section 1707 (Alternative Test Procedure).

Section 1707.1 of the 2016 California Building Code is amended as follows:

1707.1 General. In the absence of approved rules or other approved standards, the Building Official shall make, or cause to be made, the necessary tests and investigations; or the Building Official shall accept duly authenticated reports from approved agencies in respect to the quality and manner of use of new materials or assemblies as provided for in Section 104.11. The cost of all tests and other investigations required under the provisions of this code shall be borne by the owner or the owner's authorized agent.

Sec. 15.10.350 Amendment to 2016 CBC Section 1803 (Geotechnical Investigations).

Section 1803 of the 2016 California Building Code is amended as follows:

1803.1 – 1803.1.1.5 {CBC text not modified}

1803.2 {CBC text not modified}

Exceptions: The following occupancies are exempt:

1. Group U occupancies;

2. R3 Occupancies;

A. Additions to existing Group R3 occupancies: when building site is not within seismic induced landslide hazard zone; total added floor area is less than 1,000 square feet and all of the following conditions for the associated group (single or two-story additions) are met:

a. Single story additions:

a1. Existing building has a continuous foundation (spread footing) and

a2. New foundation dimensions at minimum meets requirements from CBC Table 1809.7 for 2-story structure and are 20" embedded into undisturbed soil.

b. Two-story additions:

b1. When an Architect, Civil or Structural engineer registered in the State of California provides the structural design; and b2. The Architect or Engineer of Record certifies in writing that the new foundation type matches existing foundation.

3. A new soil report is not required when an existing soil report is available for the original construction of the existing structure and the soil engineer allows extension of the existing report for the proposed addition construction. An amended soil report is required to meet the investigated conditions (CBC Section 1803.5) and reporting requirements (CBC Section 1803.6).

4. Accessories and minor additions may be exempted by the Building Official.

1803.3 – 1803.5.12 {CBC text not modified}

1803.6 {CBC text not modified}

1. – 11. {CBC text not modified}

12. Drainage and erosion control recommendations.

13. Minimum building setbacks to slope tops or toes.

14. Equivalent-fluid-density lateral loads used in design of retaining walls or basement walls.

15. Ground response evaluation by geologist licensed in California for:

a. Flexible structures located on site having soft to medium cohesion less soils in upper 50 feet and depth to bedrock is 400 feet or greater; and

b. Structures having irregular shapes, framing systems, or other unusual features as determined by the Building Official.

16. Liquefaction evaluation for the following uses:

a. Subdivisions of Group R-3 occupancy having 4 units or more;

b. Apartment or condominium complexes of Group R- 2 occupancy having 50 or more units;

c. Structure of four or more stories or over 35 feet high;

d. Commercial, industrial, and institutional projects having 250 occupants or more;

e. Essential facilities.

17. Slope stability evaluation in areas subject to localized or major landslides.

18. Surface rupture evaluation by geologist licensed in California for all projects for human occupancy located with a Geologic Hazards Special Studies Zone, as mapped by the California Division of Mines and Geology.

19. Soil corrosivity analysis and long-term corrosion control design recommendations.

1803.7 {CBC text not modified}

1803.8 Review. Before issuing a permit for a building where soil and foundation investigation is required, the Geotechnical Engineer or Civil Engineer who prepared the soil investigation shall state in writing (must be signed and stamped):

1. The plans and specifications substantially conform to the recommendations in the soil investigation.

2. The Geotechnical Engineer or Civil Engineer who prepared the soil investigation has been retained to provide soil site observation and provide periodic and final reports to the city.

1803.9 Field Report. Before requesting a foundation inspection from the city, the Geotechnical Engineer or Civil Engineer who prepared the soil investigation shall provide a written field report stating:

1. The building pad was prepared and compacted in accordance with the soil report and specification.

2. The foundation or pier excavation, depth, backfill materials, and drainage (if applicable), substantially conforms with the soil report and approved plans.

1803.10 Final Report. Before final inspection for any building or structure, the Geotechnical Engineer or Civil Engineer who prepared the soil investigation shall issue a final report stating the completed pad, foundation, finish grading, drainage, and associated site work substantially conforms to the approved plans, specifications, and investigation.

Sec. 15.10.360 Amendment to 2016 CBC Section 1804 (Excavation, Grading and Fill).

Section 1804 of the 2016 California Building Code is amended as follows:

1804.1 – 1804.4.1 {CBC text not modified}

1804.4.2 Slopes for permanent fills shall not be steeper than 3 horizontal to 1 vertical. Cut slopes for permanent excavations shall not be steeper than 3 horizontal to 1 vertical unless substantiating data justifying steeper cut slopes is submitted. Deviation from the foregoing limitations for cut slopes shall be permitted only upon the presentation of a soils report acceptable to the Building Official. All site improvements shall be designed and constructed in accordance with the recommendations contained in the soil report.

1804.4.3 Where cuts or fills are to be made as described above, pad elevation certification(s) will be required prior to foundation inspection. Required certification shall be made by a licensed Land surveyor or registered civil engineer in the State of California.

1804.5 – 1804.7 {CBC text not modified}

Sec. 15.10.370 Amendment to 2016 CBC Section 1807 (Foundation Walls, Retaining Walls and Embedded Posts and Poles).

Section 1807 of the 2016 California Building Code is amended as follows:

1807.1 – 1807.1.5 {CBC text not modified}

1807.1.6 Prescriptive design of concrete and masonry foundation walls. Concrete and masonry foundation walls that are laterally supported at the top and bottom shall be permitted to be designed and constructed in accordance with this section. Prescriptive design of foundation walls shall not be used for structures assigned to Seismic Design Category D, E or F.

1807.1.6.1 – 1807.3.3 {CBC text not modified}

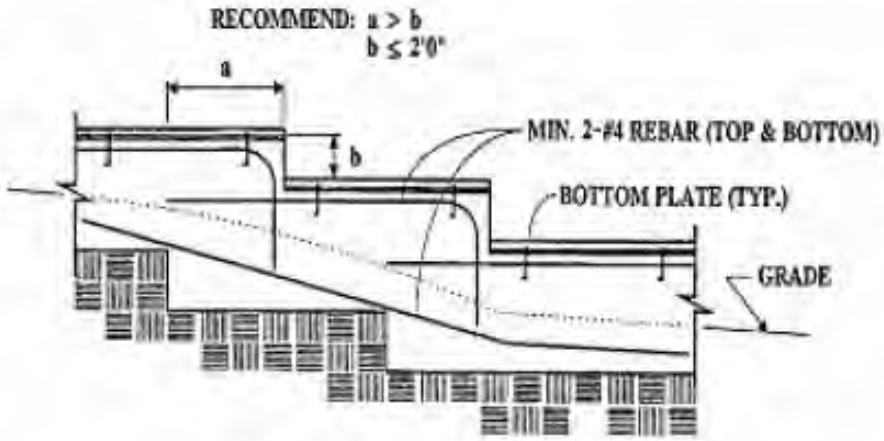
Sec. 15.10.380 Amendment to 2016 CBC Section 1809 (Shallow Foundations).

Section 1809 of the 2016 California Building Code is amended as follows:

1809.1 – 1809.2 {CBC text not modified}

1809.3 Stepped footings. The top surface of footings shall be level. The bottom surface of footings shall be permitted to have a slope not exceeding one unit vertical in 10 units horizontal (10-percent slope). Footings shall be stepped where it is necessary to change the elevation of the top surface of the footing or where the surface of the ground slopes more than one unit vertical in 10 units horizontal (10-percent slope).

For structures assigned to Seismic Design Category D, E or F, the stepping requirement shall also apply to the top surface of grade beams supporting walls. Footings shall be reinforced with four No. 4 bars. Two bars shall be place at the top and bottom of the footings as shown in Figure 1809.3.



STEPPED FOUNDATIONS

FIGURE 1809.3
STEPPED FOOTING

1809.4 – 1809.6 {CBC text not modified}

1809.7 Prescriptive footings for light-frame construction. Where a specific design is not provided, concrete or masonry-unit footings supporting walls of light-frame construction shall be permitted to be designed in accordance with Table 1809.7. Prescriptive footings in Table 1809.7 shall not exceed one story above grade plane for structures assigned to Seismic Design Category D, E or F.

TABLE 1809.7
PRESCRIPTIVE FOOTINGS SUPPORTING WALLS OF LIGHT-FRAME CONSTRUCTION [a, b, c, d, e]

NUMBER OF FLOORS SUPPORTED BY THE FOOTING [f]	WIDTH OF FOOTING (inches)	THICKNESS OF FOOTING (inches)
1	12	6
2	15	6
3	18	8 [g]

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm
a. Depth of footings shall be in accordance with Section 1809.4.
b. The ground under the floor shall be permitted to be excavated to the elevation of the top of the footing.
c. Not adopted, deleted
d. See Section 1908 for additional requirements for concrete footings of structures assigned to Seismic Design Category C, D, E or F.
e. For thickness of foundation walls, see Section 1807.1.6.
f. Footings shall be permitted to support a roof addition to the stipulated number of floors. Footings supporting roof only shall be as required for supporting one floor.
g. deleted

1809.8 deleted.

1809.9. – 1809.13 {CBC text not modified}

Sec. 15.10.390 Amendment to 2016 CBC Section 1905 (Modifications to ACI 318).

Section 1905 of the 2016 California Building Code is amended as follows:

1905.1.1 – 1905.1.2 {CBC text not modified}

1905.1.3 ACI 318, Section 18.5. Modify ACI 318, Section 18.5, by adding new Section 18.5.3:

18.5.3 – Wall segments with a horizontal length-to-thickness ratio less than 2.5 shall be designed as columns.

1905.1.4 – 1905.1.6 {CBC text not modified}

1905.1.7 ACI 318, Section 14.1.4. Delete ACI 318, Section 14.1.4, and replace with the following:

14.1.4 – Plain concrete in structures assigned to Seismic Design Category C, D, E or F.

14.1.4.1 – Structures assigned to Seismic Design Category C, D, E or F shall not have elements of structural plain concrete, except as follows:

(b) Isolated footings of plain concrete supporting pedestals or columns are permitted, provided the projection of the footing beyond the face of the supported member does not exceed the footing thickness.

Exception: deleted.

(c) Plain concrete footings supporting walls are permitted provided the footings have at least two continuous longitudinal reinforcing bars. Bars shall not be smaller than No. 4 and shall have a total area of not less than 0.002 times the gross cross-sectional area of the footing. A minimum of one bar shall be provided at the top and bottom of the footing. Continuity of reinforcement shall be provided at corners and intersections.

Exceptions:

1. In detached one- and two-family dwellings three stories or less in height and constructed with stud-bearing walls, are permitted to have plain concrete footings with at least two continuous longitudinal reinforcing bars not smaller than No. 4 are permitted to have a total area of less than 0.002 times the gross cross-sectional area of the footing.

2. Deleted.

3. Deleted.

1905.1.8 {CBC text not modified}

1905.1.9 ACI 318, Section 18.7.5. Modify ACI 318, Section 18.7.5, by adding Section 18.7.5.8 and 18.7.5.9 as follows:

18.7.5.8 Where the calculated point of contraflexure is not within the middle half of the member clear height, provide transverse reinforcement as specified in ACI 318, Sections 18.7.5.1, Items (a) through (c), over the full height of the member.

18.7.5.9 – At any section where the design strength, φP_n, of the column is less than the sum of the shears V_e computed in accordance with ACI 318, Sections 18.6.5.1 and 18.7.6.1 for all the beams framing into the column above the level under consideration, transverse reinforcement as specified in ACI 318, Sections 18.6.5.1 through 18.6.5.3 shall be provided. For beams framing into opposite sides of the column, the moment components are permitted to be assumed to be of opposite sign. For the determination of the design strength, φP_n, of the column, these moments are permitted to be assumed to result from the deformation of the frame in any one principal axis.

1905.1.10 ACI 318, Section 18.10.4. Modify ACI 318, Section 18.10.4, by adding Section 18.10.4.6 as follows:

18.10.4.6 – Walls and portions of walls with $P_u > 0.35P_o$ shall not be considered to contribute to the calculated shear strength of the structure for resisting earthquake-induced forces. Such walls shall conform to the requirements of ACI 318, Section 18.14.

1905.1.11 ACI 318, Section 18.12.6. Modify ACI 318, by adding Section 18.12.6.2 as follows:

18.12.6.2 Collector and boundary elements in topping slabs placed over precast floor and roof elements shall not be less than 3 inches (76 mm) or 6 d_b in thickness, where d_b is the diameter of the largest reinforcement in the topping slab.

Sec. 15.10.400 Amendment to 2016 CBC Section 1906 (Structural Plain Concrete).

Section 1906 of the 2016 California Building Code is deleted.

Sec. 15.10.410 Amendment to 2016 CBC Section 1907 (Minimum Slab Provisions).

Section 1907 of the 2016 California Building Code is amended by adding the following sentence to the end of subsection 1907.1:

Slabs shall have 6 x 6 x 10/-10 wire mesh or equal at mid-height.

1907.1.1 {CBC text not modified}

Sec. 15.10.420 Amendment to 2016 CBC Section 2304 (General Construction Requirements).

Section 2304 text and Table 2304.10.1 of the 2016 California Building Code are amended as follows:

2304.1 – 2304.10 {CBC text not modified}

2304.10.1 Fastener requirements. Connections for wood members shall be designed in accordance with the appropriate methodology in Section 2301.2. The number and size of fasteners connecting wood members shall not be less than that set forth in Table 2304.10.1. Staple fasteners in Table 2304.10.1 shall not be used to resist or transfer seismic forces in structures assigned to Seismic Design Category D, E or F.

Exception: Staples may be used to resist or transfer seismic forces when the allowable shear values are substantiated by cyclic testing and approved by the Building Official.

2304.10.1.1. – 2304.13 {CBC text not modified}

Add new footnote d. to Table 2304.10.1. to read as follows. The remaining portions of Table 2304.10.1 are not modified.

d. Staples shall not be used to resist or transfer seismic forces in structures assigned to Seismic Design Category D, E or F.

Sec. 15.10.430 Amendment to 2016 CBC Section 2305 (General Design Requirements for Lateral-Force-Resisting Systems).

Section 2305 of the 2016 California Building Code is amended as follows:

2305.1 – 2305.3 {CBC text not modified}

2305.4 Quality of Nails. In Seismic Design Category D, E or F, mechanically driven nails used in wood structural panel shear walls shall meet the same dimensions as that required for hand-driven nails, including diameter, minimum length and minimum head diameter. Clipped head or box nails are not permitted in new construction. The allowable design value for clipped head nails in existing construction may be taken at no more than the nail-head-area ratio of that of the same size hand-driven nails.

2305.5 Hold-down connectors. In Seismic Design Category D, E or F, hold-down connectors shall be designed to resist shear wall overturning moments using approved cyclic load values or 75 percent of the allowable seismic load values that do not consider cyclic loading of the product. Connector bolts into wood framing shall require steel plate washers on the post on the opposite side of the anchorage device. Plate size shall be a minimum of 0.229 inches by 3 inches by 3 inches (5.82 mm by 76 mm by 76 mm) in size. Hold-down connectors shall be tightened to finger tight plus one half (1/2) wrench turn just prior to covering the wall framing.

Sec. 15.10.440 Amendment to 2016 CBC Section 2306 (Allowable Stress Design).

Section 2306 of the 2016 California Building Code is amended as follows:

2306.1 – 2306.1.4 {CBC text not modified}

2306.2 Wood-frame diaphragms. Wood-frame diaphragms shall be designed and constructed in accordance with AWC SDPWS. Where panels are fastened to framing members with staples, requirements and limitations of AWC SDPWS shall be met and the allowable shear values set forth in Table 2306.2(1) or 2306.2(2) shall only be permitted for structures assigned to Seismic Design Category A, B, or C.

Exception: Allowable shear values where panels are fastened to framing members with staples may be used if such values are substantiated by cyclic testing and approved by the Building Official.

The allowable shear values in Tables 2306.2(1) and 2306.2(2) are permitted to be increased 40 percent for wind design.

Wood structural panel diaphragms used to resist seismic forces in structures assigned to Seismic Design Category D, E or F shall be applied directly to the framing members.

Exception: Wood structural panel diaphragms are permitted to be fastened over solid lumber planking or laminated decking, provided the panel joints and lumber planking or laminated decking joints do not coincide.

2306.2.1 deleted.

2306.3 Wood structural panel shear walls. Wood-frame shear walls shall be designed and constructed in accordance with AWC SDPWS. For structures assigned to Seismic Design Category D, E, or F, application of Tables 4.3A and 4.3B of AWC SDPWS shall include the following:

1. Wood structural panel thickness for shear walls shall not be less than 3/8 inch thick and studs shall not be spaced at more than 16 inches on center.

2. The maximum nominal unit shear capacities for 3/8 inch wood structural panels resisting seismic forces in structures assigned to Seismic Design Category D, E or F is 400 pounds per linear foot (plf).

Exception: Other nominal unit shear capacities may be permitted if such values are substantiated by cyclic testing and approved by the Building Official.

3. Where shear design values using allowable stress design (ASD) exceed 350 plf or load and resistance factor design (LRFD) exceed 500 plf, all framing members receiving edge nailing from abutting panels shall not be less than a single 3-inch nominal member, or

two 2-inch nominal members fastened together in accordance with Section 2306.1 to transfer the design shear value between framing members. Wood structural panel joint and sill plate nailing shall be staggered at all panel edges. See Sections 4.3.6.1 and 4.3.6.4.3 of AWC SDPWS for sill plate size and anchorage requirements.

4. Nails shall be placed not less than 1/2 inch in from the panel edges and not less than 3/8 inch from the edge of the connecting members for shear greater than 350 plf using ASD or 500 plf using LRFD. Nails shall be placed not less than 3/8 inch from panel edges and not less than 1/4 inch from the edge of the connecting members for shears of 350 plf or less using ASD or 500 plf or less using LRFD.

5. Table 4.3B application is not allowed for structures assigned to Seismic Design Category D, E, or F.

For structures assigned to Seismic Design Category D, application of Table 4.3C of AWC SDPWS shall not be used below the top level in a multi-level building for structures.

Where panels are fastened to framing members with staples, requirements and limitations of AWC SDPWS shall be met and the allowable shear values set forth in Table 2306.3(1), 2306.3(2) or 2306.3(3) shall only be permitted for structures assigned to Seismic Design Category A, B, or C.

Exception: Allowable shear values where panels are fastened to framing members with staples may be used if such values are substantiated by cyclic testing and approved by the Building Official.

The allowable shear values in Tables 2306.3(1) and 2306.3(2) are permitted to be increased 40 percent for wind design. Panels complying with ANSI/APA PRP-210 shall be permitted to use design values for Plywood Siding in the AWC SDPWS.

Sec. 15.10.450 Amendment to 2016 CBC Section 2307 (Load and Resistant Factor Design).

Section 2307 of the 2016 California Building Code is amended as follows:

2307.1 {CBC text not modified}

2307.2 Wood-frame shear walls. Wood-frame shear walls shall be designed and constructed in accordance with Section 2306.3 as applicable.

Sec. 15.10.460 Amendment to 2016 CBC Section 2308 (Conventional Light Frame Construction).

Section 2308 of the 2016 California Building Code is amended as follows:

2308.1 – 2308.6.8 {CBC text not modified except table 2308.6.1}

2308.6.8.1 Foundation requirements. Braced wall lines shall be supported by continuous foundations.

Exception: For structures with a maximum plan dimension not over 50 feet (15240 mm), continuous foundations are required at exterior walls only for structures assigned to Seismic Design Category A, B, or C.

For structures in Seismic Design Categories D and E, exterior braced wall panels shall be in the same plane vertically with the foundation or the portion of the structure containing the offset shall be designed in accordance with accepted engineering practice and Section 2308.1.1.

2308.6.8.2 – 2308.6.8.3 {CBC text not modified}

2308.6.9 Attachment of sheathing. Fastening of braced wall panel sheathing shall not be less than that prescribed in Table 2308.6.1 or 2304.10.1. Wall sheathing shall not be attached to framing members by adhesives. Staple fasteners in Table 2304.10.1 shall not be used to resist or transfer seismic forces in structures assigned to Seismic Design Category D, E or F.

Exception: Staples may be used to resist or transfer seismic forces when the allowable shear values are substantiated by cyclic testing and approved by the Building Official.

All braced wall panels shall extend to the roof sheathing and shall be attached to parallel roof rafters or blocking above with framing clips (18 gauge minimum) spaced at maximum 24 inches (6096 mm) on center with four 8d nails per leg (total eight 8d nails per clip). Braced wall panels shall be laterally braced at each top corner and at maximum 24 inches (6096 mm) intervals along the top plate of discontinuous vertical framing.

2308.6.10 – 2308.8.2 {CBC text not modified}

Add new footnotes f. and g. to Table 2308.6.1:

Footnote f.– DWB, SFB, PBS, GB, PCP, and HPS wall braces are not permitted in Seismic Design Category D or E.

Footnote g. – WSP sheathing shall be a minimum of 15/32" thick nailed with 8d common nails placed 3/8 inches from panel edges and spaced not more than 6 inches on center and 12 inches on center along intermediate framing members.

Sec. 15.10.470 Amendment to 2016 CBC Section 2505 (Shearwall Construction).

Section 2505 of the 2016 California Building Code is deleted.

Sec. 15.10.480 Amendment to 2016 CBC Section 2508 (Gypsum Construction).

Section 2508 of the 2016 California Building Code is amended as follows.

2508.1 – 2508.4 {CBC text not modified}

2508.5 deleted.

Sec. 15.10.490 Amendment to 2016 CBC Section 3304 (Site Work).

Section 3304 of the 2016 California Building Code is amended as follows.

3304.1 – 3304.1.5 {CBC text not modified}

3304.2 Dust and Mud Control Measures. Contractors performing grading operations or site work within the city where dry conditions or wet conditions are encountered shall adequately and effectively control dust or mud from spreading off site or onto existing structures on site. Prior to commencement of grading operations, contractor shall furnish details of proposed dust or mud control measures to the Building Official for approval. Failure to control dust or mud from grading operations shall result in suspension of grading operations until adequate measures are in place to allow continuance.

Sec. 15.10.500 Supplemental Building Codes.

The provisions of Fremont Municipal Code Title 15 (Buildings and Construction), Chapter 15.50 (Building Security) supplement the 2016 California Building Code as adopted by this chapter as provided in Penal Code §14051.

SECTION 4. FMC CHAPTER 15.15 REPEALED AND REPLACED

Chapter 15.15 (Fremont Mechanical Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.15.010 Title.

This chapter shall be known and may be cited as the “Fremont mechanical code” or “Fremont municipal mechanical code” or “FMMC” and will be referred to in this chapter as “this code.”

Sec. 15.15.020 Adoption of the 2016 CMC with Amendments.

The 2016 edition of the California Mechanical Code (CMC) as published by the California Building Standards Commission is adopted as the mechanical code of the city of Fremont, California, as if fully set out in this chapter, and is amended as set forth in this chapter. A copy of 2016 CMC shall be maintained on file in the office of the city clerk.

Sec. 15.15.030 2016 CMC Appendix Chapters Adopted.

The following Appendix Chapters and Divisions of the 2016 California Mechanical Code are adopted by the city of Fremont.

(a) Appendix B (Procedures to be Followed to Place Gas Equipment in Operation)

(b) Appendix C (Installation and Testing of Oil (Liquid) Fuel-Fired Equipment

(c) Appendix D (Fuel Supply: Manufactured/Mobile Home Parks and Recreational Vehicle Parks)

Sec. 15.15.040 2016 CMC Chapter 1, Division II is not Adopted.

Chapter 1, Division II of the 2013 California Mechanical Code is not adopted by the city of Fremont. Refer to FMC Section 15.05 and 15.10.040 for Administration and Enforcement requirements. References to model codes in the adopted sections shall mean the corresponding California Codes as adopted by the city of Fremont.

Sec. 15.15.050 Amendment of 2016 CMC Section 507 (Commercial Hoods & Kitchen Ventilation).

Section 507 of the 2016 California Mechanical Code is amended as follows:

507.0 – 507.3.8 { CMC text not modified}

507.3.9 Type I hoods or portions thereof penetrating a ceiling or furred space must conform to the grease duct enclosure requirements in Section 510.7.

507.3.10 Hoods less than 12 inches from a ceiling or wall shall be solidly flashed with materials of the same thickness as the hood as specified in Section 508.3.

507.4 – 507.5 {CMC text not modified}

Sec. 15.15.060 Amendment of 2016 CMC Section 510 (Exhaust Duct Systems).

Sections 510 of the 2016 California Mechanical Code is amended as follows:

510.0 – 510.6.1 {CMC text not modified}

510.7 Interior Installations in all buildings, the ducts shall be enclosed in a continuous enclosure extending from the lowest fire-rated ceiling or floor above the hood, through any concealed spaces, to or through the roof so as to maintain the integrity of the fire separations required by the applicable building code provisions. The enclosure shall be sealed around the duct at the point of penetration of the lowest fire-rated ceiling or floor above the hood in order to maintain the fire resistance rating of the enclosure and shall be vented to the exterior of the building through weather-protected openings.

510.7 Exception – 510.11 {CMC text not modified}

<u>SECTION 5.</u> FMC CHAPTER 15.20 REPEALED AND REPLACED

Chapter 15.20 (Fremont Plumbing Code) of Fremont Municipal Code Title 15 (Buildings and

Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.20.010 Title.

This chapter shall be known and may be cited as the "Fremont plumbing code" or "FPC" and will be referred to in this chapter as "this code."

Sec. 15.20.020 Adoption of the 2016 CPC With Amendments.

The 2016 edition of the California Plumbing Code (CPC) as published by the California Building Standards Commission is adopted as the Plumbing Code of the city of Fremont, California, as if fully set out in this chapter, and is amended as set forth in this chapter. A copy of the 2016 CPC shall be maintained on file in the office of the city clerk.

Sec. 15.20.030 2016 CPC Appendix Chapters Adopted.

The following Appendix Chapters of the 2016 California Plumbing Code are adopted by the City of Fremont:

(a) Appendix A (Sizing Water Supply System)

(b) Appendix B (Combination Waste and Vent System)

(c) Appendix D (Sizing Storm Water System)

(d) Appendix L (Sustainable Practices)

Sec. 15.20.040 2016 CPC Chapter 1, Division II is not adopted.

Chapter 1, Division II of the 2016 California Plumbing Code is not adopted by the city of Fremont refer to FMC Section 15.05 and 15.10.040 for Administration and Enforcement requirements. References to model codes in the adopted sections shall mean the corresponding California Codes as adopted by the city of Fremont.

Sec. 15.20.050 Amendment of 2016 CPC Section 1211 (Electrical bonding and grounding).

Section 1211 of the 2016 California Plumbing Code is amended as follows:

1211.0 – 1211.6 {CPC text not modified}

Section 1211.7 Earthquake-Actuated Gas Shutoff Valves. Earthquake-actuated gas shutoff valves designed to automatically shut off the gas at the location of the valve in the event of a seismic disturbance and certified by the Stated Architect as conforming to California Code of Regulations, Title 24, Part 12, Chapter 12-16-1, shall be installed in all new buildings and in existing buildings that undergo alterations or additions that exceed $10,000.

SECTION 6. FMC CHAPTER 15.25 REPEALED AND REPLACED

Chapter 15.25 (Fremont Electrical Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.25.010 Title.

This chapter shall be known and may be cited as the “Fremont electrical code” or “FEC” and will be referred to in this chapter as “this code.”

Sec. 15.25.020 Adoption of the 2016 California Electrical Code without amendments.

The 2016 edition of the California Electrical Code (CEC) as published by the California Building Standards Commission is adopted as the Electrical Code of the city of Fremont, California, as if fully set out in this chapter, and is amended as set forth in this chapter. A copy of the 2016 CEC shall be maintained on file in the office of the city clerk.

Sec. 15.25.030 Amendment of-2016 CEC Article 110 (Requirements for Electrical Installations).

Article 110 of the 2016 California Electrical Code is amended as follows:

110.1-110.3(A)(1) {text not modified}

110.3(A)(2) Mechanical strength and durability, including, for parts designed to enclose and protect their equipment, the adequacy of the protection thus provided. Grounding electrodes, metallic raceways, or other metallic components of electrical systems, intended for direct contact with the earth shall be constructed of non-ferrous materials such as copper where highly corrosive conditions exist based on reports from a licensed soils engineer.

110.3(A)(3)-110.79 {text not modified}

Sec. 15.25.040 Amendment of 2016 CEC Article 230 (Services)

Article 230 of the 2016 California Electrical Code is amended as follows.

230.1-230.31 {text not modified}

230.32 Protection Against Damage. Underground service-lateral conductors shall be protected against damage in accordance with 300.5. Service-lateral conductors entering a building shall be installed in accordance with 230.6 or protected by a raceway wiring method identified in 230.43. Flexible utility connections prevent undue strain on utilities during settlement and in the event of an earthquake will reduce the likely hood of significant utility failures and reduce fire ignition and fuel sources.

230.33-230.212 {text not modified}

SECTION 7. FMC CHAPTER 15.30 REPEALED AND REPLACED

Chapter 15.30 (Fremont Existing Building Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.30.010 Title.

This chapter shall be known and may be cited as the "Fremont existing building code" or "FEBC" and will be referred to in this chapter as "this code."

Sec. 15.30.020 Adoption of the 2016 California Existing Building Code with Amendments.

The 2016 edition of the California Existing Building Code (CEBC) as published by the International Code Council is adopted as the Existing Building Code of the city of Fremont, California, without amendments, as if fully set out in this chapter. A copy of 2016 CEBC shall be maintained on file in the office of the city clerk.

Sec. 15.30.030 2016 CEBC Appendix Chapters Adopted.

The following Appendix Chapters and Divisions of the 2016 California Existing Building Code are adopted by the city of Fremont. The remaining Appendix Chapters are not adopted.

(a) Appendix A3 (Prescriptive Provisions for Seismic Strengthening of Cripple Walls and Sill Plate Anchorage of Light, Wood-Frame Residential Buildings).

Sec. 15.30.040 2016 CEBC Chapter 1, Division II is not Adopted.

Chapter 1, Division II of the 2016 California Existing Building Code is not adopted by the city of Fremont. Refer to FMC Sections 15.05 and 15.10.040 for Administration and Enforcement requirements. References to model codes in the adopted sections shall mean the corresponding California Codes as adopted by the city of Fremont.

Sec. 15.30.050 Amendment of 2016 CEBC Section 301 (General).

Section 301 of 2016 California Existing Building Code is amended as follows:

301 Scope.

Additions, alterations or repairs to an existing building or structure which are located within the Wildland-Urban Interface Fire Area shall comply with the requirements of FMC Section 15.10.230.

Exceptions: {CEBC text not modified}

301.1.1 – 301.5 {CEBC text not modified}

Sec. 15.30.060 Amendment of 2016 CEBC Section 401 (General).

Section 401 of 2016 California Building Code is amended as follows:

401.1 Scope. {CEBC text not modified}

Additions, alterations or repairs to an existing building or structure which are located within the Wildland-Urban Interface Fire Area shall comply with the requirements of FMC Section 15.10.250.

Exceptions: {CEBC text not modified}

401.1.1 – 401.5 {CEBC text not modified}

Sec. 15.30.070 Amendment to 2016 CEBC 407 (Change of Occupancy).

Section 407 of 2016 California Existing Building Code is amended as follows:

407.1 – 407.4.1 {CEBC text not modified}

407.5 AFES. When a change of occupancy results in a structure being reclassified to a higher occupancy category per Table 407.5.1, an automatic fire extinguishing system shall be installed throughout the structure.

***Table 407.5.1**

Relative Hazard	Occupancy Classifications
1 (Highest Hazard)	H
2	I-2, I-3, I-4
3	A,E, I-1,M,R-1,R-2,R-4
4	B,F-1,R-3,S-1
5 (Lowest Hazard)	F-2,S-2,U

* Ref: 2015 IEBC Table 1012.4

SECTION 8. FMC CHAPTER 15.40 REPEALED AND REPLACED

Chapter 15.40 (Fremont Housing Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.40.010 Title.

This chapter shall be known and may be cited as the “Fremont swimming pool and spa code” and will be referred to in this chapter as “this code.”

Sec. 15.40.020 Adoption of the 2015 International Swimming Pool and Spa Code (ISPSC) with Amendments.

Chapters 2 through 3 and Chapters 7 through 11 of the 2015 edition of the International Swimming Pool and Spa Code (ISPSC) as published by International Code Council is adopted with amendments as the Swimming Pool and Spa Code of the city of Fremont, California, as if fully set out in this chapter and is amended as provided in this chapter. A copy of the 2015 ISPSC shall be maintained on file in the office of the city clerk.

Sec. 15.40.030 Amendment of the 2015 International Swimming Pool and Spa Code (ISPSC) with Amendments.

The text of the 2015 International Swimming Pool and Spa Code, as adopted and amended by Section 15.50.020, is further amended to conform to the 2016 California Building Standards Code and as recommended by the Building Official as follows:

The codes, standards and references in this code should be revised as follows:

Delete the following references	Insert the following code references
• International Building Code	• 2016 California Building Code and 2016 California Residential Code
• International Mechanical Code	• 2016 California Mechanical Code
• National Electrical Code or NFPA 70	• 2016 California Electrical Code
• International Fire Code	• 2016 California Fire Code
• International Plumbing Code	• 2016 California Plumbing Code
• International Existing Building Code	• 2016 California Existing Building Code
• International Residential Code	• 2016 California Residential Code
• International Fuel Gas Code	• 2016 California Plumbing Code
• International Energy Conservation Code	• 2016 California Energy Code

Sec. 15.40.040 Amendment of the 2015 ISPSC Section 303 (Energy).

Section 303 of the 2015 ISPSC is amended as follows:

303.1 – 303.3 {ISPSC text not modified}

303.3.1 Operating time. The time switch or other control mechanism shall be installed as part of a pool water circulation control system that will allow all pumps to be set or programmed to run only during off-peak electric demand period, and for the minimum time necessary to maintain the water in the condition required by applicable public health standards.

303.4 Covers. Heated pools and outdoor spas shall be provided with a vapor retardant cover.

Exception: Where pools or spas deriving at least 60 percent of the annual heating energy from site solar or recovered energy.

Sec. 15.40.050 Amendment to 2015 ISPSC Section 305 (Barrier Requirements).

Section 305 of the 2015 ISPSC is amended as follows:

305.1 {ISPSC text not modified}

305.2 Outdoor swimming pools and spas. Other than those facilities regulated in Section 305.8, all outdoor pools and spas and indoor swimming pools shall be surrounded by a barrier that complies with Sections 305.2.1 through 305.7.

305.2.1 – 305.7 {ISPSC text not modified}

305.8 Private swimming pools. Whenever a building permit is issued for construction of a new swimming pool or spa, or any building permit is issued for remodeling of an existing pool or spa, at a private, single-family home, it shall be equipped with at least one of the following seven drowning prevention safety features:

1. The pool shall be isolated from access to a home by an enclosure that meets the requirements of Section 305.8.1.

2. The pool shall incorporate removable mesh pool fencing that meets ASTM F 2286 in conjunction with a gate that is self-closing and self-latching and can accommodate a key lockable device.

3. The pool shall be equipped with an approved safety pool cover that meets all requirements of the ASTM F 1346.

4. The residence shall be equipped with exit alarms on those doors providing direct access to the pool.

5. All doors providing direct access from the home to the swimming pool shall be equipped with a self-closing, self-latching device with a release mechanism placed no lower than 54 inches (1372 mm) above the floor.

6. Swimming pool alarms that, when placed in pools, will sound upon detection of accidental or unauthorized entrance into the water. These pool alarms shall meet and be independently certified to the ASTM F 2208 which includes surface motion, pressure, sonar, laser and infrared type alarms. For purposes of this section, "swimming pool alarms" shall not include swimming protection alarm devices designed for individual use, such as an alarm attached to a child that sounds when the child exceeds a certain distance or becomes submerged in water.

7. Other means of protection, if the degree of protection afforded is equal to or greater than that afforded by any of the devices set forth in items 1-4, and have been independently verified by an approved testing laboratory as meeting standards for those devices established by the ASTM or ASME.

Exceptions:

1. This section does not apply to any facility regulated by the State Department of Social Services even if the facility is also used as a private residence of the operator. Pool safety in those facilities shall be regulated pursuant to regulations adopted therefor by the State Department of Social Services.

2. Hot tubs or spas with locking safety covers that comply with the ASTM ES 13-89.

305.9 Enclosure. The enclosure for private swimming pools shall have all of the following characteristics:

1. Any access gates through the enclosure open away from the swimming pool and are self-closing with a self-latching device placed no lower than 60 inches (1524 mm) above the ground.

2. A minimum height of 60 inches (1524 mm).

3. A maximum vertical clearance from the ground to the bottom of the enclosure of 2 inches (51 mm).

4. Gaps or voids, if any, do not allow passage of a sphere equal to or greater than 4 inches (102 mm) in diameter.

5. An outside surface free of protrusions, cavities or other physical characteristics that would serve as handholds or footholds that could enable a child below the age of five years to climb over.

Sec. 15.40.060 Amendment to 2015 ISPSC Section 310 (Suction Entrapment Avoidance).

Section 310 of the 2015 ISPSC is amended as follows:

310.1 {ISPSC text not modified}

310.2 Construction Requirements for building a pool or spa. Whenever a building permit is issued for the construction a new private swimming pool or spa, the pool or spa shall meet all of the following requirements:

1. The suction outlet of the pool or spa for which the permit is issued shall be equipped to provide circulation throughout the pool or spa as prescribed in Paragraph 2.

2. The swimming pool or spa shall have at least two circulation drains per pump that shall be hydraulically balanced and symmetrically plumbed through one or more "T" fittings, and that are separated by a distance of at least three feet in any dimension between the drains. Suction outlets that are less than 12 inches across shall be covered with anti-entrapment grates, as specified in the ASME/ANSI Standard A 112.19.8, that cannot be removed except with the use of tools. Slots of openings in the grates or similar protective devices shall be of a shape, area and arrangement that would prevent physical entrapment and would pose any suction hazard to bathers.

3. Any backup safety system that an owner of a new swimming pool or spa may choose to install in addition to the requirements set forth in subdivisions (1) and (2) shall meet the standards as published in the document, "Guidelines for Entrapment Hazards: Making Pools and Spas Safer," Publication Number 363, March 2005, United States Consumer Products Safety Commission.

4. Whenever a building permit is for the remodel or modification of any existing swimming pool, toddler pool or spa, the permit shall require that the suction outlet of the existing swimming pool, toddler pool or spa be upgraded so as to be equipped with an anti-entrapment cover meeting current standards of the American Society for Testing and Materials (ASTM) or the American Society of Mechanical Engineers (ASME).

Authority: Health and Safety Code Section 18942(b)

Reference: Health and Safety Code Section 115928 AB 3305 (Statutes 1996, c.925); AB 2977 (Statutes 2006, c.926); AB 382 (Statutes 2007, c.596)

Sec. 15.40.070 Amendment to 2015 ISPSC Section 316 (Heaters)

Section 316 of the 2015 ISPSC is amended as follows:

316.1-316.2 {ISPSC text not modified}

316.2.1 (a) Certification by manufacturers. Heating systems and equipment shall be certified by the manufacturer that the heating system and equipment complies with the following:

1. Efficiency. A thermal efficiency that complies with the Appliance Efficiency Regulations in Title 20, Division 2, Chapter 4, Article 4 of the California Code of Regulations; and

2. Instructions. A permanent, easily readable and weatherproof plate or card that gives instruction for the energy efficient operation of the pool or spa heater and for the proper care of pool or spa water when a cover is used; and

3. Electric resistance heating. No electric resistance heating; and

Exception 1 to Section 110.4(a)4: Listed package units with fully insulated enclosures, and with tight-fitting covers that are insulated to at least R-6.

Exception 2 to Section 110.4(a)4: Pools or spas deriving at least 60 percent of the annual heating energy from site solar energy or recovered energy.

316.2.1 (b) Installation. Any pool or spa system or equipment shall be installed with all of the following;

1. Piping. At least 36 inches of pipe shall be installed between the filter and the heater or dedicated suction and return lines, or built-in or built-up connections shall be installed to allow for the future addition of solar heating equipment.

3. Directional inlets. The swimming pool shall have directional inlets that adequately mix the pool water.

316.3 – 316.5.2 {ISPSC text not modified}

Sec. 15.40.080 Amendment to 2015 ISPSC Section 504 (Pumps and Motors).

Section 504 of the 2015 ISPSC is amended as follows:

504.1 Emergency shutoff switch. One emergency shutoff switch shall be provided to disconnect power to circulation and jet system pumps and air blowers. Emergency shutoff switches shall be clearly labeled, accessible, located within sight of the spa and shall be located not less than 5 feet (1524 mm) but not greater than 10 feet (3048 mm) horizontally from the inside walls of the spa.

504.1.1 {ISPSC text not modified}

<u>SECTION 9.</u> FMC CHAPTER 15.44 ADDED

Chapter 15.44 (Fremont Energy Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is added to read as follows:

Sec. 15.44.010 Title.

This chapter shall be known and may be cited as the "Fremont energy code" or "FEnC" and will be referred to in this chapter as "this code."

Sec. 15.44.020 Adoption of the 2016 California Energy Code With Amendments.

The 2016 edition of the California Energy Code (CEnC) as published by the State of California is adopted as the Energy Code of the city of Fremont, California, as if fully set out in this chapter, and is amended as set forth in this chapter. A copy of the 2016 CEnC shall be maintained on file in the office of the city clerk.

Sec. 15.44.030 Amendment to 2016 CEnC Table 140 (Performance and Prescriptive Compliance Approaches).

Table 140.7 of the 2016 California Energy Code is amended by modifying the following rows below the header to read as follows. The remainder of Table 140.7B is unchanged:

Lighting Application	Lighting Zone 0	Lighting Zone 1	Lighting Zone 2	Lighting Zone 3	Lighting Zone 4
Primary Entrances to Senior Care Facilities, Police Stations, Hospitals, Fire Stations, and Emergency Vehicle Facilities	Not applicable	20 watts	40 watts	60 watts	80 watts
Drive up Windows	Not applicable	30 watts	40 watts	60 watts	100 watts
Outdoor Sales Frontage	Not applicable	No Allowance	15 W/linear ft	25 W/linear ft	30 W/linear ft
Outdoor Sales Lot	Not applicable	0.100 W/ft^2	0.250 W/ft^2	0.500 W/ft^2	1.000 W/ft^2
Vehicle Service Station Hardscape	Not applicable	0.010 W/ft^2	0.100 W/ft^2	0.150 W/ft^2	0.200 W/ft^2
Non-sales Canopies and Tunnels	Not applicable	0.080 W/ft^2	0.160 W/ft^2	0.300 W/ft^2	0.400 W/ft^2
Outdoor Dining	Not applicable	0.010 W/ft2	0.100 W/ft2	0.150 W/ft2	0.200 W/ft2

SECTION 10. FMC CHAPTER 15.45 REPEALED AND REPLACED

Chapter 15.45 (Fremont Abatement of Dangerous Buildings Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.45.010 Title.

This chapter shall be known and may be cited as the "Fremont property maintenance code" or "FPMC" and will be referred to in this chapter as "this code."

Sec. 15.45.020 Adoption of the 2015 International Property Maintenance with Amendments.

The 2015 edition of the International Property Maintenance Code as published by the International Code Council is adopted as the Fremont Property Maintenance Code of the city of Fremont, California, as if fully set out in this chapter and is amended as provided in this chapter. A copy of the 2015 FPMC shall be maintained on file in the office of the city clerk.

Sec. 15.45.030 2015 International Property Maintenance Code Appendix Chapter Adopted.

The following Appendix Chapters of the 2015 International Property Maintenance Code are adopted by the city of Fremont:

(a) Appendix A (Boarding Standard).

Sec. 15.45.040 Amendments of the 2015 International Property Maintenance Code.

The text of the 2015 International Property Maintenance Code, as adopted and amended by Section 15.45.020, is further amended to conform to the current California Building Standards Code and as recommended by the building official as follows:

Delete the following references	**Insert the following code references**
• International Building Code	• Current California Building Code and current California Residential Code
• International Mechanical Code	• Current California Mechanical Code
• National Electrical Code	• Current California Electrical Code
• International Fire Code	• Current California Fire Code
• International Plumbing Code	• Current California Plumbing Code
• International Existing Building Code	• Current California Existing Building Code
• International Zoning Code	• City of Fremont- Zoning Ordinance
• International Fuel Gas Code	• Current California Plumbing Code
• Name of jurisdiction	• City of Fremont

Delete the following references	Insert the following code references
• Jurisdiction to insert appropriate schedule	• Current fees that are established by resolution of the city council.
• Board of appeals	• Hearing officer appointed by the city manager or designee
• Code Official or Health Official	• Building Official

Sec. 15.45.50 Amendment of 2015 IPMC Section 102 (Applicability).

Section 102 of the 2015 IPMC is amended as follows:

102.1-102.7 {IPMC text not modified}

102.7.1 Conflicts. Where conflicts occur between provision of this code and the referenced standards, the provisions of this code shall apply. Where conflicts occur between the provisions of this code and California Statutes, the provisions of the latter shall apply.

102.8-102.10 {IPMC text not modified}

Sec. 15.45.60 Amendment of 2015 IPMC Section 103 Department of Property Maintenance Inspection.

Section 103 Department of Property Maintenance Inspection of the 2015 IPMC is amended as follows:

103.1 General. The Building Official in charge of the Fremont Building & Safety Division shall be known as the code official in this chapter.

103.2 {IPMC text not modified}

103.3 Deputies. The code official shall have the authority to appoint one or more deputies. Such employees shall have the powers as delegated by the code official.

103.4 Liability. The code official or employee charged with the enforcement of this code, while acting for the jurisdiction, in good faith and without malice in the discharge of the duties required by this code or other pertinent law or ordinance, shall not thereby be rendered liable personally, and is hereby relieved from all personal liability for any damage accruing to persons or property as a result of an act or by reason of an act or omission in the discharge of official duties. Any suit instituted against any officer or employee because of an act performed by that officer or employee in the lawful discharge of duties and under the provisions of this code shall be defended by the city until the final termination of the proceedings. The code official or any subordinate shall not be liable for costs in an action, suit or proceeding that is instituted in pursuance of the provisions of this code.

103.5 {IPMC text not modified}

Sec. 15.45.70 Amendment of 2015 IPMC Section 104 (Duties and Powers of the Code Official).

Section 104 of the 2015 IPMC is amended as follows:

104.1-104.2 {IPMC text not modified}

104.3 Right of entry. Where it is necessary to make an inspection to enforce the provisions of this code, or whenever the code official has reasonable cause to believe that there exists in a structure or upon a premises a condition in violation of this code, the code official is authorized to enter the structure or premises at reasonable times to inspect or perform the duties imposed by the code, provided that if such structure or premises is occupied the code official shall present credentials to the occupant and request entry. If such structure or premises is unoccupied, the code official shall first make a reasonable effort to locate the owner, owner's authorized agent, or other person having charge or control of the structure or premises and request entry. If entry is refused, the code official shall have recourse to the remedies provided by law to secure entry.

Sec. 15.45.80 Amendment of 2015 IPMC Section 106 (Violations).

Section 106 of the 2015 IPMC is amended as follows:

106.1 Unlawful acts. It is hereby declared to be unlawful and a public nuisance for any person, firm or corporation to erect, construct, enlarge, alter, repair, move, improve, remove, convert or demolish, equip, use, occupy or maintain any premise, building, structure or building service equipment, or cause or permit the same to be done in violation of this code or this division.

106.2 Notice of violation. The code official shall serve a notice of violation in accordance with Section 107.

106.3 Prosecution of violation. Any person failing to comply with a notice of violation served in accordance with Section 107 shall be deemed guilty of a misdemeanor, but may be charged with an infraction at the discretion of the city attorney, or civil infraction enforceable under Chapter 1.20 as determined by the city and the violation shall be deemed a strict liability offense. If the notice of violation is not complied with, the code official shall institute the appropriate administrative, civil, or criminal proceeding to restrain, correct or abate such violation, or to require the removal or termination of the unlawful occupancy of the structure in violation of this code or of the order or direction made pursuant thereto.

106.4 Separate Offenses. Each day during any portion of which any violation of this ordinance is committed or continued by such person shall constitute a separate offense and shall be punishable as provided in this code and Title 15.

106.5 Abatement of violation. The city may abate a violation of this code pursuant to the abatement process set forth in Chapter 8.60.

Sec. 15.45.90 Amendment of 2015 IPMC Section 107 (Notices and Orders).

Section 107 of the 2015 IPMC is amended as follows:

107.1 {IPMC text not modified}

107.2 Form. Such notice prescribed in Section 107.1 shall be in accordance with all of the following:

1. Be in writing, bearing title letters at least one inch high reading “NOTICE AND ORDER TO ABATE NUISANCE”;

2. Include a description of the real property sufficient for identification.

3. Include a statement of the violation or violations and why the notice is being issued.

4. Include a correction order allowing a reasonable time to make the repairs and improvements required to bring the dwelling unit, structure, or premises into compliance with the provisions of this code.

5. Inform the owner or owner’s authorized agent of the right to appeal and failure to appeal shall constitute a waiver of their right to an administrative hearing to contest the violation, nuisance determination, the civil penalty, or the abatement cost.

6. Include a statement of the city’s right to file a lien against the real property in accordance with FMC Chapter 8.60.

107.3 Method of service. Such notice shall be deemed to be properly served if a copy thereof is:

1. Delivered personally;

2. Sent by certified or first class mail addressed to the property owner as listed on the last equalized assessment roll of the county recorder or owner as determined by the code official.

3. If the mailed notice is returned showing that the letter was not delivered, a copy of the notice shall be posted in a conspicuous place on in or about the structure or premises affected by such notice.

Proof of services of notices shall be certified at the time of service by a written declaration under penalty of perjury executed by the person effecting service, declaring the time, date, and manner in which service was made. The declaration, together with any receipt card returned in acknowledgment of receipt by certified mail shall be affixed to the copy of the notice and order retained by the city. The failure of any person to receive any notice required under this chapter shall not affect the validity of any proceedings taken under this chapter.

107.4 Unauthorized tampering. Signs, tags, placards, notices, or seals posted or affixed by the code official shall not be mutilated, destroyed, tampered with or removed without authorization from the code official.

107.5-107.6 {IPMC text not modified}

Sec. 15.45.100 Amendment of 2015 IPMC Section 108 (Unsafe Structures and Equipment).

Section 108 of the 2015 IPMC is amended as follows:

108.1 General. When a structure or equipment is found by the code official to be unsafe, or when a structure is found unfit for human occupancy, or is found unlawful, such structure shall be condemned and shall be posted and vacated in accordance with this section and declared to be a public nuisance and the violations shall be abated by repair, rehabilitation, demolition or removal pursuant to the provisions of this code.

Sections 108.1.1 -108.1.3 {IPMC text not modified}

108.1.4 Unlawful structure. An unlawful structure is one found in whole or in part to be occupied by more persons than permitted under this code, or was erected, altered, occupied or maintained contrary to Title 15; or one that is partially constructed, reconstructed or demolished upon which work is abandoned. Work is deemed abandoned when there is no valid building or demolition permit.

Section 108.1.5 {IPMC text not modified}

Section 108.2 Closing of vacant structures. If the structure is vacant and unfit for human habitation and occupancy, and is not in danger of structural collapse, the code official is authorized to post a placard of condemnation on the premises and order the structure boarded according to Appendix A or fenced, so as not to be an attractive nuisance and/or to prevent entry. Upon failure of the owner or owner's authorized agent to board the premises within the time specified in the order, the code official shall cause the premises to be boarded and secured through any available public agency or by contract or arrangement by private persons and the cost for such boarding shall be a debt owed by the owner, shall be charged against the real property upon which the structure is located, shall be a lien upon such real property and shall be collected by any legal means.

108.2.1 {IPMC text not modified}

108.3 Notice. Whenever the code official has condemned a structure or equipment under the provisions of this section, the code official shall obtain a preliminary or survey title report as to the building, structure, or premises, which shall identify all owners of record, holders of mortgages, deeds of trust or other liens and encumbrances of record. In accordance with Section 107.3 of this code, the code official shall serve the persons listed in the preliminary or survey title report with notice described in Section 107.2 of this code. In addition, the notice shall be posted in a conspicuous place on or about the structure or premises affected by such notice. If the notice pertains to equipment, it shall be placed on the condemned equipment.

108.4 {IPMC text not modified}

108.4.1 Placard removal. The code official shall remove the condemnation placard whenever the defect or defects upon which the condemnation and placarding action was based has been eliminated. Any person who defaces or removes a condemnation placard without the approval of the code official shall be subject to the penalties provided by this code; applicable state law and Title 15.

108.5 Prohibited occupancy. Any occupied structure condemned and placarded by the code official shall be vacated as ordered by the code official. Any person who occupies a placarded premises or operates placarded equipment, and any owner, owner's authorized agent or person responsible for the premises who lets anyone occupy a condemned premises or operate condemned equipment shall be liable for the penalties provided by this code and Title 15.

108.6 {IPMC text not modified}

108.7 Recordation of notice and order. If the dangerous, damaged or substandard building is not repaired or demolished by the owner within the prescribed time(s), and no appeal has been properly and timely filed, the code official shall file in the office of the county recorder a certificate describing the property and certifying (i) that the building is a substandard building and (ii) that the owner has been so notified, if such recordation has not already been made during the course of the proceedings.

Whenever the corrections ordered shall thereafter have been completed or the building demolished so that it no longer exists as a substandard building described in the certificate, the code official shall file a new certificate with the county recorder certifying that the building has been demolished or all required corrections have been made so that the building is no longer substandard, whichever is appropriate.

Sec. 15.45.110 Amendment of 2015 IPMC Section 109 (Emergency Measures).

Section 109 of the 2015 IPMC is amended as follows:

109.1-109.4 {IPMC text not modified}

109.5 Costs of emergency repairs. Costs incurred in the performance of emergency work may be paid by the city. Such costs shall be a debt owed to the city by the owner. The city attorney may institute appropriate legal action against the owner of the premises or the owner's authorized agent where the unsafe structure is or was located for the recovery of such costs.

109.6 Appeal. Once the emergency work has been completed, the owner may appeal the need for the emergency repairs and/or the costs for such work, in the manner provided in Sections 8.60.120 and 8.60.190 within seven calendar days after service according to Section 107 of this code of the statement of costs.

Sec. 15.45.120 Amendment of 2015 IPMC Section 110 (Demolition).

Section 110 of the 2015 IPMC is amended as follows:

110.1-110.2 {IPMC text not modified}

110.3 Failure to comply. If the owner of a premises or owner's authorized agent fails to comply with a demolition order within the time prescribed, the code official may cause the structure to be demolished and removed according to the procedure for specific abatement of nuisance in Chapter 8.60.

110.4 {IPMC text not modified}

Sec. 15.45.130 Amendment of 2015 IPMC Section 111 (Means of Appeal).

Section 111 of the 2015 IPMC is amended as follows:

111.1 Application for appeal. Any person directly affected by a decision of the code official or a notice or order issued under this code may appeal that decision, notice or order by filing an appeal with the city clerk within seven calendar days of the date of service of that decision, notice, or order. The appeal shall be based on a claim that the true intent of this code or the rules legally adopted thereunder have been incorrectly interpreted, the provisions of this code do not fully apply, or the requirements of this code are adequately satisfied by other means. The appeal shall identify the real property, state the grounds for the appeal, and state all material facts in support of the appeal.

111.2 Notice of hearing. Notice of hearing and the hearing shall be conducted as provided for in Chapter 8.60, Sections 8.60.130 through 8.60.150.

111.2.1-111.6.2 deleted.

111.7 Court review. Judicial review of the hearing officer's decision shall be commenced in accordance with Cal. Code of Civil Procedure § 1094.6 no later than 90 calendar days after the decision is signed. Cal. Code of Civil Procedure § 1094.6 is hereby adopted for purposes of this Title. Review shall be in accordance with Cal. Code of Civil Procedure § 1094.5.

111.8 deleted

Sec. 15.45.140 Amendment of 2015 IPMC Section 112 (Stop Work Order).

Section 112 of the 2015 IPMC is amended as follows:

112.1-112.3 {IPMC text not modified}

112.4 Failure to comply. Any person who continues any work after having been served with a stop work order, except such work as that person is directed to perform to remove a violation or unsafe condition, shall be liable for civil penalties pursuant to Fremont Municipal Code Chapter 1.20.

Sec. 15.45.150 Amendment of 2015 IPMC Section 202 (General Definitions).

The following definitions are amended or added to Section 202 of the 2015 IPMC. The remaining definitions are not modified.

GARBAGE. Garbage shall be defined pursuant to Fremont Municipal Code Section 8.45.045 (Municipal Solid Waste, defined)

INOPERABLE MOTOR VEHICLE. A vehicle which cannot be driven upon the public streets for reasons, including but not limited to being unlicensed, wrecked, abandoned, in a state of disrepair, incapable of being moved under its own power or is prohibited from being operated on a public street or highway for any reason pursuant to the provisions of the California Vehicle Code.

RUBBISH. Rubbish shall be defined pursuant to Fremont Municipal Code Section 8.45.045 (Municipal Solid Waste, defined)

TEMPORARY. Temporary shall mean buildings, facilities, or structures intended for use at one location for not more than six months for the purpose of this code only.

Sec. 15.45.160 Amendment of 2015 IPMC Section 302 (Exterior Property Areas).

Section 302 is amended as follows:

302.1 Sanitation. The owner or authorized agent shall maintain the property exterior and premises in a clean, safe and sanitary condition. Such owner or authorized agent shall remain liable for violations thereof regardless of any contract or agreement with any third party regarding such property. The occupant may also be held jointly and severally liable for causing or contributing violations of this section.

302.2 Grading and drainage. All premises shall be graded and maintained to prevent the erosion of soil and prevent the accumulation of stagnant water thereon, or within any structure located thereon. Excess or concentrated drainage shall be contained on site or directed to the nearest practicable drainage facility approved by the code official.

Exception: Approved retention areas and reservoirs.

302.3 Sidewalks and driveways. Sidewalks, walkways, stairs, driveways, parking spaces and similar areas shall be kept in proper state of repair, and maintained free from hazardous conditions. The owner or owner's authorized agent of any building, lot or premises within the city shall maintain the sidewalks and/or walkways located upon such premises that are accessible to the general public and the public sidewalks between such premises and any adjacent public street or alley in a clean, safe sanitary, and in a proper state of repair, free from hazardous conditions. Maintenance shall include the removal and proper disposal of any unsightly or unsanitary conditions such as accumulations of garbage, refuse, rubbish, litter, dirt, gum or other sticky substances or items, which have been dropped or spilled upon the sidewalks.

302.4 Weeds. No owner, authorized agent, lessee or occupant or other person having charge or control of any building, lot or premises within the city shall permit weeds exceeding six inches in height to remain or accumulate upon such premises or upon public sidewalks or streets or alleys between such premises and the centerline of any public street or alley. All noxious weeds shall be prohibited. Weeds shall be defined per Fremont Municipal Code Section 8.25.010.

Upon failure of the owner or authorized agent having charge of a premises to cut and destroy weeds after service of a warning notice of violation, they shall be subject to prosecution in accordance with Section 106.3 and as prescribed by the city. Upon failure to comply with the warning notice of violation, any duly authorized employee of the city or contractor hired by the city shall be authorized to enter upon the premises and cut and destroy the weeds growing thereon, and the costs of such removal shall be paid by the owner or authorized agent responsible for the premises.

302.5-302.7 {IPMC text not modified}

302.8 Motor vehicles {IPMC text not modified}

Exception: An owner, authorized agent, lessee, or occupant of the premises may repair, wash, clean, or service personal property, provided they comply with Fremont Municipal Code Title 18 (Zoning Regulations) and any other applicable requirements or laws.

302.9 {IPMC text not modified}

Sec. 15.45.170 Amendment of 2015 IPMC Section 303 (Swimming Pools, Spas, and Hot Tubs).

Section 303 of the 2015 IPMC is amended as follows:

303.1 {IPMC text not modified}

303.2 Enclosures. Except as provided for in other regulations, private swimming pools, hot tubs, spas and ponds, containing water more than 18 inches (457 mm) in depth shall be completely surrounded by a fence or barrier 48 inches (1219 mm) in height above the finished ground level measured on the side of the barrier away from the pool. Gates and doors in such barriers shall be self-closing and self-latching. Where the self-latching device is less than 54 inches (1372 mm) above the bottom of the gate, the release mechanism shall be located on the pool side of the gate. Self-closing and self-latching gates shall be maintained such that the gate will positively close and latch when released from an open position of 6 inches (152 mm) from the gatepost. No existing pool enclosure shall be removed, replaced, changed or maintained in a manner that reduces its effectiveness as a safety barrier.

Exception: Pool fences or barriers that do not meet the above minimum requirements can remain as long as the fence or barrier complied with the building code provisions at time of building permit and passed the final inspection from the city.

Sec. 15.45.180 Amendment of 2015 IPMC Section 304 (Exterior Structure).

Section 304 Exterior structure of the 2015 IPMC is amended as follows:

304.1-304.2 {IPMC text not modified}

304.3 deleted.

304.4-304.13.2 {IPMC text not modified}

304.14 Insect screens. Every door, window and other outside opening required for ventilation of habitable rooms, food preparation areas, food service areas or any areas where products to be included or utilized in food for human consumption are processed, manufactured, packaged or stored shall be supplied with approved tight fitting screens of minimum 16 mesh per inch (16 mesh per 25 mm), and every screen door used for insect control shall have a self-closing device in good working condition.

Exception: Screens shall not be required where other approved means, such as air curtains or insect repellent fans, are employed.

304.15 Doors. All exterior doors, door assemblies, including weather stripping, thresholds and hardware, shall be maintained in good condition. Locks at all entrances to dwelling units and sleeping units shall tightly secure the door. Locks on means of egress doors shall be in accordance with Section 702.3.

304.16 Under-Floor areas. Under-floor access doors and ventilation openings shall be maintained to prevent the entrance of rodents, rain and surface drainage water. Doors shall be tight fitting and ventilation openings shall be properly screened with corrosion-resistant wire mesh with openings not exceeding 1/4 inch in any dimension or alternate approved materials pursuant to current CBC 1203.4.1.

304.17-304.18.1 {IPMC text not modified}

304.18.2 Windows. Operable windows located in whole or in part within 12 feet above ground level or a walking surface below that provides access to a dwelling unit, rooming unit or housekeeping unit that is rented, leased or let shall be equipped with a window sash locking device. Vacant/abandoned buildings shall provide internal window coverings to prevent easy view of the building interior.

304.18.3-304.19 {IPMC text not modified}

Sec. 15.45.190 Amendment of 2015 IPMC Section 309 (Pest Elimination).

Section 309 of the 2015 IPMC is amended as follows:

309.1 Infestation. All structures shall be kept free from insect, rodent and vermin infestation. When an insect, rodent or vermin infestation is brought to the attention of the code official, he or she may require the owner or agent having charge or control of the building, lot or premise to hire a licensed exterminator or other qualified professional to inspect the building, lot or premise and provide a written report verifying the presence and severity of such infestation including in the report a recommendation for proper extermination of the infestation. All structures in which insect, rodent or vermin infestations are found shall be promptly exterminated by approved processes that will not be injurious to human health. After the extermination of the infestation is complete, the code official may request a written notice from a licensed exterminator or other qualified professional attesting to the completion and success of the recommended extermination procedures. After the infestation is eliminated, proper precautions shall be taken to prevent reinfestation.

309.2 Owner. The owner of any structure shall be responsible for pest elimination within the structure prior to renting or leasing the structure, and maintaining the structure and premise in a rodent or pest-free condition. The owner does not have to remedy the condition if it is caused by an occupant who substantially fails to maintain his occupied area of the structure or premise as “clean and sanitary as the condition of the structure of premise permits”, causes or contributes to the infestation in any substantial way, or interferes with the owner’s ability to remedy or exterminate the condition.

309.3 - 309.5 Deleted

Sec. 15.45.200 Amendment of 2015 IPMC Section 505 (Water System).

Section 505 of the 2015 IPMC is amended as follows:

505.1-505.3 {IPMC text not modified}

505.4 Water heating facilities. Water heating facilities shall be properly installed, maintained and capable of providing an adequate amount of water to be drawn at every required sink, lavatory, bathtub, shower and laundry facility at a minimum temperature of 110° F (43°C). A gas-burning water heater shall not be located in any bathroom, toilet room, bedroom or other occupied room normally kept closed, unless the installation complies with Chapter 5 of the current California Plumbing Code and Section 904 of the current California Mechanical Code. An approved combination temperature and pressure-relief valve discharge pipe shall be properly installed and maintained on water heaters.

Sec. 15.45.210 Amendment of 2015 IPMC Section 602 (Heating Facilities).

Section 602 of the 2015 IPMC is amended as follows:

602.1 {IPMC text not modified}

602.2 Residential occupancies. Dwellings shall be provided with heating facilities capable of maintaining a room temperature of 68°F (20°C) in all habitable rooms, bathrooms and toilet rooms as measured per IPMC Section 602.5. Cooking appliances or fireplaces shall not be used, nor shall portable space heaters be used, as a means to provide required heating.

602.3 Heat Supply. Every owner and operator of any building who rents, leases or lets one or more dwelling units or sleeping units on terms, either expressed or implied, to furnish heat to the occupants thereof shall supply heat to maintain a minimum temperature of 68°F (20°C) in all habitable rooms, bathrooms and toilet rooms.

Exceptions:

1. When the outdoor temperature is below the winter outdoor design temperature for the locality, maintenance of the minimum room temperature shall not be required provided that the heating system is operating at its full design capacity. The winter outdoor design temperature for the locality shall be 32°F.

602.4 deleted.

Sec. 15.45.220 Amendment of 2015 IPMC Section 604 (Electrical Facilities).

Section 604 of the 2015 IPMC is amended as follows:

604.1-604.2 {IPMC text not modified}

604.3 Electrical system hazards. Where it is found that the electrical system in a structure constitutes a hazard to the occupants or the structure by reason of inadequate service, improper fusing, insufficient receptacle and lighting outlets, improper wiring or installation including the improper use of extension cords as permanent wiring, deterioration or damage, or for similar reasons, the code official shall require the defects to be corrected to eliminate the hazard.

604.3.1-604.3.2.1 {IPMC text not modified}

Sec. 15.45.230 Amendment of 2015 IPMC Section 702 (Means of Egress).

Section 701 of the 2015 IPMC is amended as follows:

702.1 General. A safe, continuous and unobstructed path of travel shall be provided from any point in a building or structure to the public right-of-way. Means of egress shall comply with the current California Building Code.

702.2-702.4 {IPMC text not modified}

SECTION 11. FMC CHAPTER 15.47 REPEALED AND REPLACED

Chapter 15.47 (Fremont Residential Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.47.010 Title

This chapter shall be known and may be cited as the "Fremont Residential Building Code" or "FRBC" and will be referred to in this chapter as "this code."

Sec. 15.47.020 Adoption of the 2016 CRC with Amendments.

The 2016 edition of the California Residential Code (CRC) as published by the California Building Standards Commission is adopted with amendments as the Residential Code of the city of Fremont, California, as if fully set out in this chapter, and is amended as set forth in this chapter. A copy of the 2016 CRC shall be maintained on file in the office of the city clerk.

Sec. 15.47.030 Adoption of Certain 2016 CRC Appendix Chapters.

The following Appendix Chapters of the 2016 California Building Code are adopted by the city of Fremont. The remaining Appendix Chapters are not adopted.

(a) Appendix Chapter H (Patio Covers)

(b) Appendix Chapter J (Existing Buildings and Structures)

(c) Appendix Chapter K (Sound Transmission)

(d) Appendix Chapter V (Swimming Pool Safety Act)

Sec. 15.47.040 Administration of 2016 Residential Building Code

Chapter 1, Division II of the 2016 California Residential Code is not adopted by the city of Fremont. Refer to FMC Sections 15.05 and 15.10.040 for Administration and Enforcement requirements.

Sec. 15.47.050 Amendment of 2016 CBC Section R301 (Design Criteria).

Section R301 of the 2016 California Residential Code is amended as follows:

R301.1 – R301.2.2.2.4 {CRC text not modified}

R301.2.2.2.5 (Irregular Buildings)

1. Where exterior shear wall lines or braced wall panels are not in one plane vertically from the foundation to the uppermost story in which they are required.

2.Where a section of floor or roof is not laterally supported by shear walls or braced wall lines on all edges.

Exception: Portions of floors that do not support shear walls or braced wall panels above, or roofs, shall be permitted to extend not more than 6 feet (1829 mm) beyond a shear wall or braced wall line.

3. When the end of a braced wall panel occurs over an opening in the wall below and ends at a horizontal distance greater than 1 foot (305 mm) from the edge of the opening. This provision is applicable to shear walls and braced wall panels offset in plane and to braced wall panels offset out of plane as permitted by the exception to item 1.

4. Where an opening in a floor or roof exceeds the lesser of 12 feet (3658 mm) or 50 percent of the least floor or roof dimension

5. Where portions of a floor level are vertically offset.

6. – 7. {CRC text not modified}

Exception: deleted

R301.2.2.3 – R301.2.2.3.7 {CRC text not modified}

R301.2.2.3.8. Mechanical, electrical, or plumbing components and equipment shall be anchored to the structure. Anchorage of the components and equipment shall be designed to resist loads in accordance with the California Building Code and ASCE 7, except where the component is positively attached to the structure and flexible connections are provided between the component and associated ductwork, piping, and conduit; and either

1. The component weighs 400 lbs. (1,780 N) or less and has a center of mass located 4 ft (1.22 m) or less above the supporting structure; or

2. The component weighs 20 lbs. (89N) or less or, in the case of a distributed system, 5 lb/ft (73 N/m) or less.

R301.2.2.4 – R301.8 {CRC text not modified}

Sec. 15.47.060 Amendment of 2016 CBC Section R302 (Fire-Resistant Construction).

Section R302 of the 2016 California Residential Code is amended as follows:

R302.1 – 302.2.4 {CRC text not modified}

R302.3 Two-family dwellings {CRC text not modified}

Exceptions:

1. deleted.

2. {CRC text not modified}

R302.3.1 – R302.5 {CRC text not modified}

R302.5.1 {CRC text not modified}

Exception: deleted

R302.5.2 – R302.14 {CRC text not modified}

Table R302.6 is amended as follows:

TABLE R302.6
DWELLING-GARAGE AND/OR CARPORT SEPARATION

SEPARATION	MATERIAL
From the residence and attics	Not less than 5/8-inch Type X gypsum board or equivalent applied to the garage side
From all habitable rooms above the garage or	Not less than 5/8-inch Type X gypsum board

carport	or equivalent
Structure(s) supporting floor/ceiling assemblies used for separation required by this section	Not less than 5/8-inch Type X gypsum board or equivalent
Garages located less than 3 feet from a dwelling unit on the same lot	Not less than 5/8-inch Type X gypsum board or equivalent applied to the interior side of exterior walls that are within this area

Sec. 15.47.070 Amendment to 2016 CRC Section R313 (Automatic Fire Sprinkler Systems).

Section R313 of the 2016 California Residential Code is amended as follows:

R313.1 Townhouse automatic fire sprinkler systems. Automatic sprinkler systems shall be installed in townhouses.

Exception: An automatic residential fire sprinkler system shall not be required when additions or alterations are made to existing townhouses that do not have an automatic residential fire sprinkler system installed unless as required by FMC Section 15.35.140.

R313.1.1 Design and Installation. Automatic residential fire sprinkler systems for townhouses shall be designed and installed in accordance with Section R313 and as amended by FMC Section 15.35.140.

R313.2 One- and two-family dwellings automatic fire systems. An automatic residential fire sprinkler system shall be installed in one- and two-family dwellings.

Exception: An automatic residential fire sprinkler system shall not be required for addition or alteration to existing buildings that are not already provided with an automatic residential sprinkler system unless as required by FMC Section 15.35.140.

R313.2.1 Design and Installation. Automatic residential fire sprinkler systems shall be designed and installed in accordance with Section 313 and as amended by FMC Section 15.35.140.

R313.3 – R313.3.8.2 deleted

Sec. 15.47.080 Amendment to 2016 CRC Section R322 (Flood-Resistant Construction).

Section R322 of the 2016 California Residential Code is amended as follows:

R322.1 – R322.1.3 {CRC text not modified}

R322.1.4 Determination of design flood elevation. See FMC Section 15.10.310 for design flood elevation.

R322.1.4.1 – R322.3.7 {CRC text not modified}

Sec. 15.47.090 Amendment to 2016 CRC Section R337.1 (Scope, Purpose and Application).

Section R337.1.1 of the 2016 California Residential Code is amended as follows:

R337.1.1 Scope. This chapter applies to building materials, systems and or assemblies used in the exterior design and construction of new or existing buildings or structures erected, constructed, altered, or moved within a Wildland-Urban Interface Fire area as defined in Section R337.2A.

R337.1.2 {CRC text not modified}

R337.1.3 Application. New or existing buildings or structures erected, constructed, altered, or moved in any Fire Hazard Severity Zone or any Wildland-Urban Interface Fire Area designated by the enforcing agency constructed after the application date shall comply with the provisions of this chapter.

Exceptions*:*

1. {CRC text not modified}

2. {CRC text not modified}

3. {CRC text not modified}

4. - deleted.

R337.1.3.1 – R337.1.5 {CRC text not modified}

Sec. 15.47.100 Amendment to 2016 CRC Section R337.2 (Definitions).

Section R337.2 of the 2016 California Residential Code is amended by modifying the following definitions. The remaining definitions are not modified.

LOCAL AGENCY VERY-HIGH FIRE HAZARD SEVERITY ZONE means those areas designated by the city of Fremont as Very High Fire Hazard Severity Zones in Fremont Municipal Code Title 15, Chapter 15.65.

WILDLAND-URBAN INTERFACE FIRE AREA is a geographical area identified by the state as a “fire hazard severity zone” in accordance with Public Resources Code Sections 4201 through 4204 and Government Code Sections 51175 through 51189, and includes those areas designated by the city of Fremont as very high fire hazard severity zones in Fremont Municipal Code Title 15, Chapter 15.65.

Sec. 15.47.110 Amendment to 2016 CRC Section R337.5 (Roofing).

Section R337.5 of the 2016 California Residential Code is amended and additional sections added as follows:

R337.5.1 – R337.5.2 {CRC text not modified}

R327.5.2.1 Wildland Urban-Interface Fire Area. The roof covering of any new structure or the re-roofing of any existing building within Wildland-Urban Interface Fire Area, regardless of the type of construction or occupancy classification, shall be a fire-retardant roof covering that is at least Class A. All alteration, repair, replacement or reroofing shall conform to the applicable provisions of the 2016 California Residential Code, Chapter 8 "Roof-Ceiling Construction" and any other applicable engineering requirements, including Chapter 9, "Roof Assemblies".

R337.5.3 – R337.5.4 {CRC text not modified}

Sec. 15.47.120 Amendment to 2016 CRC Section R337.7 (Exterior Covering).

Section R337.7 of the 2016 California Residential Code is amended as follows:

R337.7.1 – R337.7.3.1 {CRC text not modified}

R337.7.3.2 Exterior wall covering. All exterior faces of the exterior walls shall be of an assembly qualified for exterior face of recognized one-hour fire resistive assemblies. All exterior wall coverings shall meet a Class I flame spread requirement and be installed over materials approved for one-hour fire-resistive construction.

Exception: Class I flame spread requirement may be waived for additions not to exceed 50%, cumulatively over the life of the structure, of the existing structure including garage areas with 1-hour fire resistive exterior wall assembly.

R337.7.4 – R337.7.8 {CRC text not modified}

R337.7.9 Utilities. Utilities, pipes, furnaces, water heaters or other mechanical devices located in an exposed under-floor area of a building or structure shall be enclosed with material as required for exterior, one-hour, fire-resistive construction. Adequate covered access opening for servicing such utilities shall be provided as required by appropriate codes.

R337.7.10 Historical buildings. Repairs, alterations and additions necessary for the preservation, restoration, rehabilitation or continued use of a building or structure may be made without conformance to all the requirements of this code when authorized by the Building Official, provided:

1. The building or structure conforms to Part 8, Title 24, of the California Code of Regulations; and

2. A fire protection plan is implemented so that the building or structure will be no more of a fire hazard than any new building. The plan must be prepared and signed by a

registered Fire Protection Engineer. The plan must be approved by the Building Official and fire chief prior to the commencement of any work.

Sec. 15.47.130   Amendment to 2016 CRC Section R401 (General).

Section R401 of the 2016 California Residential Code is amended as follows:

R401.1 – R401.3 {CRC text not modified}

R401.4 Soils tests. Exception is added at end of the CRC text as follows:

Exception: Refer to FMC Section 15.10.360.

R401.4.1 Geotechnical evaluation. When permitted by the Building Official, in lieu of a complete geotechnical evaluation, the load-bearing values in Table R401.4.1 shall be assumed.

R401.4.1.1 – R401.4.2 {CRC text not modified}

Sec. 15.47.140   Amendment to 2016 CRC Section R403 (Footings).

Section R403 of the 2016 California Residential Code is amended as follows:

R403.1 – R403.1.1 {CRC text not modified}

R403.1.2 Continuous footing in Seismic Design Categories D_o, D_1 and D_2. Exterior walls of buildings located in Seismic Design Categories D_o, $D_1$and D_2 shall be supported by continuous solid or fully grouted masonry or concrete footings. All required interior braced wall panels in buildings located in Seismic Design Categories D_0, $D_1$and D_2 shall be supported on continuous foundations.

R403.1.3 – R403.1.3.5.4 {CRC text not modified}

R403.1.3.6 Isolated concrete footings. In detached one- and two-family dwellings located in Seismic Design Category A, B, or C that are three stories or less in height and constructed with stud bearing walls, isolated plain concrete footings supporting columns or pedestals are permitted.

R403.1.4 – R403.1.4.1 {CRC text not modified}

R403.1.5 Slope. The top surface of footings shall be level. The bottom surface of footings shall not have a slope exceeding one unit vertical in 10 units horizontal (10-percent slope). Footings shall be stepped where it is necessary to change the elevation of the top surface of the footings or where the slope of the bottom surface of the footings will exceed one unit vertical in 10 units horizontal (10-percent slope).

For structures located in Seismic Design Categories D_0, D_1or D_2, stepped footings shall be reinforced with four No. 4 rebar. Two bars shall be placed at the top and bottom of the footings as shown in Figure R403.1.5.

R403.1.6 – R403.4.2 {CRC text not modified}

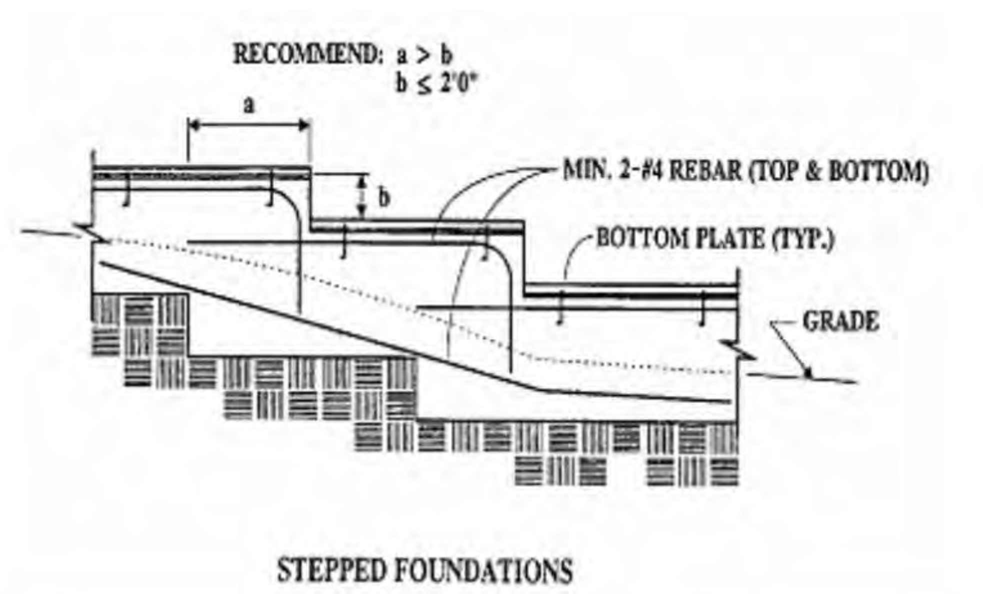


FIGURE R403.1.5
STEPPED FOOTING

Sec. 15.47.150 Amendment to 2016 CRC Section R404 (Foundation and Retaining Walls).

Section R404 of the 2016 California Residential Code is amended as follows:

R404.1 – R404.1.9.5 {CRC text not modified}

R404.2 Wood foundation walls. Wood foundation walls shall be constructed in accordance with the provisions of Sections R404.2.1 through R404.2.6 and with the details shown in Figures R403.1(2) and R403.2(3). Wood foundation walls shall not be used for structures located in Seismic Design Category D_0, D_1 or D_2.

R404.2.1 – R404.5.3 {CRC text not modified}

Sec. 15.47.160 Amendment to 2016 CRC Section R602 (Wood Wall Framing).

Section R602 of the 2016 California Residential Code is amended as follows:

R602.1 - R602.3.1 {CRC text not modified}

R602.3.2 {CRC text not modified}

Exception: In other than Seismic Design Category D_0, D_1or D_2, a single top plate used as an alternative to a double top plate shall comply with the following:

1. The single top plate shall be tied at corners, intersecting walls, and at in-line splices in straight wall lines in accordance with Table R602.3.2.

2. The rafters or joists shall be centered over the studs with a tolerance of not more than 1 inch (25 mm).

3. Omission of the top plate is permitted over headers where the headers are adequately tied to adjacent wall sections in accordance with Table R602.3.2.

TABLE R602.3.2
SINGLE TOP-PLATE SPLICE CONNECTION DETAILS

CONDITION	TOP-PLATE SPLICE LOCATION			
	Corners and intersecting walls		Butt joints in straight walls	
	Splice plate size	Minimum nails each side of joint	Splice plate size	Minimum nails each side of joint
Structures in SDC A-C; ~~and in SDC D_0, D_1 and D_2 with braced wall line spacing less than 25 feet~~	3″ × 6″ × 0.036″ galvanized steel plate or equivalent	(6) 8d box ($2^1/_2$″ × 0.113″) nails	3′ × 12″ × 0.036″ galvanized steel plate or equivalent	(12) 8d box ($2^1/_2$″ × 0.113″) nails
~~Structures in SDC D_0, D_1 and D_2, with braced wall line spacing greater than or equal to 25 feet~~	~~3″ × 8″ by 0.036″ galvanized steel plate or equivalent~~	~~(9) 8d box ($2^1/_2$″ × 0.113″) nails~~	~~3′ × 16″ × 0.036″ galvanized steel plate or equivalent~~	~~(18) 8d box ($2^1/_2$″ × 0.113″) nails~~

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

R602.3.3 – R602.10.2.2.3 {CRC text not modified}

R602.10.2.3 Minimum number of braced wall panels. Braced wall lines with a length of 16 feet (4877 mm) or less shall have a minimum of two braced wall panels of any length or one braced wall panel equal to 48 inches (1219 mm) or more. Braced wall lines greater than 16 feet (4877 mm) shall have a minimum of two braced wall panels. No braced wall panel shall be less than 48 inches in length in Seismic Design Category D_0, D_1, or D_2.

R602.10.3 - R602.12.8 {CRC text not modified}

Footnote j. is added to Table R602.3(1).

j. Use of staples in braced wall panels shall be prohibited in Seismic Design Category D_0, D_1 or D_2.

Footnote b. is amended to Table R602.3(2).

b. Staples shall have a minimum crown width of 7/16-inch on diameter except as noted. Use of staples in roof, floor, subfloor, and braced wall panels shall be prohibited in Seismic Design Category D_0, D_1 or D_2.

Footnote d. is added to Table R602.10. 3(1).

d. Bracing methods LIB, DWB, SFB, PBS, HPS, GB and PCP are not permitted.

Footnote d. is added to Table R602.10. 3(2).

d. Bracing methods LIB, DWB, SFB, PBS, HPS, GB and PCP are not permitted.

Footnote f. is added.

f. Methods LIB, DWB, SFB, PBS, HPS, GB, and PCP are not permitted in SDC Category D_0, D_1 or D_2.

Footnotes f., g. and h. are added to Table R602.10.4 of the 2016 California Residential Code.

f. Methods LIB, DWB, SFB, PBS, HPS, GB, PCP, and PFG are not permitted in SDC Category D_0, D_1 or D_2.

g. Use of staples in braced wall panels shall be prohibited in SDC Category D_0, D_1 or D_2.

h. WSP sheathing shall be a minimum of 15/32" thick nailed with 8d common nails placed 3/8 inches from panel edges and spaced not more than 6 inches on center and 12 inches on center along intermediate framing members.

Figure R602.10.6.1 of the 2016 California Residential Code is amended to read as follows:

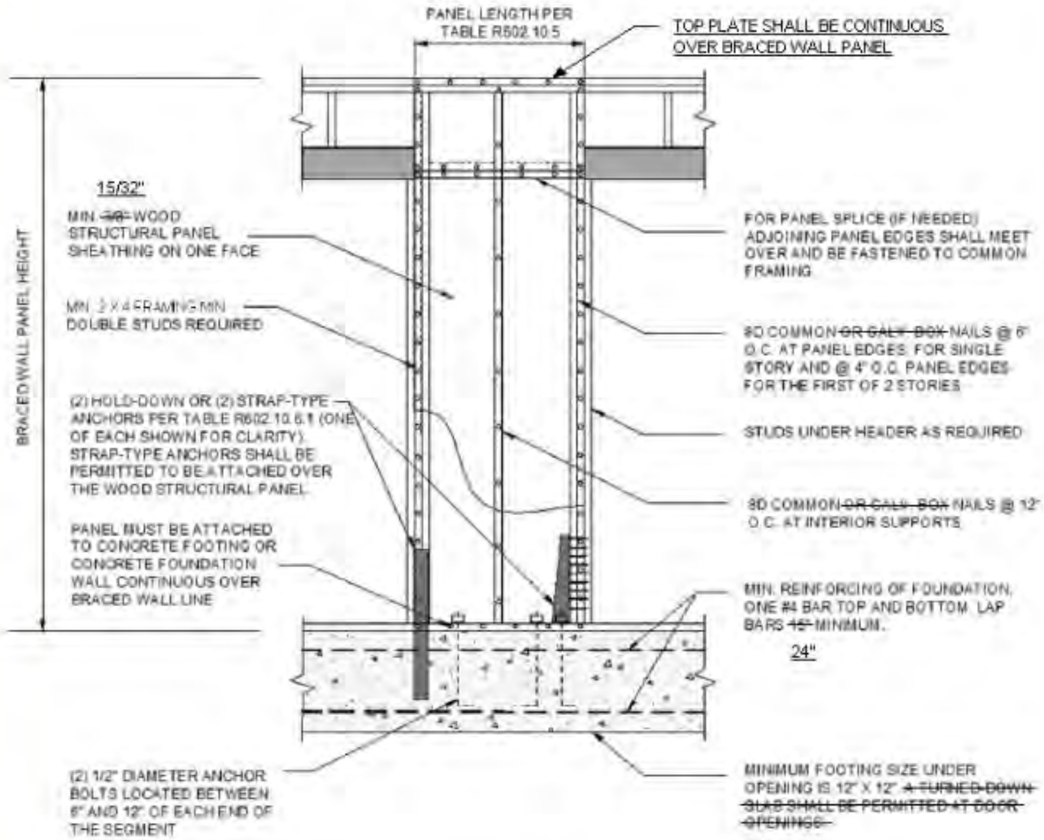
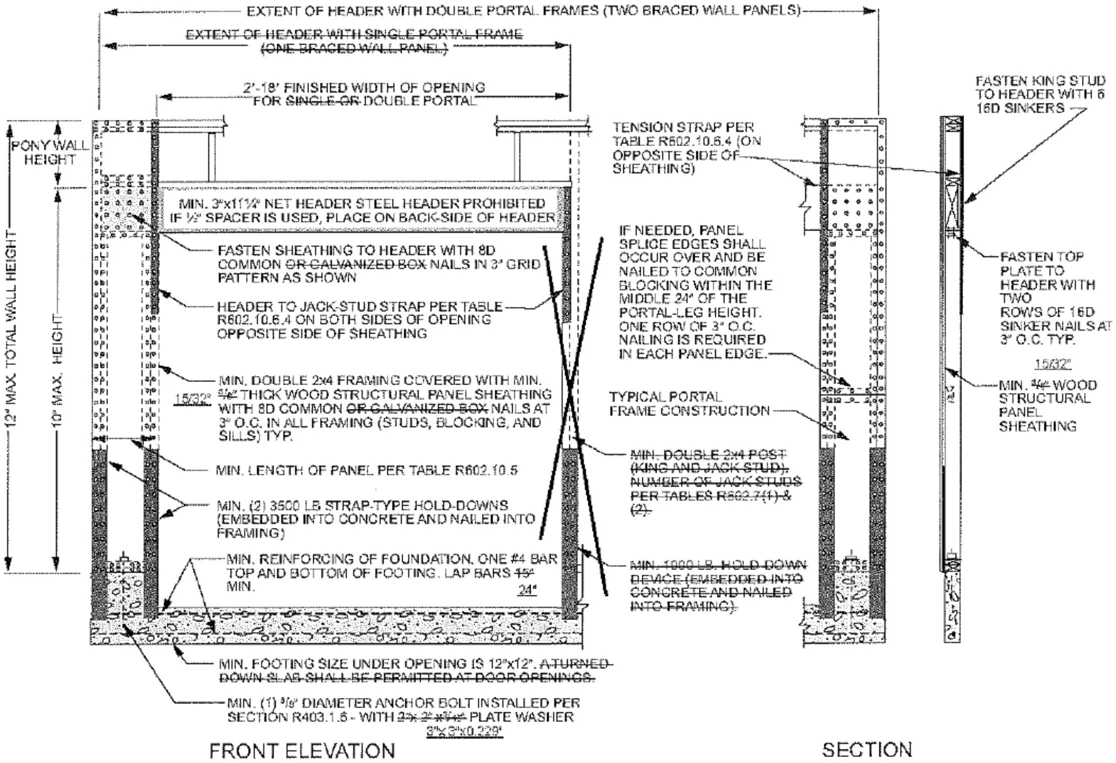


FIGURE R602.10.6.1
METHOD ABW—ALTERNATE BRACED WALL PANEL

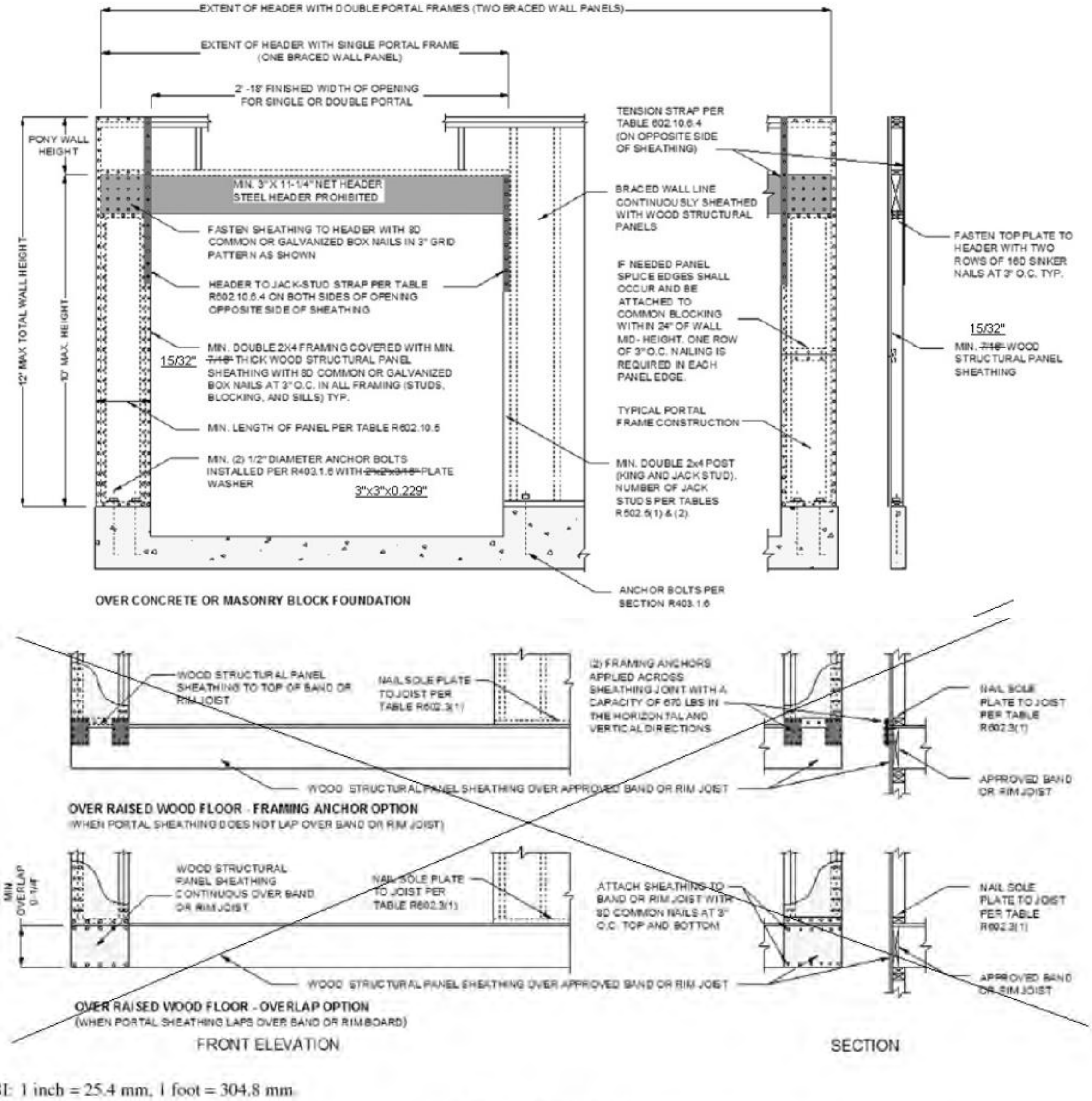
Figure R602.10.6.2 of the 2016 California Residential Code is amended to read as follows:



For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

FIGURE R602.10.6.2
METHOD PFH—PORTAL FRAME WITH HOLD-DOWNS
AT DETACHED GARAGE DOOR OPENINGS

Figure R602.10.6.4 of the 2016 California Residential Code is amended to read as follows:



I: 1 inch = 25.4 mm, 1 foot = 304.8 mm

FIGURE R602.10.6.4
METHOD CS-PF-CONTINUOUSLY SHEATHED PORTAL FRAME PANEL CONSTRUCTION

Sec. 15.47.170 Amendment to 2016 CRC Section R606 (General Masonry Construction).

Section R606 of the 2016 California Residential Code is amended as follows:

R606.1 – R606.12.2.2.2 {CRC text not modified}

R606.12.2.2.3 Reinforcement of requirements for masonry elements. Masonry elements listed in Section R606.12.2.2.2 shall be reinforced in either the horizontal or vertical direction as shown in Figure R606.11(3) and in accordance with the following:

1. Horizontal reinforcement. Horizontal reinforcement shall be provided within 16 inches (406 mm) of the top and bottom of these masonry elements.

2. Vertical reinforcement. Vertical reinforcement shall consist of at least one No. 4 bar spaced not more than 48 inches (1219 mm). Vertical reinforcement shall be within 8 inches (406mm) of the ends of masonry walls.

R606.12.2.3 - R606.14.2 {CRC text not modified}

SECTION 12. FMC CHAPTER 15.48 REPEALED AND REPLACED

Chapter 15.48 (Fremont Green Building Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is repealed and replaced to read as follows:

Sec. 15.48.010 Title.

This chapter shall be known and may be cited as the "Fremont green building standards code" or "FGBC" and will be referred to in this chapter as "this code."

Sec. 15.48.020 Adoption of the 2016 California Green Building Standards Code With Amendments.

The 2016 edition of the California Green Building Standards Code (CGBSC or CALGreen) as published by the State of California is adopted as the Green Building Code of the city of Fremont, California, as if fully set out in this chapter, and is amended as set forth in this chapter. A copy of the 2016 CGBSC shall be maintained on file in the office of the city clerk.

Sec. 15.48.030 Amendment to 2016 CGBSC Section 202 (Definitions).

Section 202 of the 2016 California Green Building Standards Code is amended by modifying the following definition. The remaining definitions are not modified:

EV READY PARKING SPACE: A parking space served by a complete 208/240 V 40 ampere electrical circuit.

Sec. 15.48.040 Amendment to 2016 CGBSC Section 301 (General).

Section 301 of the 2016 California Green Building Standards Code is amended as follows:

301.1 – 301.3.2 {CGBSC text not modified}

301.3.3 Additions to Parking Facilities: The requirements related to electric vehicle charging also apply to additions to increase the number of parking spaces at any facility. The requirements will apply only to the number of new parking spaces.

301.4 – 301.5 {CGBSC text not modified}

Sec. 15.48.050 Amendment to 2016 CGBSC Section 4.106 (Site Development)

Section 4.106 of the 2016 California Green Building Standards Code is amended as follows:

4.106.1 – 4.106.3 {CGBSC text not modified}

4.106.4 Electric vehicle (EV) charging for new construction and additions. New construction and additions as described in Section 301.3.3 shall comply with this section. Electric vehicle supply equipment (EVSE) shall be in accordance with the California Electrical Code, Article 625.

Exceptions:

On a case-by-case basis, where the local enforcing agency has determined EV charging and infrastructure are not feasible based upon one or more of the following conditions:

1. Where there is no commercial power supply.

2. Where there is evidence substantiating that meeting the requirements will alter the local utility infrastructure design requirements on the utility side of the meter so as to increase the utility side cost to the homeowner or the developer by more than $400.00 per dwelling unit or $400.00 per parking space, whichever is greater. In such cases, buildings subject to Section 4.106.4 shall meet the requirements by maximizing the number of EV Ready Parking Spaces, without exceeding the limit above. Cost per parking space shall be determined by dividing total cost by total number of EV and non-EV parking spaces.

4.106.4.1 New one- and two-family dwellings and town-houses with attached or adjacent private garages or carports. For each dwelling unit, install a listed raceway, associated overcurrent protective device and the balance of a dedicated 208/240-volt branch circuit rated at 40 amperes minimum. The raceway shall not be less than trade size 1 (nominal 1-inch inside diameter). The raceway shall originate at the main service or unit subpanel and shall terminate into a listed cabinet, box or other enclosure in close proximity to the proposed location of an EV charger. Raceways are required to be continuous at enclosed, inaccessible or concealed areas and spaces. The service panel and/or subpanel shall provide capacity for a 40-ampere minimum dedicated branch circuit. All electrical circuit components and EVSE, including a receptacle or box with a blank cover, related to this section shall be installed in accordance with the California Electrical Code.

4.106.4.1.1 Identification. The service panel or subpanel circuit directory shall identify the overcurrent protective device space(s) reserved for future EV charging as "EV READY". The raceway termination location shall be permanently and visibly marked as "EV READY".

4.106.4.2 New multifamily dwellings and additions.

The following number of EV Ready Parking Spaces are required at the time of original construction:

Total Number of Actual Parking Spaces	Number of Required EV Ready Parking Spaces
0-9	0
10-25	2
26-50	3
51-75	5
76-100	7
101-150	10
151-200	14
201 and over	8 percent of total[1]

[1]Calculation of number of spaces shall be rounded up to the nearest whole number.

4.106.4.2.1 {CGBSC text not modified}

4.106.4.2.2 {CGBSC text not modified}

4.106.4.2.3 EV ready parking spaces. Construction documents shall verify that the electrical panel service capacity and electrical system, including any on-site distribution transformer(s), have sufficient capacity to simultaneously charge all EVs at all required EV spaces at the full rated amperage of the EV Ready Parking Space.
A raceway, electrical panel capacity, wire and termination point supporting a 208/240 volt 40 ampere circuit, are required to be installed at the time of construction for each EV Ready Parking Space required under 4.106.4.2. Where a single EV Ready Parking Space is required, the raceway shall not be less than trade size 1 (nominal 1-inch inside diameter). All electrical circuit components and EVSE related to this section shall be installed in accordance with the California Electrical Code.

Note: Termination point should be a receptacle suitable for EVSE and located near the proposed EVSE location.

4.106.4.2.4 – 4.106.4.2.5 {CGBSC text not modified}

Sec. 15.48.060 Amendment to 2016 CGBSC Section 5.106 (Site Development).

Section 5.106 of the 2016 California Green Building Standards Code is amended as follows:

5.106.1 – 5.106.5.2.1 {CGBSC text not modified}

5.106.5.3 Electric vehicle (EV) charging for new construction and additions.

The following number of EV Ready Parking Spaces are required at the time of original construction:

Total Number of Actual Parking Spaces	Number of Required EV Ready Parking Spaces
0-9	0
10-25	2
26-50	3
51-75	5
76-100	7
101-150	10
151-200	14
201 and over	8 percent of total[1]

[1] Calculation of number of spaces shall be rounded up to the nearest whole number.

5.106.5.3.1 EV ready parking space-requirements. Construction documents shall verify that the electrical panel service capacity and electrical system, including any on-site distribution transformer(s), have sufficient capacity to simultaneously charge all EVs at all required EV Ready Parking Spaces at the full rated amperage of the EV Ready Parking Space.

A raceway, electrical panel capacity, wire and termination point supporting a 208/240 volt 40 ampere circuit is required to be installed at the time of construction for each EV Ready Parking Space required under 5.106.5.3. Where a single EV Ready Parking Space is required, the raceway shall not be less than trade size 1 (nominal 1-inch inside diameter). All electrical circuit components and EVSE, related to this section shall be installed in accordance with the California Electrical Code.

Note: Termination point should be a receptacle suitable for EVSE and located near the proposed EVSE location.

Exceptions: On a case-by-case basis where the local enforcing agency has determined EV charging and infrastructure is not feasible based upon one or more of the following conditions:

1. Where there is insufficient electrical supply.

2. Where there is evidence suitable to the local enforcing agency substantiating that additional local utility infrastructure design requirements, directly related to the implementation of Section 5.106.5.3, may adversely impact the construction cost of the project.

5.106.5.3.2 Identification. The service panel or subpanel(s) circuit directory shall identify the reserved overcurrent protective device space(s) for future EV charging as “EV READY”. The raceway termination location shall be permanently and visibly marked as "EV READY."

5.106.5.3.3 Future charging spaces qualify as designated parking as described in Section 5.106.5.2 Designated parking for clean air vehicles.

5.106.5.3.4. deleted.

5.106.5.3.5 – 5.106.10 {CGBSC TEXT NOT MODIFIED}

SECTION 13. FMC CHAPTER 15.49 ADDED

Chapter 15.49 (Fremont Historical Building Code) of Fremont Municipal Code Title 15 (Buildings and Construction), Division 1 (Fremont Building Standards Code) is added to read as follows:

Sec. 15.49.010 Title.

This chapter shall be known and may be cited as the "Fremont historical building code" or "FHBC" and will be referred to in this chapter as "this code."

Sec. 15.49.020 Adoption of the 2016 California Historical Building Standards Code without Amendments.

The 2016 edition of the California Historical Building Code (CHBC) as published by the California Building Standards Commission is adopted without amendments as the Historical Building Code of the city of Fremont, California, as if fully set out in this chapter. A copy of the 2016 CHBC shall be maintained on file in the office of the city clerk.

SECTION 14. EFFECTIVE DATE

This ordinance shall take effect and be enforced beginning on January 1, 2017.

SECTION 15. CEQA

The City Council finds under Title 14 of the California Code of Regulations, Section 15061(b)(3), that this ordinance is exempt from the requirements of the California Environmental Quality Act (CEQA) in that it is not a Project which has the potential for causing a significant effect on the environment. The Council therefore directs that a Notice of Exemption be filed with the Alameda County Clerk in accordance with the CEQA Guidelines.

SECTION 16. SEVERABILITY

If any section, subsection, sentence, clause or phrase of this ordinance is for any reason held by a court of competent jurisdiction to be invalid, such a decision shall not affect the validity of the remaining portions of this ordinance. Such section, subsection, sentence, clause or phrase, instead, shall be superseded and replaced by the corresponding provisions, if any exist, of Title 24 of the California Code of Regulations. The City Council of the City of Fremont hereby declares that it would have passed this ordinance and each section or subsection, sentence, clause and phrase thereof, irrespective of the fact that any one or more sections, subsections, sentences, clauses or phrases be declared invalid.

SECTION 17. PUBLICATION OF SUMMARY

The City Clerk has prepared and published at least five days before the date of adoption a summary of this ordinance once in a newspaper of general circulation printed and published in Alameda County and circulated in the City of Fremont. A certified copy of the full text of the ordinance was posted in the office of the City Clerk since at least five days before this date of adoption. Within 15 days after adoption of this ordinance, the City Clerk shall cause the summary to be published again with the names of those City Council members voting for and against the ordinance and shall post in the office of the City Clerk a certified copy of the full text of this adopted ordinance with the names of those City Council members voting for and against the ordinance.

* * * * *

The foregoing ordinance was introduced before the City Council of the City of Fremont, at the regular meeting of the City Council, held on the ___th day of __________, 2016 and finally adopted at a regular meeting of the City Council held on the ___th day of _________, 2016 by the following vote:

AYES:

NOES:

ABSENT:

ABSTAIN:

____
Mayor

ATTEST: APPROVED AS TO FORM:

______________________________ ______________________________
City Clerk Deputy City Attorney

Electric Vehicle Charging Station Installation Best Practices:

A Guide for San Diego Region Local Governments and Contractors

June 2016

Submitted by

Center for Sustainable Energy

Summary of Acronyms

AHJ: authority having jurisdiction

BEV: battery electric vehicle

CSE: Center for Sustainable Energy

EVSE: electric vehicle supply equipment

EVCS: electric vehicle charging station

GHG: greenhouse gas

NRTL: Nationally Recognized Testing Laboratory

PEV: plug-in electric vehicle

PHEV: plug-in hybrid electric vehicle

SANDAG: San Diego Association of Governments

SAE: Society of Automotive Engineers

ZEV: zero-emission vehicle

Executive Summary

As adoption of plug-in electric vehicles (PEVs) grows in the San Diego region and statewide, there is a greater demand for residential, workplace and commercial electric vehicle charging stations (EVCS). Although the region has made great strides in facilitating the adoption of vehicles and infrastructure, more work is necessary. Through funding from the California Energy Commission, the San Diego Association of Governments (SANDAG) and the Center for Sustainable Energy (CSE) have partnered to implement the EVCS best practice recommendations from the 2014 San Diego Regional PEV Readiness Plan (Readiness Plan) that was developed through the San Diego Regional Electric Vehicle Infrastructure (REVI) Working Group.[i] This implementation program is known as **Plug-in SD**.

In July 2015, SANDAG and CSE launched Plug-in SD to promote regionally consistent and streamlined residential and commercial EVCS permitting, inspection and installation best practice resources for local governments and installers. This report serves as one of these resources and includes:

- A review of codes and standards relating to EVCS installations
- An overview of common installation challenges in different scenarios
- Best practices to assist local building departments and electrical contractors to prepare for the anticipated increase of EVCS installations

EVCS installation best practices presented in this report derive from those currently in place through San Diego region local governments, the Readiness Plan and the Governor's Office of Planning and Research Zero-Emission Vehicle Guidebook (ZEV Guidebook).[ii] These best practices include:

- Standardization of EVCS building codes and installation requirements
- Training for electrical contractors
- Electric vehicle charging station installation guides and checklists
- Electric vehicle charging station encouragement programs

Plug-in SD provides technical assistance to municipalities to facilitate the adoption and implementation of this project's best practices and resources. Consultations with technical staff, or "EV experts," are available via in-person or remote (email and phone) meetings. EV experts can be contacted by email at evexpert@energycenter.org or by phone at (866) 967-5816. Resources and information will be hosted at http://energycenter.org/pluginsd.

This report does not discuss local permitting authority requirements in depth. For more information on the local government EVCS permitting and inspection process, see Plug-in SD's *Electric Vehicle Charging Station Permitting and Inspection Best Practices: A Guide for Local Governments.*[iii]

I. Introduction

As adoption of plug-in electric vehicles (PEVs) grows in the San Diego region and statewide, there is a greater demand for residential, workplace and commercial electric vehicle charging stations (EVCS), also known as, electric vehicle supply equipment (EVSE). More than 150,000 PEVs[iv] have been deployed statewide, and nearly 13,000 of those vehicle owners reside in San Diego County. Charging infrastructure not only needs to be installed for existing electric vehicles, but also to accommodate up to 1 million zero-emission vehicles (ZEVs) by 2020 and 1.5 million ZEVs on California roadways by 2025 per Governor Brown's Executive Order.[v] In order to accommodate the expected increase of PEVs, the Executive Order requires that the state's major metropolitan areas, including the San Diego region, have adequate infrastructure plans to be "ZEV-ready" by 2015. According to the Alternative Fuels Data Center, the San Diego region currently has 687 charging stations open to the public.[vi] The state has estimated the San Diego region needs to deploy approximately 75,000 residential charging ports and 12,000 workplace charging ports to support this growth.[vii] EVCS installers and local governments play a key role in PEV adoption and deployment of charging infrastructure.

II. Electric Vehicle Charging Technology

Table 1 displays the three levels of PEV charging. The majority of PEVs come with a 120-volt charging cord that enables owners to charge their vehicle with a conventional three-prong outlet. This is classified as Level 1 charging. Level 2 charging stations use 240 volts and offer two to three times the charging speed compared with 120-volt charging. Level 2 charging stations are commonly installed in residential as well as commercial settings. DC fast charging has high power requirements only suited to commercial settings; not all PEVs are capable of DC fast charging.

Table 1: Levels of Charging and Miles of Range[viii]

Type of Charging	Power Levels (installed circuit rating)	Miles of Range per Hour of Charge*	Where to Charge
Level 1	110/120VAC at 15 or 20 Amps	~4-6 miles/hour	At home or workplace
Level 2 **3.3kW (low)** **6.6kW (medium)** **9.6kW (high)** **19.2kW (highest)**	 208/240 VAC at 20 Amps 208/240 VAC at 40 Amps 208/240 VAC at 50 Amps 208/240 VAC at 100 Amps	 8-12 miles/hour 16-24 miles/hour 32-48 miles/hour >60 miles/hour	At home, workplace or public charging station
DC Fast Charging	440 or 480 VAC	~80% in <30 minutes	Public or commercial

***Refer to vehicle specifications for exact ratings.**

III. Common EVCS Installation Barriers

During previous PEV readiness planning efforts, the San Diego Regional Electric Vehicle Infrastructure (REVI) Working Group identified several common EVCS installation barriers. These barriers are summarized in Table 2. The best practices discussed in Section V of this report address the identified EVCS installation barriers specific to contractor education, technical installation guides and the use of building codes that support dedicated EVCS infrastructure.

Table 2: Regional Barriers to PEV Infrastructure

Barrier	Description
Permitting/Inspection	Lack of streamlined permitting and inspection processes and inconsistent (high) costs across jurisdictions.
Building Codes	Lack of standard building codes that accommodate charging infrastructure or dedicate circuits for charging infrastructure in new construction and major renovations.
Zoning and Parking Rules	Lack of standard regional ordinances that facilitate the installation and access to publicly available charging infrastructure.
Training and Education for Municipal Staff and Electrical Contractors	Lack of knowledge about PEVs and EVCS.
Consumer Awareness of PEV and EVCS Availability	Consumer lack of understanding of the electric vehicle types and EVCS equipment availability.
EVCS at Multi-Unit Dwellings	Building managers, building owners and homeowner associations lack understanding of unique challenges associated with EVCS installations at multi-unit dwellings.
Commercial and Workplace Charging	Businesses lack of understanding regarding benefits of and approaches to implementing successful workplace charging programs.

As identified in the Readiness Plan,[ix] EVCS installations face common barriers of permit application delays, inconsistent permit fees and inspection corrections. Installation delays result from electrical contractor unfamiliarity with charging infrastructure and applicable codes and standards specific to EVCS. The following information serves as a reference for installers and local governments on relevant codes and standards.

EVCS Codes and Standards

The California Green Building Standards Code (CALGreen),[x] known as Title 24, Part 11, was the first state-adopted green building code in the nation. CALGreen includes both mandatory and voluntary measures that ensure residential and commercial new construction projects are ready for EV infrastructure. Local jurisdictions have authority to adopt their own PEV-readiness building codes standards beyond CALGreen's mandatory requirements. Cities can adopt the voluntary measures in CALGreen or adapt them to reflect local priorities.

CALGreen requirements include prewiring of the site to allow for the future installation of a charging circuit and electrical retrofits to support EVCS. The specific requirements for residential and nonresidential buildings are described in Tables 3 and 4.

Table 3: CALGreen Residential EVCS Requirements

Multifamily Residential	
Mandatory Requirements	**Voluntary Requirements**
PEV "readiness" (i.e., electrical system capacity, building plans and any underground conduits) for at least 3% of total parking spaces	Multifamily PEV "readiness" applies to at least 5% of total parking spaces
All developments under 17 units exempt	All developments under 17 units exempt
Single-family Residential	
Mandatory Requirements	**Voluntary Requirements**
Raceway (such as conduit) and electrical panel capacity to support 40-amp capacity electric circuit	Install complete 40-amp electrical circuit
Does not include pulling wire nor installing receptacle	

Table 4: CALGreen Nonresidential EVCS Requirements

Nonresidential	
Current Mandatory Requirements	**Current Voluntary Requirements**
PEV "readiness" which includes raceway (such as conduit) and electrical panel capacity to support 40-amp PEV charging capacity	At least 4% (Tier 1) or 6% (Tier 2) of parking spaces must be PEV ready
If there are more than 50 parking spaces, at least 3% must be PEV-ready	No minimum parking space threshold
Proposed New Mandatory Requirements	**Proposed New Voluntary Requirements**
If there are more than 10 parking spaces, at least 6% or more must be PEV-ready (Raceway (such as conduit) and electrical panel capacity to support 40-amp PEV charging capacity)	At least 8% (Tier 1) or 10% (Tier 2) of parking spaces must be PEV ready

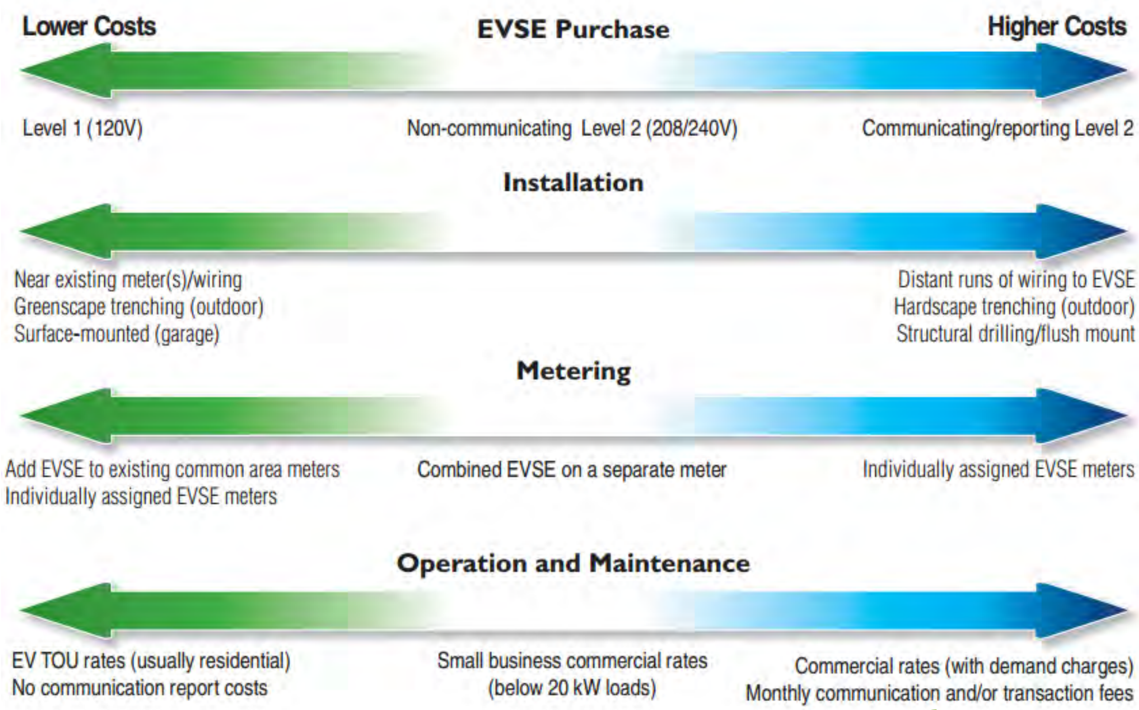
The 2013 CALGreen Code became effective on January 1, 2014, after adoption by the California Building Standards Commission. The PEV readiness requirements were included in supplementary changes adopted and approved in the 2013 Intervening Code Adoption Cycle, which became effective on July 1, 2015. Proposed changes and possible amendments for the 2016 CALGreen Code are currently in process and will go into effect January 1, 2017. These changes to the code include enhanced statewide mandatory requirements for EVCS readiness and expanded voluntary "reach" codes for new construction. The current proposed change in the Code Adoption Cycle of CALGreen is to increase the threshold for non-residential parking lots from 3% of lots with 51 or more parking spaces to 6% of lots with 10 or more parking spaces.

As a local jurisdiction that adopted the 2013 CALGreen Code, the County of San Diego is working toward streamlining enforcement of the California Green Building Code requirements. The County's Building Division of the Planning and Development Services Department encourages constituents to be aware of the CALGreen Code and familiarize themselves with the regulations. The County enforces mandatory energy efficiency requirements and offers a Green Building Incentive Program for projects that go beyond the minimum requirements.

Installation Costs

Varying and unpredictable installation costs present a barrier to EVCS deployment. Figure 1 provides insight on the range of costs for various scenarios as a guide for consumers and contractors. While not included in this figure, permitting costs can add to the overall EVCS installation cost.

Figure 1: PEV Collaborative EVCS Cost Spectrum[xi]



The EV Project identified the San Diego region as having the highest fees associated with obtaining a permit for residential Level 2 charging installation.

The EV Project examined the installation costs associated with residential EVCS in 10 metropolitan areas across the United States. Installation costs include materials, labor, permit fees, administration and the unit itself. Costs also include installation of conduit, wiring and trenching depending on the location and capacity of the existing power supply. The EV Project identified the San Diego region as having the highest fees associated with obtaining a permit for residential Level 2 charging installation.[xii]

Electrical service panel upgrades were a significant cost driver in EV Project's installations. There are various methods to power EVCS that can involve coordinating with the utility to complete a panel upgrade or a new service drop. To accommodate the circuit for a Level 2 charger, individuals with older homes typically require an upgrade of their electrical service panel that adds significant cost to an EVCS installation project.

IV. Existing EVCS Installation Processes

This section begins with the general installation processes and standards, from pre-installation to final inspection, that exist across residential and nonresidential EVCS installations. Residential project types include single-family homes; nonresidential project types include multi-unit family or dwelling buildings with more than two units, workplaces, commercial retail centers and public locations. This section also addresses the unique installation challenges of both multifamily and commercial projects and provides resources to help installers avoid project delays.

Installation Standards for Residential and Nonresidential EVCS

The general EVCS installation standards described relate to electrical code and workmanship requirements, equipment, determining proper electrical load, physical installation, post-installation equipment use and maintenance, and communications.

Electrical Code and Workmanship Requirements
The National Electrical Contractors Association (NECA) publishes the National Electrical Installation Standards (NEIS) to define a minimum baseline of quality and workmanship for installing electrical products and systems. The NEIS for EVCS is NECA 413-2012, *Standard for Installing and Maintaining Electric Vehicle Supply Equipment.*[xiii] NECA 413 includes guidance on the electrical supply equipment itself, the installation process, ongoing maintenance, and communications. Additionally, NECA 413 recommends that all work should be performed in accordance with established requirements for electrical safety. In California, those requirements are in the California Electrical Code, Title 24, Part 3, Article 625 *Electric Vehicle Charging System*.[xiv] Article 625 specifies required methods for wiring, equipment construction and safety [shock] protection systems and overcurrent control and protection as well as proper equipment marking, placement, orientation and location. Table 6 highlights requirements for the EVCS as listed in the National Electric Code.

Table 6: EVCS Code Requirements and Standards[xv]

Applicable Code	Description
NEC 110.28	The enclosure must be NEMA-rated
NEC 625.17	Cord length will reach vehicle's inlet without excessive slack and must be no more than 25' in length
NEC 625.29	Connector must be mounted at a height between 36" and 48" from the ground unless otherwise indicated by the manufacturer
NEC 110.26	The recommended space around electrical equipment is 30" wide, 3' deep and 6'6" high
NEC 110.27	Equipment operating above 50 volts must be protected against physical damage
NEC 625.23	For EVCS greater than 60 amperes, a separate disconnect is required and should be installed concurrently with conduit and visible from EVCS
NEC 625.21	Conductors should be sized to support 125% of the rated equipment load

Equipment

- Equipment should be certified by a Nationally Recognized Testing Laboratory (NRTL) and listed for electric vehicle use.
- Society of Automotive Engineers (SAE) J1772-2009 standard includes a number of safety features between the charging station and the electric vehicle, such as ground fault current interrupter, proximity detection and signaling. Power is only supplied after a connection is made.
- Equipment should be located away from potential hazards to be protected from physical damage. Bollards, wheel stops or other devices can be used to ensure appropriate setbacks between vehicle and equipment.
- Equipment should be positioned to minimize tripping hazard from cords or include cord management devices, such as self-retracting reels.

Determining Proper Electrical Load

- EV charging is a continuous load. Required wiring size and overcurrent protection for EVCS must be 125 percent of the EVCS nameplate continuous output rating.
- Load calculations or a load study may be required to ensure there is sufficient electrical capacity to support EVCS. Load control strategies may be employed to fit charging within existing capacity.

Physical Installation

- Before beginning work, the intended EVCS electrical circuit must be properly de-energized via industry standard lockout/tagout procedures. The vehicle should not be connected to the equipment during installation or service.
- Use personal protective equipment and treat all conductors as energized until confirmed to be de-energized.
- Ensure installation follows manufactures specifications and approved design plans. Note any deviations or corrections to the plans, or stop and inform permitting authority.

- The U.S. DOE *Clean Cities Electric Vehicle Handbook*[xvi] includes detailed information on the phases of an EVCS installation, as well as associated topics of maintenance and technical requirements. An EVCS installation example is highlighted in the handbook along with lessons learned for the general installation and inspection process.

Post-installation equipment use and maintenance

- An EVCS requires little ongoing maintenance; however maintenance should be performed in accordance with manufacturer recommendations.
- Units may be cleaned with a damp cloth and mild detergent.
- Connectors and wiring should be regularly inspected for damage.
- It is good practice to shut off, discontinue use and/or replace EVCS couplers or plugs if observed to be damaged, discolored, disfigured, modified, hot, sparking, popping or otherwise suspect.
- Always ensure equipment is de-energized before performing service on electrical components.

The largest volume of PEV charging is performed by single-family homeowners.

Communications

Many commercial EVCS require a communications connection to manage access control, billing, power metering or other features. Contractors should be aware of communications requirements of EVCS equipment they are installing. There are three types of communication methods:

- Cell-based communication
- Wi-Fi based communication
- Hard-wired communication

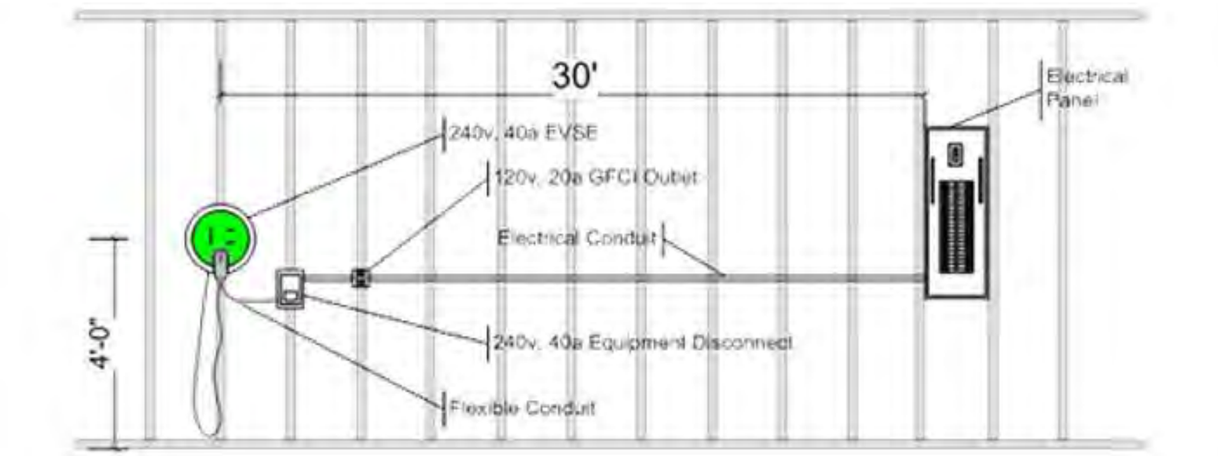
Communications protocols depend on vendors, and the method of communication may depend on the installation site. For example cell-based communications will generally not function in subterranean parking structures. Communications should be considered as part of project planning to support a successful installation. Communicating residential units most commonly use Wi-Fi.

Residential-Specific EVCS Installation Considerations

As mentioned in OPR's *ZEV Guidebook*,[xvii] the largest volume of PEV charging is performed by single-family homeowners. A majority of PEV drivers install Level 1 or Level 2 charging at their single-family home. For single-family homes, the electrical contractor will examine the customers' home panel to determine wiring needs and potential load capacity. During the site assessment, the contractor determines what process is needed for the panel to accommodate the load of installing EVCS and provides a quote to the homeowner. Some contractors may perform an initial assessment remotely using pictures of the electrical panel and proposed installation site. Following this assessment, the installer must obtain a building or electrical permit for the installation and coordinate with the local utility (i.e., San Diego Gas & Electric) if an electrical service upgrade is needed.[xviii] The installation commences once a building permit is issued and utility service approval (if needed) is granted. The contractor will pull the necessary wiring and mount the EVCS in the permitted location. For residential installations, wire can run through the attic, crawlspace or exterior and surface mount conduits.

A typical EVCS is mounted indoors in the garage or outdoors on a solid wall that can be drywall, concrete block or brick as well as other standard wall materials. A helpful example depicting a standard residential EVCS installation is shown in Figure 2 as described in AeroVironment (AV) Inc.'s Cal Electric: Residential EVCS Deployment program.

Figure 2: AV Cal Electric's standard installation route to EVCS location[xix]



AV defined the typical installation for their program as a 30 linear feet electrical run from the electrical panel that has sufficient space and capacity (additional 40-ampere circuit breaker and load of 200 amperes) to the EVCS location. A 30-foot run would accommodate charging in many residential houses.

Nonresidential-Specific EVCS Installation Considerations

Nonresidential installations include multi-unit dwelling (MUD) communities, commercial and retail centers, public locations and workplace charging stations. These types of installations are more complex than single-family installations. Common considerations are described, as well as challenges that are unique to multifamily and workplace installs.

Permitting

Nonresidential installations require a more comprehensive review by local building, fire, environmental and electrical permitting authorities. In order to obtain a permit, proposed EVCS installations must comply with codes and regulations set forth locally, statewide and nationally.

During the pre-installation process, the scope design requires planning for site layout, number of chargers, parking availability and existing electrical panel capacity. Parking considerations such as parking stall size, orientation and minimum number of required parking stalls for the site are important variables that need to be evaluated prior to EVCS installations.

Utility Coordination

Additional site assessment includes determining the current electrical service capability and potential upgrade requirements to support an EVCS installation. These assessments will involve the utility provider as well as the local permitting authority. Utility considerations can complicate nonresidential installations in total load management and rate structures for the EVCS. More detailed planning is required and the electrical contractor must check with the electrical services utility prior to modifying an existing electrical system. A contractor with proper expertise and training should notify the local utility of proposed charging infrastructure so that there can be proper planning for local increases in electricity demand.

Installation and Inspection

To complete the installation, preparation and scheduling of contractor and utility work must be coordinated in detail as the EVCS installation can require shutoff of the main power supply at a nonresidential building. Cooperating with local utility requirements and organizing the scheduling of when electrical work can be completed are vital to providing power to the EVCS. In addition, the EVCS installation requires permit approval and issuance from the local building department. Following installation, the local building inspector will verify that the equipment is installed per the manufacturer's specifications and instructions. EVCS installations must comply with applicable electrical codes and safety requirements, as noted earlier.

Parking and Accessibility

While single-family residential installations do not have complex parking requirements, nonresidential and MUD installations have additional parking considerations that include Americans with Disabilities Act (ADA) accessible EVCS spaces and meeting the minimum requirements for spaces in parking lots and facilities. EVCS site hosts often experience challenges in providing ADA accessible EVCS spaces in addition to standard EVCS spaces while maintaining the minimum requirements for parking. Consideration of the available parking is important for residents as well as employers. Installing charging in unassigned spaces or common areas for availability to all residents at MUDs requires compliance with ADA accessibility regulations.

Statewide EVCS accessibility standards have been approved for the 2016 California Building Standards Code and go into effect January 2017.

The California Building Standards Commission (CBSC) approved proposed amendments by the Division of the State Architect (DSA) for the 2016 California Building Standards Code, Title 24, Part 2, Chapter 11B at CBSC's January 19-20, 2016 public meeting. Prior to approval of these access regulations, there has been no single, comprehensive guidance on what is needed to ensure that charging infrastructure is accessible to all users. The approved EVCS regulations that apply to both new construction as well as alterations to existing buildings and facilities for the 2016 CBC in sections 11B-812, 11B-206, 11B-228 and 11B-309 will be effective January 1, 2017. These proposed changes to the accessibility standards for EVCS can be viewed in detail on DSA's 2016 Access web reference of Final Express Terms.[xx]

The 2016 edition of the California Building Code includes requirements for accessible EVCS. Accessibility requirements define a minimum number of accessible EVCS per the total number of EVCS at a facility based on type of EVCS. Where four or fewer total EVCS are provided, identification with an International Symbol of Accessibility (ISA) shall not be required. Where more than four total EVCS are provided, the van accessible space will be identified with an ISA and is reserved for the use of persons with disabilities. Newly constructed parking facilities, and existing parking facilities that undergo alteration, must meet requirements for accessibility unless otherwise exempted.

The number of EVCS spaces is determined by the number of vehicles that can be charged, not by the number of service pedestals that are installed. Installing accessible electric vehicle charging equipment includes requirements for accessible routes, path of travel, operable parts, and reach ranges. An accessible route must be provided between the vehicle space and the EV charger that serves it. EV chargers and vehicle spaces that serve a particular building or facility must be located on an accessible route to an entrance. Where EV chargers and vehicle spaces serve more than one accessible entrance, EV chargers and vehicle spaces must be dispersed and located on an accessible route to the accessible entrances. Where EV chargers and vehicle spaces do not serve a particular building or facility, EV chargers and vehicle spaces must be located on an accessible route to an accessible pedestrian entrance of the EVCS. For new construction or alterations, accessible charging stations must be provided when EVCS are installed. According to Title 24, Part 2, Chapter 11B, all building entrances and path of travel to building facilities must provide an accessible path of travel for the disabled; this includes access to EVCS parking stalls and equipment. EVCS must be located so that ADA routes maintain a pathway of 36" at all times.

While accessibility standards for EVCS were being developed by the DSA, a majority of local San Diego jurisdictions look to the City of San Diego for guidance on the topic of accessibility for EVCS. The City of San Diego's Development Services created Technical Policy 11B-1[xxi] in April 2012 to address accessibility to EVCS in both new and existing construction. The policy requires EVCS installations in public areas to be made accessible to persons with disabilities. The policy is consistent with the 2010 California Building Code requirements for accessible parking, public accommodations and services and includes specifications for the number of accessible EVCS required as well as the dimensions, identification and disabled access to accessible EVCS. The City of San Diego is currently making updates to their Technical Policy 11B-1 to align with DSA's approved accessibility standards.

Architects, developers and installers should work with the local permitting authority to determine a site's EVCS accessible parking needs during the project design phase. Installers can reference Advanced Energy's Charging Station Installation Handbook for Electrical Contractors and Inspectors[xxii]. This includes information on parking design and accessibility installation examples and codes that provide information to contractors on disabled access charging stations.

Challenges Unique to Multi-Unit Dwellings

Multi-unit dwelling communities face challenges with EVCS station ownership, siting in parking areas, electrical supply and billing. Solutions to these issues vary depending on community type (e.g., high-rise condominium, rental apartments, homeowner association-controlled townhome development). The California Plug-in Electric Vehicle Collaborative *Plug-in Electric Vehicle Charging Infrastructure Guidelines for Multi-unit Dwellings*[xxiii] provides extensive guidance on these subjects.

Installer should work with building owners and community members to make sure the following issues are considered:

- How many residents will want charging, should stations be dedicated or shared?
- Will the EVCS be installed in assigned parking spaces or in common areas?
- Will the power be supplied from existing common areas meters, individual units or on a new meter?
- Assigning construction and operation costs.
- Equipment or building insurance.

Case Study: CityFront Terrace[xxiv]

CityFront Terrace is a 320-unit condominium community located in downtown San Diego. When a few residents expressed interest in getting electric vehicles, the property managers decided to look for a flexible installation that could serve current and future needs. The homeowner association (HOA) installed 20 individual meters on different floors of the parking structure. Otherwise, residents who want to install EVCS in their assigned space are responsible for the costs of purchasing their own equipment and completing the wiring. Residents then establish their own service directly with the utility and are able to benefit from PEV specific time of use rates. Although doing this means the initial installation is costly, this approach allows residents full responsibility for their own charging equipment and costs, rather than having ongoing involvement of the property management or HOA.

Challenges Unique to Commercial and Workplace Charging

Charging at commercial and workplace sites is a benefit to visitors and employees. CALSART's *Best Practices for Workplace Charging*[xxv] provides details and solutions for many of the challenges faced when installing EVCS at commercial and workplace sites, including:

- Scalability of charging solution
- Operational costs including energy and demand charges
- Billing policies and network costs
- Employee charging guidelines and managing etiquette

Case Study: Scripps Memorial Hospital Encinitas
Scripps Encinitas originally installed two EVCS that were available free to staff and the public. Some staff members would regularly leave their car plugged into the stations all day, which limited their utility to other users. To expand access, the hospital replaced these units with networked ones that included a fee for charging with an additional fee for remaining plugged in after charging. This encourages users to move their vehicles after they are finished charging and frees up the units for other users.

V. Best Practice Recommendations

The following best practices offer potential opportunities for jurisdictions and PEV stakeholders to improve the installation process and encourage greater adoption of EVCS. The Plug-in SD program will provide assistance to jurisdictions to adopt best practices. This includes the development of resources and technical assistant from an "EV expert."

Best Practice: Standardization of EVCS Building Codes and Installation Requirements
Standardization of EVCS requirements across jurisdictions during planning, design and installation helps installers understand local requirements and deploy EVCS in a more streamlined fashion. Adoption of a streamlined permitting process may become a requirement for California jurisdictions over the next two years if Assembly Bill 1236[xxvi] is signed into law.

To facilitate EVCS installations, local building departments can establish guidelines highlighting model installation scenarios at residential and nonresidential buildings. The OPR *ZEV Guidebook* has recommendations for standardized permitting and installation processes that local jurisdictions can adopt. For example, the guidebook recommends local governments to include language about ZEV readiness in their general plans and to prioritize different types of charging as part of a general land use or zoning ordinance update.

Best Practice: Adopt Voluntary CALGreen Codes

Local governments can consider adopting CALGreen voluntary codes that require a higher number of parking spaces to be capable of supporting PEV charging, including sufficient panel capacity and conduit. By adopting CALGreen voluntary standards, local governments can advance PEV adoption to reach near-term and long-term state goals for zero-emission vehicles while avoiding retrofit costs per charging space by prewiring spaces for EV charging infrastructure.

The California Air Resources Board (ARB) has prepared suggested code changes as documented in a Technical and Cost Analysis[xxvii] for Nonresidential Buildings for EV Charging Provisions in the CALGreen Code. ARB's suggested code changes for nonresidential buildings recognize that the latest CALGreen Code, effective July 1, 2015, for EV-capable building are a good first step that provide EV charging infrastructure in new construction. In order to adequately meet future demand for EV charging, the ARB recommends that CALGreen Code be strengthened to require more EV charging infrastructure during the 2016 code cycle and be adopted by local governments. Jurisdictions who adopt CALGreen can provide cost savings for PEV owners and EVCS installers as shown in ARB's Technical and Cost Analysis.

Jurisdictions can encourage EVCS installations by offering reduced permit fees.

Best Practice: Training for Electrical Contractors

To meet the demand for additional infrastructure, there is a need for local electrical contractors who are trained and knowledgeable about PEVs and EVCS. It is important to the PEV industry and local governments to ensure that contractors are completing safe and reliable installations for their customers and constituents. EVCS installations should be completed by a licensed electrical contractor. The Contractor State License Board (CSLB) classifies the licensed electrical contractor as a C-10 Electrical Contractor.[xxviii] A C-10 Electrical Contractor will need to be familiar with National Electric Code (NEC) Article 625 specific to EVCS. The California Building Standards Commission bases the California Electrical Code Title 24, Part 3, Article 625 on the NEC standards.

NEC considers EVCS a continuous load, which impacts how wiring must be sized. Electricians who do not have familiarity with EV charging may not be aware of this and install the incorrect size of wire or circuit breaker. Load monitoring and completing accurate load calculations is crucial in the site assessment phase. Incorrect load calculations can delay permit processing and approval. Electrical load calculations and examining the existing electrical panel are imperative to determining if a panel upgrade is necessary, which significantly impacts the overall costs and timeline of the installation.

Training programs on regulations, standards and code provisions facilitates the development of a skilled workforce to support the large-scale deployment of PEV infrastructure. The Electric Vehicle Infrastructure Training Program (EVITP)[xxix] provides training for EVCS installation in commercial and residential markets. EVITP facilitates training and certification for installations addressing technical, safety and performance requirements. Additional training is available at training centers in the San Diego region as described in *Plug-in Electric Vehicles: Resources for Electrical Contractors.*[xxx] EVCS training for all licensed contractors is an important component of providing safe, high-quality and efficient installations. Local governments could work with community colleges or NECA/IBEW instructors to set up training in their jurisdictions.

Best Practice: EVCS Incentives and Financing Programs

EVCS Installation Incentives

Various federal, state and local programs have provided incentives for EVCS installation. Although many of these programs are no longer active, the ARB's Drive Clean website[xxxi] maintains a listing of current incentives.

Jurisdictions can encourage proper EVCS installations by offering EVCS incentive programs that reduce the cost of installations to be performed by qualified, licensed EVCS contractors and demonstrate closure of building permits. The City of Encinitas provides an "energy efficiency permit waiver" that foregoes the fee for residential EVCS applications. A permit fee waiver incentivizes contractors and customers to obtain a permit and ensures that the installation will receive a final inspection. This best practice also saves installation costs for applicants, incentivizes permit pulling and allows a jurisdiction to track EVCS installation in its community.

San Diego Gas & Electric has proposed a vehicle-grid integrated charging program that would include utility-funded installation of EVCS at multi-unit and workplace sites. SDG&E would use price signals to encouraging charging at times when there is sufficient grid capacity and discharge charging at times the grid is under strain. This program is currently under review by the California Public Utilities Commission, but would likely result in increased local installations if approved.

Financing for EVCS

For potential EVCS hosts, the upfront cost of installation can be a deterrent; however, there are financing programs available that contractors can promote to customers.[xxxii] PACE financing allows property owners to fund energy efficiency and renewable energy projects for residential or commercial properties with little or no upfront costs. Currently, all 19 jurisdictions in the San Diego region offer PACE financing. Coupling EVCS with the installation of solar photovoltaic (PV) systems is also an option when applying to for financing through PACE. The installation cost can also be lower when combined with a larger project.

Lastly, the California Energy Commission has allocated $2 million to the CalCap Electric Vehicle Charging Station (EVCS) Pilot Financing Program[xxxiii] launched in June 2015. The CalCap program encourages small businesses to install EVCS through a combination of low-interest financing combined with a rebate. Small businesses work directly with the lender to apply for a loan and are eligible for a 10-15% rebate when the load is repaid. Participating lenders are identified on the CalCap website.

Best Practice: EVCS Guidelines and Installation Checklists

The City of Oceanside's Building and Division provides Residential Electric Vehicle (EV) Charger Guidelines[xxxiv] to assist permit applicants in the permitting, installation and inspection process. The guidelines provide tools to assist in service load calculations, as well as general installation guidelines for Level 2 residential chargers and type and size of wire and conduit for EVCS circuits.

To streamline the permitting process and assist municipal staff and contractors with completing installations more smoothly, Plug-in SD will create an installation checklist and provide subregional workshops for training. (See Appendix A.)

An installation checklist will guide both contractors and inspectors in completing the installation properly and efficiently. The checklist will including all the steps to plan and execute a successful EVCS installation project including equipment and site considerations, permitting, electrical connections and commissioning.

VI. Conclusion

As the State of California seeks to achieve its ambitious energy and climate goals, the adoption of plug-in electric vehicles is expected to greatly increase.

Improving the installation process for EVCS will aid the growth of infrastructure and, in turn, continue to encourage the deployment of PEVs throughout the San Diego region. This report offers several recommendations to improve the existing installation processes in the region. EVCS installations should be a routine task performed by electrical contractors and supported by building department staff. The Plug-in SD program will help to support jurisdictions and contractors that want to institute best practices for EVCS installation

A separate Plug-in SD report, *Electric Vehicle Charging Station Permitting and Inspection Best Practices: A Guide for Local Governments*,[xxxv] offers more information on the local government EVCS permitting and inspection process. In addition, the “EV expert” offers assistance and serves as a one-stop shop for jurisdictions looking for more resources to support permitting and installation and encourage EVCS deployment. Through sustained efforts, the San Diego region can foster widespread and accessible PEV infrastructure that meets the needs of current and future PEV drivers.

Appendix A: Installation Checklists

INSTALLATION CHECKLIST FOR MULTI-UNIT DWELLING ELECTRIC VEHICLE CHARGING STATION (EVCS)

Installations must be completed by a licensed electrical contractor (C-10). (Local Regulations, California Electrical Code CEC Article 625) Plans must show conformance with the California Electrical Code Title 24, Part 3, the California Building Code (Volume 1 and 2), Title 24, Part 2, and other applicable local municipal codes.

Submittal Documents required*

- ☐ **Permit Application**
    - **i.** Include job address (a unique address for the EVCS installation that is used for billing), parcel number, existing use, description of work, name, address, and contact information of the applicant and the owner.
- ☐ **Plan Sets (#, size of plans)**
    - **a. Site/Plot Plan**
        - **i.** Show full property extent (property lines, parking areas, structures, etc.).
        - **ii.** List relevant property information, such as existing parking counts and ratios.
        - **iii.** Provide a detailed site plan showing where the charging unit is located within the parking garage or lot, and any necessary accessibility improvements
        - **iv.** As required by type of EVCS, installation mounting method, and local jurisdiction requirements provide necessary structural details.
    - **b. Electrical Plan**
        - **i.** Provide a complete electrical single line drawing showing the main service, sub panels and disconnecting means as applicable, and proposed EV charging unit, include; size of overcurrent protection devices (in amperes) for main service, sub panels, disconnects and EV charger circuit supply, show conduit sizes and types, and conductor sizes and types.
        - **ii.** Provide a trenching detail and call out trench work in the scope of work on the plan if trenching is required. Trenching may result in a structural plan review if conduit trenches undermine foundations.
        - **iii.** Note electrical feeder requirements when trenching structure to structure (CEC 225). The feeder from structure to structure should be noted in the scope of work. Verify that trenching is in compliance of minimum cover requirements for wiring methods or circuits (18" for direct burial per CEC 300).
        - **iv.** Provide EVSE manufacturer's specification sheets showing Nationally Recognized Testing Laboratory (NRTL) approved listing mark for indoor or outdoor (UL 2202/UL 2200).
- ☐ **Electrical Load Calculation Worksheet**
    - **i.** Include existing and proposed load to estimate if existing electrical service will handle the new load from EVCS and wiring methods. Note: Unless electrical service equipment is 100% rated, the calculated load demand on the main

service shall not exceed 80% of the nameplate rating of the main service over-current protection device (OCPD).

***All plans and documents listed above must be provided for multi-unit dwelling electric vehicle charging stations at time of permit submittal prior to issuance.**

Pre-Installation Work

1. Determine units to be installed. Follow all manufacturer specifications for installation. Must be NRTL listed and suitable for the location, indoor or outdoor.

2. Conduct site assessment and submit quote to customer for approval of work and utility upgrades or new service if applicable. Assess the site for:
    a. All electrical system elements (main service, sub-panels, disconnecting means, etc.)
    b. Current electrical code deficiencies
    c. Existing electrical load
    d. Wet and dry utility locations (affecting trench paths for electrical)
    e. Presence of corrosive conditions (e.g. salt air, etc.) affecting recommended equipment
    f. Water drainage (to avoid locating EVCS in areas with possible standing water)
    g. Site accessible parking, and / or accessibility of proposed EVCS
        i. Site slope at proposed EVCS location
        ii. Surface conditions
        iii. Access path(s) connectivity to on-site uses
    h. Visibility of proposed EVCS from uses on site, and/or from public rights-of-way (safety)
    i. Site lighting for use of EVCS and general safety
    j. Placement of EVCS to serve only one versus multiple parking stalls (dependent on hosts intended use of the EVCS)
    k. EVCS protection from vehicle damage through proper placement, and then physical protection (e.g. wheel stops, bollards)
    l. EVCS orientation
        i. Facilitating ease of human interface
        ii. Minimizing sun exposure on digital screens
        iii. Facilitating ease of cable management
    m. Placement and/or screening of electrical support equipment (e.g. transformers, meter pedestals/cabinets, etc.) as it relates to site aesthetics
    n. Need for signage and / or stenciling at the EVCS location(s), and / or as directional signage on large sites

3. Complete permit application from local jurisdiction and electrical load calculation for proposed stations (Include load calculations for EVCS):
    a. Mandatory requirements for new construction in new multifamily dwellings of 17 or more units to be EV Capable. 3% of the total parking spaces, but not less than one, shall be capable for supporting future EVCS. (CALGreen Code Section 4.106.4.2)

4. Contact SDG&E for service work order for utility upgrades/notification of new service. File Service and Meter Request Form (http://www.sdge.com/service-and-meter-request-form).
    a. Ensure SDG&E work order is approved. Any work on the utility side of the electric service requires a work order and disconnect/re-connect.

b. Following SDG&E approval, permit is approved, issued and appropriately posted.

5. Construction plans indicate how requirements for types of wiring and installation siting. Show compliance with requirements of NFPA 70, CEC Article 625.

6. Construction plans show compliance with the California Building Code Title 24, Part 2, Section 11B-812 and Section 11B-228.

   a. Signage for EVCS (International Symbol of Accessibility (ISA) signage for ADA accessible spots be provided in compliance with Section 11B-812.8).
   b. For a facility for public and common use, minimum number of EVCS required to comply with Section 11B-812.

Equipment and Scheduling

7. Schedule all necessary contract work for installation of new service (if applicable), and pulling wires from electric panel(s) / meter pedestals to parking structure(s) or lot(s):
   a. Boring, trenching, concrete and/or paving restoration if these operations are included in project scope
   b. Indoor-rated EVCS can be installed in a garage (CEC 625.29)
   c. Outdoor installations require outdoor-rated EVCS (CEC 625.30)
   d. Coordinate with property manager, Homeowners Association, property owner(s), and/or tenants for scheduling installation

8. Coordinate with the utility for markings of existing power lines, gas lines or other infrastructure is completed and utilize "call before you dig" services (811), service upgrade, new service/meter pull.

Installation

9. Secure the construction area appropriately (e.g. temporary fencing, barriers and signage) for safe working conditions. Prepare mounting surface prior to installation.

10. Remove material to run conduit and/or wiring (i.e., drywall, insulation, pavers, concrete, pavement, earth, etc.).

11. Install rough electrical conduit, boxes and fittings, subpanels etc. in walls, ceilings, floors and trenches to be covered.

12. Request a rough inspection from the building inspection office prior to covering any rough electrical installations.

13. Install charging unit(s) per manufacturer instructions and permitted construction plans. (CEC 110.3)

    a. Install circuit conductors of appropriate size to comply with rating of the overcurrent protection. Securely fasten wiring to the structure. (CEC 300.11, CEC 210.19, CEC 215.2(A), CEC 110.3(B); CEC 310.15(B))

b. Identify and install properly sized equipment grounding conductor with the branch circuit. Connect at the EVCS and panelboard or service. (CEC 250.110, 112, 114, 119, 120, 122; CEC 300.3(B))

c. Bring grounded conductor to the service disconnect and bond to the enclosure. (CEC 250.24 (C))

d. Install overcurrent protection for any newly installed service equipment and conductors. (CEC 230.90, 91)

e. Install disconnect in proper readily accessible location for EVCS that is rated more than 60 amperes or more than 150 Volts to ground (CEC 625.23) If additional service disconnects are installed, verify that they are grouped and do not exceed the maximum number of service disconnects. (CEC 230.71, 72)

f. Identify branch circuit device and disconnects. (CEC 408.4 (A); CEC 110.22(A))

g. Install properly sized supply-side bonding jumpers. (CEC 250.50, 104(A) and (B))

14. Install wheel blocks/safety bollards as needed, and per approved plans. (CEC 110.27(B))

15. Perform finish work to repair existing surfaces, infrastructure, and landscaping, and parking lot striping (if applicable).

16. Make electrical connection and schedule for inspection with local jurisdiction Building Inspector

INSTALLATION CHECKLIST FOR NON-RESIDENTIAL ELECTRIC VEHICLE CHARGING STATION (EVCS)

Installations must be completed by a licensed electrical contractor (C-10). (Local Regulations, California Electrical Code CEC Article 625) Plans must show conformance with the California Electrical Code Title 24, Part 3, the California Building Code (Volume 1 and 2), Title 24, Part 2, and other applicable local municipal codes.

Submittal Documents required*

- ☐ **Permit Application**
  - **a.** Include job address (a unique address for the EVCS installation that is used for billing), parcel number, existing use, description of work, name, address, and contact information of the applicant and the owner.
- ☐ **Plan Sets (#, size of plans)**
  - **a. Site/Plot Plan**
    - **i.** Show full property extent (property lines, parking areas, structures, etc.).
    - **ii.** List relevant property information, such as existing parking counts and ratios.
    - **iii.** Provide a detailed site plan showing where the charging unit is located within the parking garage or lot, and any necessary accessibility improvements
    - **iv.** As required by type of EVCS, installation mounting method, and local jurisdiction requirements provide necessary structural details.
  - **b. Electrical Plan**
    - **i.** Provide a complete electrical single line drawing showing the main service, sub panels and disconnecting means as applicable, and proposed EV charging unit, include; size of overcurrent protection devices (in amperes) for main service, sub panels, disconnects and EV charger circuit supply, show conduit sizes and types, and conductor sizes and types.
    - **ii.** Provide a trenching detail and call out trench work in the scope of work on the plan if trenching is required. Trenching may result in a structural plan review if conduit trenches undermine foundations.
    - **iii.** Note electrical feeder requirements when trenching structure to structure (CEC 225). The feeder from structure to structure should be noted in the scope of work. Verify that trenching is in compliance of minimum cover requirements for wiring methods or circuits (18” for direct burial per CEC 300).

iv. Provide EVSE manufacturer's specification sheets showing Nationally Recognized Testing Laboratory (NRTL) approved listing mark for indoor or outdoor (UL 2202/UL 2200).

☐ **Electrical Load Calculation Worksheet**

a. Include existing and proposed load to estimate if existing electrical service will handle the new load from EVCS and wiring methods Note: Unless electrical service equipment is 100% rated, the calculated load demand on the main service shall not exceed 80% of the nameplate rating of the main service over-current protection device (OCPD).

***All plans and documents listed above must be provided for non-residential electric vehicle charging stations at time of permit submittal prior to issuance.**

Pre-Installation Work

1. Determine unit to be installed. Follow all manufacturer specifications for installation. Must be NRTL listed and suitable for the location, indoor or outdoor.

2. Conduct site assessment and submit quote to customer for approval of work and utility upgrades or new service if applicable. Assess the site for:

   a. All electrical system elements (main service, sub-panels, disconnecting means, etc.)
   b. Current electrical code deficiencies
   c. Existing electrical load
   d. Wet and dry utility locations (affecting trench paths for electrical)
   e. Presence of corrosive conditions (e.g. salt air, etc.) affecting recommended equipment
   f. Water drainage (to avoid locating EVCS in areas with possible standing water)
   g. Site accessible parking, and / or accessibility of proposed EVCS
      i. Site slope at proposed EVCS location
      ii. Surface conditions
      iii. Access path(s) connectivity to on-site uses
   h. Visibility of proposed EVCS from uses on site, and/or from public rights-of-way (safety)
   i. Site lighting for use of EVCS and general safety
   j. Placement of EVCS to serve only one versus multiple parking stalls (dependent on hosts intended use of the EVCS)
   k. EVCS protection from vehicle damage through proper placement, and then physical protection (e.g. wheel stops, bollards)
   l. EVCS orientation
      i. Facilitating ease of human interface
      ii. Minimizing sun exposure on digital screens
      iii. Facilitating ease of cable management
   m. Placement and/or screening of electrical support equipment (e.g. transformers, meter pedestals/cabinets, etc.) as it relates to site aesthetics

n. Need for signage and/or stenciling at the EVCS location(s), and / or as directional signage on large sites

3. Complete permit application from local jurisdiction and electrical load calculation for proposed stations:
    a. Mandatory requirements for new construction to be EV Capable. 3% of spaces in lots of 51+ spaces must be capable of supporting future charging. (CALGreen Code Section 4.106.4 and 5.106.5.3)
    b. Comply with zoning setbacks and easements. (Local Regulations)

4. Contact SDG&E for service work order for utility upgrades/notification of new service. File Service and Meter Request Form (http://www.sdge.com/service-and-meter-request-form).
    a. Ensure SDG&E work order is approved. Any work on the utility side of the electric service requires a work order and disconnect/re-connect.
    b. Following SDG&E approval, permit is approved, issued and appropriately posted.

5. Construction plans show compliance with the California Building Code Title 24, Part 2, Section 11B-812 and Section 11B-228:
    a. Signage for EVCS (International Symbol of Accessibility (ISA) signage for accessible spots be provided in compliance with Section 11B-812.8)
    b. For a facility for public and common use, minimum number of EVCS required to comply with Section 11B-812.

6. Construction plans must show compliance with requirements of NFPA 70, CEC Article 625.

Equipment and Scheduling

7. Schedule all necessary contract work for installation of new service (if applicable), and pulling wires from electric panel/meter pedestal to parking structure or lot:
    a. Boring, trenching, concrete and/or paving restoration
    b. Coordinate with building managers, tenants and/or property owner(s) for scheduling installation, including site cleanup/closeout

8. Coordinate with the utility for markings of existing power lines, gas lines or other infrastructure is completed and utilize “call before you dig” services (811), service upgrade, new service/meter pull.

Installation

9. Secure the construction area appropriately (e.g. temporary fencing, barriers and signage) for safe working conditions. Prepare mounting surface prior to installation.

10. Remove material to run conduit and/or wiring (i.e., drywall, insulation, pavers, concrete, pavement, earth, etc.).

11. Install rough electrical conduit, boxes and fittings, subpanels etc. in walls, ceilings, floors and trenches to be covered.

12. Request a rough inspection from the building inspection office prior to covering any rough electrical installations.

13. Install charging unit(s) per manufacturer instructions and permitted construction plans. (CEC 110.3)

    a. Install circuit conductors and wiring of appropriate size to comply with rating of the overcurrent protection. Securely fasten wiring to the structure. (CEC 300.11, CEC 210.19, CEC 215.2(A), CEC 110.3(B); CEC 310.15(B))

    b. Identify and install properly sized equipment grounding conductor with the branch circuit. Connect at the EVCS and panelboard or service. (CEC 250.110, 112, 114, 119, 120, 122; CEC 300.3(B))

    c. Bring grounded conductor to the service disconnect and bond to the enclosure. (CEC 250.24 (C))

    d. Install overcurrent protection for any newly installed service equipment and conductors. (CEC 230.90, 91)

    e. Install disconnect in proper readily accessible location for EVCS that is rated more than 60 amperes or more than 150 Volts to ground (CEC 625.23) If additional service disconnects are installed, verify that they are grouped and do not exceed the maximum number of service disconnects. (CEC 230.71, 72)

    f. Identify branch circuit device and disconnects. (CEC 408.4 (A); CEC 110.22(A))

    g. Install properly sized supply-side bonding jumpers. (CEC 250.50, 104(A) and (B))

14. Install wheel blocks/safety bollards as needed, and per approved plans. (CEC 110.27(B))

15. Perform finish work to repair existing surfaces, infrastructure, and landscaping, and parking lot striping (if applicable).

16. Make electrical connection and schedule for inspection with local jurisdiction Building Inspector.

Endnotes

[i] During 2012-13, REVI identified major barriers to EVCS deployment and PEV adoption through collaboration with local jurisdictions, regional public agencies, San Diego Gas & Electric, local universities and community colleges, IBEW Local 569, the National Electric Contractors Association and the local San Diego business community. The outcome of REVI was the San Diego Regional PEV Readiness Plan that identifies and resolves barriers to the widespread deployment of private and public PEV charging infrastructure, http://www.sandag.org/index.asp?projectid=413&fuseaction=projects.detail.

[ii] *Zero-Emission Vehicles in California: Community Readiness Guidebook* (2013), Governor's Office of Planning and Research, http://opr.ca.gov/docs/ZEV_Guidebook.pdf.

[iii] See *Plug-in SD's EVCS Permitting and Inspection Best Practices: A Guide for Local Governments*, 2016, http://www.sandag.org/uploads/projectid/projectid_511_19814.pdf.

[iv] PEVs include battery electric vehicles and plug-in hybrid electric vehicles. Center for Sustainable Energy (2016). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. Data last updated June 6, 2016. Retrieved June 16, 2016 from https://cleanvehiclerebate.org/eng/rebate-statistics

[v] Governor Brown's Zero-Emission Vehicle Executive Order, March 23, 2012, https://www.gov.ca.gov/news.php?id=17463.

[vi] Alternative Fuels Data Center, Alternative Fuel Stations Dataset. Data last updated September 28, 2015. Retrieved September 28, 2015, from http://www.afdc.energy.gov/data_download/.

[vii] National Renewable Energy Laboratory, *California Statewide Plug-In Electric Vehicle Infrastructure Assessment*, 2014, http://www.energy.ca.gov/2014publications/CEC-600-2014-003/CEC-600-2014-003.pdf.

[viii] *San Diego Regional Plug-In Electric Vehicle Readiness Plan* (2014), p. 13, http://www.sandag.org/uploads/publicationid/publicationid_1817_17061.pdf.

[ix] Ibid. p. 8-9.

[x] CALGreen, 2013, http://hcd.ca.gov/codes/state-housing-law/calgreen_guide_rev_12-13.pdf.

[xi] PEV Collaborative MUD Guidelines, figure 5.1, page 13, http://www.pevcollaborative.org/sites/all/themes/pev/files/docs/reports/MUD_Guidelines4web.pdf.

[xii] The EV Project, *How do Residential Level 2 Charging Installation Costs Vary by Geographic Location?*, 2015, http://avt.inel.gov/pdf/EVProj/HowDoResidentialChargingInstallationCostsVaryByGeographicLocations.pdf.

[xiii] NEIS® ANSI standard for EVCS, http://www.necanet.org//store/product/neca-413-2012-standard-for-installing-and-maintaining-electric-vehicle-supply-equipment-(EVCS)-Standard.

[xiv] California Electrical Code, Title 24, Part 6, Article 625, http://www.nfpa.org/codes-and-standards/document-information-pages/free-access?mode=view.

[xv] OPR Zero-Emission Vehicles in California: Community Readiness Guidebook Permitting Checklist, p. 112-115.

[xvi] Clean Cities, *Plug-in Electric Vehicle Handbook for Electrical Contractors*, http://www.afdc.energy.gov/pdfs/51228.pdf.

[xvii] *Zero-Emission Vehicles in California: Community Readiness Guidebook*, 2013, http://opr.ca.gov/docs/ZEV_Guidebook.pdf.

[xviii] *Plug-in SD's EVCS Permitting and Inspection Best Practices: A Guide for Local Governments*, 2016, http://www.sandag.org/uploads/projectid/projectid_511_19814.pdf.

[xix] The Cal Electric Residential EVCS Program, 2015, http://www.energycentral.com/enduse/electricvehicles/articles/3203/The-Cal-Electric-Residential-EVCS-Program.

[xx]DSA's 2016 access web reference, Final Express Terms for Proposed Building Standards of the Division of the State Architect (DSA-AC), pages 74-90, http://www.documents.dgs.ca.gov/dsa/access/2016-Pt2_Final-Express-Terms_12-22-15.pdf.

[xxi] City of San Diego Technical Policy 11B-1, http://www.sandiego.gov/development-services/pdf/industry/tpolicy11b1.pdf.

[xxii] Advanced Energy, 2014, Charging Station Installation Handbook for Electrical Contractors and Inspectors, http://www.advancedenergy.org/portal/ncpev/resources/ESVEHandbook.pdf.

[xxiii] PEV Collaborative, *Plug-In Electric Vehicle Charging Infrastructure Guidelines for Multi-Unit Dwellings*, *http://www.pevcollaborative.org/sites/all/themes/pev/files/docs/MUD_Guidelines4web.pdf.*

[xxiv] *Plug-In Electric Vehicle Charging Infrastructure Guidelines for Multi-Unit Dwellings*, Ibid., p. 24-25, http://www.pevcollaborative.org/sites/all/themes/pev/files/cityfront%20copy.pdf.

[xxv] CALSTART, 2013, Best Practices for Workplace Charging, *http://www.calstart.org/Libraries/Publications/Best_Practices_for_Workplace_Charging.sflb.ashx*.

[xxvi] AB 1236 local ordinances: electric vehicle charging stations, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1236, enrolled September 11, 2015.

[xxvii] California Air Resources Board, 2015, Electric Vehicle Charging Infrastructure Provisions, http://www.documents.dgs.ca.gov/bsc/2015TriCycle/CAC/GREEN/Exhibit-B-CARB-Cost-Analysis-and-Technical-Report.pdf.

[xxviii] C-10 Electrical Contractor, http://www.cslb.ca.gov/About_Us/Library/Licensing_Classifications/C-10_-_Electrical.aspx.

[xxix] EVITP Training Program, http://www.evitp.org/training-programs/.

[xxx] Plug-in Electric Vehicles: Resources for Electrical Contractors, https://energycenter.org/sites/default/files/docs/nav/programs/pev-planning/san-diego/fact-sheets/Electrical%20Contractor%20Fact%20Sheet.pdf.

[xxxi] California Air Resources Board, DriveClean.ca.gov, http://www.driveclean.ca.gov/.

[xxxii] Property assessed clean energy (PACE), http://energycenter.org/policy/property-assessed-clean-energy-pace.

[xxxiii] CalCap EVCS Financing Program, http://www.treasurer.ca.gov/cpcfa/calcap/evcs/.

[xxxiv] City of Oceanside Residential Electric Vehicle (EV) Charger Guidelines, 2012 http://www.ci.oceanside.ca.us/civicax/filebank/blobdload.aspx?blobid=30053.

[xxxv] *Plug-In SD's EVCS Permitting and Inspection Best Practices: A Guide for Local Governments*, 2016, http://www.sandag.org/uploads/projectid/projectid_511_19814.pdf

GEORGETOWN CLIMATE CENTER

EV-READY CODES FOR THE BUILT ENVIRONMENT

Electric Vehicle Supply Equipment Support Study

Prepared for:
New York State Energy Research and Development Authority
and
Transportation and Climate Initiative

Prepared by:
WXY Architecture + Urban Design
Bruce J. Spiewak, AIA, Consulting Architect, LLC
and
Energetics Incorporated

November 2012

NOTICE

This material is based upon work supported by the U.S. Department of Energy under Award Number #DE-EE0005586.

This report was prepared as an account of work sponsored by an agency of the United States Government, the New York State Energy Research and Development Authority and the State of New York. Neither the United States Government, the State of New York nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer or otherwise does not necessarily constitute or imply its endorsement, recommendation or favoring by the United States Government, the State of New York or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Information and documents published under the name of the Transportation and Climate Initiative (TCI) represent work produced in support of the TCI or its projects. TCI materials do not necessarily reflect the positions of individual jurisdictions or agencies unless explicitly stated.

TCI is a collaboration of the transportation, energy and environment agencies from the 11 Northeast and Mid-Atlantic states and Washington, DC, focused on reducing greenhouse gas emissions from the transportation sector. Jurisdictions participating in this TCI project are Connecticut, Delaware, Washington, D.C., Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont. Clean Cities Coalitions from the Northeast and Mid-Atlantic regions are working with the TCI states on this project through the Northeast Electric Vehicle Network.

This document was commissioned by TCI, and was developed as part of the Electric Vehicle Supply Equipment (EVSE) Support project awarded under NYSERDA Program Opportunity Notice (PON) 2392 to Energetics Incorporated. The research, interviews and analysis in this report were performed by WXY Architecture + Urban Design (Project team Adam Lubinsky, Jennifer Gardner and Paul Salama), with support from Energetics Incorporated and Bruce J. Spiewak, AIA, Consulting Architect LLC.

ACKNOWLEDGEMENTS

Thank you to the following individuals for their experience and insight into planning, regulating and deploying electric vehicle charging infrastructure:

Denis Clements, Electrical Program Chief, Oregon Building Codes Division

Richard Cromie, Program Manager, Advanced Technology, Southern California Edison

Mark W. Earley, P.E., Chief Electrical Engineer, National Fire Protection Association

Ken Frank, Sustainability Manager, New Jersey Department of Environmental Protection

Jim Jensen, Senior Bioenergy and Alternative Fuels Specialist, Energy Program, Washington State University

Ari Kahn, Electric Vehicle Policy Analyst, New York City Office of Long-Term Planning and Sustainability

Brian Kiley, Edgewood Electric

James McCabe, Senior Director of Standards Facilitation, American National Standards Institute

Patti Miller-Crowley, Washington State Department of Commerce and member of the State EV Task Force

Beth Neaman, External Engagement, Advance Technology Group, PEV Readiness Program, Southern California Edison

Michael Pfeiffer, Deputy Senior Vice President, Technical Services, International Code Council

Malcolm Shield, Climate Programs Engineer, Sustainability Group, City of Vancouver Sustainability Group

Additional thanks to the Georgetown Climate Center, particularly **Cassandra Powers** of the Transportation and Climate Initiative (TCI), for its guidance and coordinating efforts without which this report and review process would not have been possible, as well as to the **Clean Cities Coordinators,** the **TCI Clean Vehicles and Fuels Workgroup, Gustavo Collantes,** President, Logios and **Mark Stout**, President, Mark L. Stout Consulting for their collective review and feedback.

LIST OF ABBREVIATIONS

AC	Alternating Current
ANSI	American National Standards Institute
ANSI EVSP	American National Standards Institute Electric Vehicles Standards Panel
ARRA	American Recovery and Reinvestment Act
BC	British Columbia
BCD	Building Codes Division (Oregon)
CALGreen	California Green Building Code
DC	Direct Current
DOE	U.S. Department of Energy
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse Gas
IBC	International Building Code
ICC	International Code Council
IgCC	International Green Construction Code
IRC	International Residential Code
MOU	Memorandum of Understanding
NEC	National Electrical Code
NEIS	National Electrical Installation Standards
NFPA	National Fire Protection Association
NTTAA	National Technology Transfer and Advancement Act
NYSERDA	New York State Energy Research and Development Authority
ODOT	Oregon Department of Transportation
PGE	Portland General Electric
SAE	Society of Automotive Engineers
SCE	Southern California Edison
SEC	Seattle Electrical Code
TCI	Transportation and Climate Initiative
UL	Underwriters Laboratory
VAC	Volt Alternating Current

CONTENTS

	ACKNOWLEDGEMENTS	**i**
	LIST OF ABBREVIATIONS	**ii**
	EXECUTIVE SUMMARY	**v**
	Overview: EV-Ready Codes for the Built Environment	v
	Case Studies	vi
	Summary of Key Findings	vi
1.	**INTRODUCTION**	**1**
1.1.	Project Origins	2
1.2.	Codes Regulate the Built Environment	2
1.3.	Codes Contribute to EV Readiness	4
1.4.	Code Modifications are Just One Tool at a Jurisdiction's Disposal	6
1.5.	Objectives and Methodology	8
1.6.	Report Structure	9
2.	**CODES IN POLICY AND PRACTICE: NATIONAL LANDSCAPE**	**11**
2.1.	What are Codes and Standards?	11
2.2.	National Codes and the Federal Role	15
2.3.	Overview of National Model Codes and their Purview	16
2.4.	New Technology Outlook	22
3.	**LOCAL CODES FROM MODEL STATES AND MUNICIPALITIES**	**24**
3.1.	Local Planning for a Regional Infrastructure Network	24
3.2.	Vancouver: An EV-Ready Building Code	27
3.3.	Los Angeles: Green Construction Codes and Utility Planning	33
3.4.	Oregon: State-Level Electrical Code Amendments	40
4.	**SUMMARY AND NEXT STEPS**	**47**
4.1.	Case Studies in Summary	47
4.2.	Central Themes and Preliminary Recommendations	48
	APPENDIX A: CHARGING LEVELS	**56**
	APPENDIX B: SUMMARY OF EVSE STANDARDS	**577**
	APPENDIX C: OTHER LOCAL PLANNING TOOLS	**588**
	APPENDIX D: CODE LANGUAGE DOCUMENTATION	**60**
	Sample Building Code Amendments for EVSE	60
	Sample Electrical Code Amendments for EVSE	666

This page intentionally left blank.

EXECUTIVE SUMMARY

Overview: EV-Ready Codes for the Built Environment

Electric vehicles (EVs) are being delivered to the Northeast and Mid-Atlantic markets in increasing numbers, and the battery-charging infrastructure that supports them is being deployed with different location and business models, technology configurations and utility communication networks. Each state, city and town will face a need consider the full scope of regulatory measures available to plan for the anticipated growth in the EV sector in order to facilitate and encourage consistent and accessible infrastructure deployment. The challenges presented by evolving technology and market transitions are significant but not insurmountable; however, they call for comprehensive planning and implementation strategies to account for stakeholder needs and to allow localities to capture the economic and environmental benefits associated with EVs.

The purpose of this report is to build on the discussion and knowledge base required to support electric vehicle supply equipment (EVSE) deployment through the elimination of barriers to widespread deployment by describing the role of building and electrical codes in encouraging or inhibiting the implementation of EVSE and to aid local and state practitioners in assessing local code-specific barriers and identifying the code provisions that would encourage a basic or advanced level of EV readiness in local policies and regulations. EVSE is the infrastructure required to charge an EV—from the cable that connects the vehicle to the charging unit up to the conduit that links the charging location to the utility grid and power supply.[1] The report will also highlight the processes and participants in creating, administering and amending such codes, and will explore the potential for jurisdictions to adopt codes that could encourage EVSE. The subject of analysis is the policy framework and state- and local-level adoption and amendment processes specific to the two key national model codes that impact EVSE installation and inspection: the National Electrical Code (NEC), published by the National Fire Protection Association (NFPA), and the International Building Code (IBC), published by the International Code Council (ICC). While there are other aspects of EVs and EVSE communications networks, as well as electrical utility issues that are standardized by different types of codes, these two relate most specifically to the construction and electrical equipment installation procedures associated with EVSE.

The report finds that the current national codes neither inhibit nor facilitate the implementation of EVSE, and that there are strong examples of jurisdictions where codes are successfully encouraging EV readiness. This report also finds that a proactive, rather than neutral, regulatory framework can assist in the deployment of a connected and strategically located EVSE infrastructure network in the places where drivers are most likely to charge. Structural codes are a part of that framework.

Case studies and expert interviews with codes officials, utility representatives and state and local government agencies were undertaken and describe ways in which codes adopted by states and other jurisdictions having authority can be an instrumental part of an EVSE-ready planning toolkit. A handful of states and jurisdictions across North America have already taken steps to include EV-ready provisions in some part of their structural code, and their experiences demonstrate many of the key reasons and benefits of approaching this type of infrastructure planning from the perspective of building and electrical codes. The lack of such code language at the state level in

---

[1] Please refer to Appendix A for further description and illustration of EVSE systems and requirements.

the Georgetown Transportation and Climate Initiative (TCI) region is a missed opportunity that the Northeast and Mid-Atlantic region states can work to amend.

Case Studies

Through case studies of model jurisdictions, the report will examine the efforts of and lessons learned by states and local jurisdictions regarding incorporation of EVSE-specific provisions into the building code, and consider lessons learned for model code development. Case studies include: a profile of municipal planning in Vancouver, British Columbia, Canada; initiatives in state-level planning in Oregon; and regional approaches linking city, county and utility planning in Los Angeles, California. The case studies highlight three approaches to metropolitan area and regional cooperation to address the regulatory framework that supports and monitors EV infrastructure deployment. Looking at advanced efforts at state, metropolitan area and municipal levels in forward-thinking jurisdictions, several common factors emerge regarding the successful creation of policy and regulation supportive of EV infrastructure:

- Each jurisdiction took specific and multifaceted steps to encourage use of EVs.
- Each jurisdiction considered opportunities and challenges associated with regulation at multiple levels of government, or with multiple layers of agency, authority or private sector participation, demonstrating the wide range of possibility in working with codes and other components of the regulatory environment.
- Actors in each jurisdiction identified and overcame potential regulatory barriers.

Municipal Planning in Vancouver, BC

In **Vancouver**, a municipality created a collaborative working group to develop EV-readiness strategies with the intent of meeting long-range GHG reduction goals, and it became the first North American municipality to mandate EVSE-ready electrical installation in all new residential and commercial construction.

State-Level Planning in Oregon

Oregon amended the electrical code to reflect a need to address EV-charging infrastructure in an inefficient statewide market with many early adopters concentrated in specific geographic areas and corridors, opting instead to expedite and dramatically reduce costs associated with the permitting process for residential EVSE.

Linking City, County and Utility in Los Angeles, California

In the **Los Angeles** metropolitan area, high statewide standards required by CALGreen, the nation's first mandatory green building code, and local amendments work in concert with utility-led efforts to plan for EV readiness across complex jurisdictional boundaries.

Summary of Key Findings and Recommendations

Despite the complexities inherent in the state and local decision-making process of evaluating options for EV-ready planning, there are opportunities that can be created for supporting consistent EVSE deployment planning. Structural codes do not operate alone in the local regulatory environment; they are one tool available on the regulatory menu to jurisdictions seeking to govern infrastructure deployment. Despite the environmental benefits and growing EV market in many areas across the United States and throughout the region, each jurisdiction will need to assess the costs and benefits associated with its own goals pursuant to energy efficiency, transportation electrification, green construction, air quality and economic development in order to effectively prioritize EV-readiness steps.

Existing Codes Present No Significant Barriers to EVSE Deployment

While there are no specific barriers to EVSE installation embedded in the existing national model building and electrical codes, there is room within the codes as adopted by the states to more clearly encourage EV readiness. Despite differences between jurisdictions, the structural codes themselves—model and adopted—cover existing safety concerns related to existing automotive and charging technology and permit or facilitate conditions under which EVSE can be installed.

Recommendation to Promote General Code-Related EV Readiness

- Education and training programs for inspectors and installers have become the norm as an early evaluative step in EV-readiness planning. States seeking to evaluate the need of codes and permitting processes should initiate EVSE training for professionals in related fields.

Codes Can Achieve Regional EV Readiness

There are specific reasons to consider changing codes at the state and local levels. Because code amendments are one of several interrelated strategies to encourage EVSE deployment, in considering changes, it is important for jurisdictions to consider what codes can accomplish. Codes are generally revised at the national level every three years and at the local level every six years or more, and they will be updated at the national level to meet new structural or fire safety concerns, such as those related to new and emerging technologies. Local codes will not address this topic. Where codes have more impact is specification of scoping requirements that define numerical goals or limits for certain features in new construction (e.g., percentage of required parking spaces to be built EVSE-ready). Similarly effective, codes can provide for new permitting or inspection protocols and encourage the reduction of associated administrative costs.

Local conditions will factor heavily into the decision to regulate for EVSE based on codes. Variations across the TCI region will mean that states will make different choices. States such as New Jersey, for example, with a relatively evenly distributed, dense population and centrally located transportation corridors, may find scoping requirements in the building code to be a good solution. By contrast, Maine's lack of uniform population density with residential concentration around key urbanized centers may suggest a different approach.

Recommendations for State and Regional Code Policy Cohesion

- Reduce real consumer costs of EV adoption by addressing the extreme variation in permitting fees and lowering fees for residential installations, such as through classifying residential EVSE installations as minor label work.
- Incentivize and encourage incorporation of EVSE by modifying building codes when economically appropriate to require that a percentage of accessory parking associated with new development to be pre-wired for EVSE, providing flexibility for future capacity.
- Enable state and local participation in a forum for interstate cooperation.

EVSE Deployment Contributes to Economic Development

Codes factor into economic development planning. EVs and EVSE deployment influence such disparate areas as maintaining housing affordability; providing equitable access to transportation infrastructure; creating green jobs and marketing metropolitan areas to attract new businesses, residents and institutions.

For the development and construction community, there is a need to keep costs low enough to be easily absorbed into overall project costs. However, inclusion of ESVE readiness in the building phase can be more cost effective than retrofit and increase the value of individual units as well as the community at large.

Another aspect of economic development for EVSE is that jurisdictions encouraging EV readiness will likely gain growth associated with EVs and charging infrastructure. The presence or stimulation of markets for EV and EVSE has primed the pump in early adopting jurisdictions. For example, Vancouver's signing of memoranda of understanding with auto manufacturers highlights an approach to capture a portion of the EV market.

Recommendations for Outreach, Research and Economic Development:

- Incorporate or acknowledge EVSE deployment through TCI-region state-level economic development strategy.
- Fund further research and program assessment specific to the TCI region to enable local jurisdictions to make informed decisions about costs and benefits associated with public expenditures for EVSE, and to guide development of public-private partnerships.
- Fund ongoing demonstration programs, particularly those that focus on innovation and new technology.

High-Level Flexibility Leads to Meaningful Local Options

Standardization is an important goal for EVSE and EV adoption as a means to generate industry consistency, lower costs and avoid excessive fragmentation. At the same time, EVSE policy and planning should not tie hands at the local level. California's CALGreen is an excellent example of the ability of codes to create a high-level planning framework while retaining flexibility at the local level. Significantly, a local jurisdiction's codes must be in compliance with state-level legislation, meaning state laws play a central role in establishing the range and impact of local regulatory requirements. Challenges in this arena include the creation of seamless and simple regulations using consistent language in state and local laws that limit code revision to what is necessary for compliance. State codes can offer an a la carte menu of options, standardized at the state level but adopted through tiered systems and/or on a voluntary basis by the local jurisdiction. Well-written codes may also offer phased provisions or optional parameters, maximizing the adaptability and efficacy of local regulations.

Recommendations for Maximizing Consistency across Local Jurisdictional Boundaries:

- Adopt state code amendments containing voluntary scoping and implementation options, such as tiers of compliance and voluntary appendices.
- Make consistent information and technical support available to officials across state and local agencies through the Clean Cities' Coalitions.
- State agencies having jurisdiction should introduce locally vetted modifications to the discussion of national model codes in the next possible code cycle (2015).

Partnerships Will Guide Infrastructure Deployment

Successful local plans for EVSE rollout have been comprehensive in scope; because codes are one part of the local regulatory environment, they must work in concert with other statutory requirements, economic policies, local planning and regulatory processes. It is necessary for key factors to be in place to successfully advance policy, legislation and ordinances pertaining to EV infrastructure advancement.

Highly significant among these is a forum for cooperation. The reduction of barriers to EVSE deployment will not come from code amendments alone, but rather from the collaborative efforts that can produce such amendments as a part of a comprehensive deployment strategy. Large-scale and multi-agency coalitions and working groups, public-private partnerships and work with academic and research institutions have contributed to a broad-based understanding of intersections among local and regional goals in model jurisdictions.

The role of the private sector can be just as, if not more, important in preparing the region for more comprehensive EVSE deployment. Federal and state funding can be allocated to private infrastructure developers (e.g., ECOtality's EV Project) to gather data, test business models and pilot high-visibility EV charging. Private-sector outcomes will determine many aspects of EVSE.

Recommendations for Legislative Measures to Encourage Public-Private Collaboration:

- Enable the creation of special purpose clean energy districts to connect interests and regulatory processes in the TCI region.
- Enable data exchange and access to EV ownership and EVSE installation to improve utility performance and enhance utility involvement in local and regional planning.
- Create and/or engage EVSE working groups housed within the appropriate agency in each state to leverage TCI regional stakeholder information and influence and to promote high-level cooperation.

1. INTRODUCTION

Plug-in electric vehicles are being delivered to the Northeast and Mid-Atlantic markets in increasing numbers, and the battery-charging infrastructure that supports them is being deployed with different location and business models, technology configurations and utility communication networks. Electric vehicles (EVs) and charging infrastructure are coming to states, cities and towns that have highly individualized regulations—from taxes and EV incentive programs to zoning, permitting and structural codes. Anticipated growth in the EV sector creates a need to plan ahead to facilitate and encourage consistent and accessible infrastructure deployment. The challenges presented by evolving technology and market transitions are significant but not insurmountable; however, they call for comprehensive planning and implementation strategies to account for stakeholder needs and to allow localities to capture the economic and environmental benefits associated with EVs.

This report will build on the discussion and knowledge base required to support electric vehicle supply equipment (EVSE) deployment through the elimination of barriers to widespread deployment by describing the role of building and electrical codes in encouraging or inhibiting the implementation of EVSE. Further, the report will highlight the processes and participants in creating, administering and amending such codes, and will explore the potential for jurisdictions to adopt codes that could encourage EVSE. EVSE is the infrastructure required to charge an EV—from the cable that connects the vehicle to the charging unit up to the conduit that links the charging location to the utility grid and power supply.[2] The EV industry is a developing one, and the entities that create and govern the codes and administrative processes that regulate EVs and charging infrastructure are just beginning to work together to regulate and plan for the charging infrastructure that will anticipate and provide right-sized service for a growing number of EV users.

The regulatory environment that shapes the distribution of infrastructure is itself shaped at the national, state and local levels of government. At each intersection or level of decision making, the private market—including the auto industry, utility, real estate and environmental interests—influences the regulatory choices made by a jurisdiction. For example, a town with no ability to address EVSE through codes or zoning may not be able to assist and benefit from a developer seeking to install EV charging stations in a new apartment complex. Each state or local jurisdiction will need to assess the best implementation strategy for creating an EV-friendly regulatory environment based on unique local criteria. Standards and codes ideally will make it as easy as possible for the public and private realms to interact, resulting in widespread infrastructure distribution and stimulating investment in the EVSE sector.

Codes impact one of the most significant values derived from EV use—the ability of the EV driver to charge directly from the grid—anywhere, anytime. According to University of British Columbia (BC) researcher and city of Vancouver sustainability engineer Malcolm Shield, an estimated 80%–90% of EV charging will happen at home,[3] EV drivers will also need access at work and other common driving destinations in order to achieve this key EV value proposition.[4] Where, when and how drivers are able to charge is at the discretion of the state and local jurisdictions[5]

[2] Refer to Appendix A for further description and illustration of EVSE systems and requirements.
[3] Malcolm Shield, (presentation, 2012 BC Power Symposium, Vancouver, BC).
[4] For at-home charging, multiunit dwellings and commercial locations.
[5] The term "local jurisdiction" refers broadly to municipalities, counties, towns or other designated administrative subdivisions having some powers of self-government. For the purposes of this report, local jurisdictions will primarily include incorporated municipalities or other legally separate entities with some

that regulate and permit new charging infrastructure. Of course, other significant market factors influence the value of EVs as well. For example, the regulation of electricity protects the consumer from the price fluctuations that affect petroleum fuel.

The extent to which codes and other regulatory tools can impact EV and EVSE markets has yet to be demonstrated in most U.S. cities. Case studies and expert interviews with code officials, utility representatives, planning and installation practitioners and state and local government agencies were undertaken and describe ways in which codes adopted by states and other jurisdictions having authority can be an instrumental part of an EVSE-ready planning toolkit. A handful of jurisdictions across North America have already taken steps to include EV-ready provisions in some part of their building or electrical codes, and their experiences demonstrate many of the reasons and benefits of approaching this type of infrastructure planning from the perspective of codes. A lack of specific code language addressing EVSE deployment allows for both flexibility in a developing market and the continued possibility for confusion about how to use codes to influence EV readiness, and it represents a missed opportunity in many areas for a smoother transition. This report highlights key challenges and opportunities associated with the building and electrical codes implemented nationwide. A first step is to understand which codes regulate the built environment and whether they cover EVSE, and then understand what can be gained, if anything, by altering them.

Critical and Transportation Infrastructure Development

The market for EVs is growing. There are now 11 highway-capable EV models and approximately 50,000 plug-in EVs already on the road across the United States. Anticipated changes in technology will continue to make these vehicles an increasingly viable consumer choice over the next decade. Just as gas stations provide a critical service to gasoline engine vehicles, charging infrastructure will be necessary to serve this expanding group of drivers. Further, the technological advancement projected for this field will continue to redefine this class of energy-efficient vehicles and, as such, it is critical that innovation and industry growth occur in accordance with uniform policy and high levels of safety.[6] Codes should be comprehensive but not overly restrictive to ensure this advancement.

1.1. Project Origins

The research leading to this report is supported by the New York State Energy Research and Development Authority (NYSERDA) in association with PON 2392, Electric Vehicle Supply Equipment Support, and it has been conducted by WXY Architecture and Urban Design in partnership with TCI, Energetics Incorporated and Bruce J. Spiewak, AIA, Consulting Architect LLC, with funding provided by the U.S. Department of Energy (DOE).

TCI is a collaboration of the transportation, energy and environment agencies from the 11 Northeast and Mid-Atlantic states and Washington, DC, focused on reducing greenhouse gas (GHG) emissions from the transportation sector. Jurisdictions participating in this TCI project are Delaware; Washington, DC; Maine; Maryland; Massachusetts; New Hampshire; New Jersey; New York; Pennsylvania; Rhode Island and Vermont. TCI states work closely with Clean Cities Coalitions throughout the region through the Northeast Electric Vehicle Network.

1.2. Codes Regulate the Built Environment

This report considers the policy framework and state- and local-level adoption and amendment processes specific to the two key national model codes that impact EVSE installation and

---

corporate powers. Ideally these powers include the authority to amend and adopt codes, but this will vary from state to state.

[6] James McCabe (ANSI), interview, July 12, 2012.

inspection: the National Electrical Code (NEC), published by the National Fire Protection Association (NFPA), and the International Building Code (IBC), published by the International Code Council (ICC). While there are other aspects of EVs and EVSE that will require the attention of other standards and code-setting bodies, such as communications technology and utility connections, these two model codes relate most specifically to the construction and electrical installation associated with EVSE.

In concert with zoning and other state laws and local ordinances, these structural codes determine what, where and how different types of buildings and facilities can be built, modified and used. EV infrastructure will be a critical part of the built environment in future cities and towns, and developing an understanding of the way these regulations impact the deployment of EVSE is central to planning effective infrastructure deployment across the region.

Several central considerations in planning for EVSE deployment relate to code-based regulation:

- Safety requirements for charging infrastructure
- Interoperability of EVs and EVSE across boundaries, including manufacturers, service networks and jurisdictions, as well as future-proofing against technology changes
- Implications for the electrical grid
- Growth of EVs as a viable consumer choice in a transitioning market

Unlike zoning or parking ordinances, codes are developed at the national or international level in an advisory capacity. However, states and localities generally have jurisdiction and wide latitude to adopt their own building and electrical codes and administrative permitting processes. One of the best ways of generating uniformity in design, manufacture and installation of charging facilities is to ensure the key safety and user concerns and parameters are regulated through the national codes, so that local codes operate in service of these goals.[7] Other standardized aspects of EVSE deployment and site design, such as signage, handicapped accessibility, communications systems and user interface, will require uniformity as well for effectiveness and efficiency, but fall outside the scope of the codes addressed in this report. EV infrastructure will be a critical part of the built environment in our future cities and towns, and developing an understanding of the way these codes impact the deployment of EVSE is central to planning a broadly distributed infrastructure deployment across the region and encouraging EV adoption through the elimination of barriers to charging vehicle batteries at home, at work and in transit.

As the EV market grows, the process of code writing is also evolving toward increased cooperation. Codes and standards organizations such as the ICC, the NFPA and the American National Standards Institute (ANSI) recognize that for mutual economic development across state, regional and national divisions, it is important to have consistent rules across these boundaries and to actively work toward harmonizing codes and filling gaps.[8]

1.2.1. The Infrastructure Domain

Codes and standards related to EVs apply to the vehicle and related systems in four general categories: vehicle systems, batteries, vehicle interface and charging infrastructure. This report focuses most closely on the electrical and building codes—those that directly impact installation and have implications for site design and zoning regulations and that fall under the purview of state and local governments.

ANSI's 2012 comprehensive standards and code review document for vehicle charging infrastructure, *The ANSI EVSP Standardization Roadmap for Electric Vehicles*, defines this area of

---

[7] Michael Pfeiffer (ICC), interview, July 20, 2012.
[8] Fred Wagner (Program Director, Energetics Incorporated and editor of ANSI's EVSP Roadmap), interview, August 13, 2012.

standardization as the "infrastructure domain," which "generally encompasses the technologies, equipment, components, and issues that fall within the confines of the charging infrastructure up to and including the connector portion of the charge coupler." This area of standardization includes the following:

- The charging system itself
- The vehicle interface, comprising the points of contact with the vehicle and power supply, as well as onboard communications systems
- Infrastructure-grid communications
- Electrical installation

Overall, standardization of EVSE relates to five central product and service goals: product design and durability, power use and communication with the utility grid, environmental impacts, user safety and interoperability of the device.[9] The last two goals fall under the infrastructure domain.

There are codes and standards that apply to every aspect of the EVSE that connects the vehicle to the power source. These standards supply a basic framework for electrical safety for charging equipment that covers the EVSE from coupler to transformer in a variety of typical installation contexts. Electrical and building codes and standards govern the installation of the physical and electrical infrastructure that connects the EV to the grid.

1.3. Codes Contribute to EV Readiness

The central finding of this report is that while there are **no specific barriers to EVSE installation** embedded in the existing building and electrical codes, **there is room within the existing codes to more clearly encourage EV readiness** and, in some contexts, increased electrical safety.[10] Codes do not function to anticipate new technology, so they are not an appropriate tool to foster market development or specific technological innovation.

EV readiness in policy and regulation at the state and local levels will take a wide range of forms along the spectrum of allowing, incentivizing or requiring EVSE infrastructure deployment, including eliminating procedural barriers, considering potential for financial incentives or mandating pre-wiring for EVSE installation.

The current model codes do not inhibit the ability to safely install and use the most common types of EV charging units (level 1 and level 2 charging). Neither level 1 nor level 2 charging requires significant electrical work so long as the existing circuitry supports the device.[11] The safety of EVSE design and electrotechnical components is regulated by other standards that deal with products and production processes, such as those issued by the Society for Automotive Engineers (SAE), and provisions exist within the NEC in other chapters and articles for their safe installation based on the components and wiring requirements.

Code officials and local practitioners have noted that, in general, a state or local jurisdiction would have limited reason to amend the model codes, unless a state law or other similarly compelling requirement for compliance exists. For example, local environmental conditions such as high heat applications or high alkalinity of the soil would require specific instructions for certain electrical installations.

---

[9] Electric Vehicles Standards Panel, *Standardization Roadmap for Electric Vehicles*, Version 1.0 (Washington, DC: American National Standards Panel, April 2012), http://publicaa.ansi.org/sites/apdl/evsp/ANSI_EVSP_Roadmap_April_2012.pdf.
[10] In some states, single-family residential self-installation of EVSE is permitted to bypass the inspection process, depending on the type of residential code adopted.
[11] See Appendix A for a review of levels of charge and their attributes.

ANSI senior director James McCabe notes that, at the national level, the main idea supporting the generation of national model codes is to provide a baseline for jurisdictions to be able to follow best practices in terms of safety as well as other concerns relevant to the locality. These baseline provisions address specific issues, including EVSE; according to ANSI, "Standards, code provisions, and regulations, as well as conformance and training programs…are a critical enabler of the large-scale introduction of EVs and the permanent establishment of a broad, domestic EV and infrastructure industry and support services environment."[12] EVSE appears to be a compelling reason for code changes in some cases. A number of states have adopted amended codes specific to EVSE. In these cases, climate action plans and carbon emissions reduction goals, executive orders regarding emissions and other environmental policies that turn to transportation electrification as a strategy have compelled states and local jurisdictions to make EV-ready amendments. A secondary reason for supporting EV-ready plans and policies is the economic benefits associated with attracting EVs, infrastructure and related services and production to an area. A handful of states and jurisdictions across North America have taken steps to include EV-ready provisions in some part of their structural code, and **the lack of EV-specific code language may be an opportunity** that the Northeast and Mid-Atlantic states can capitalize on as the region seeks to prepare for the arrival of consumer EVs in greater numbers.

1.3.1. EV-Ready Planning for Networked Infrastructure

EV-ready planning is a comprehensive approach to the creation of regulatory and physical environments that support EV and EVSE. EV readiness has different components, and policies and programs to bring EVs and EVSE to an area may include financial incentives such as discounted tolls, tax credits or grants to finance charging equipment. However, non-financial incentives can also be effective in paving the way for EV-charging infrastructure. Project Get Ready cites preferential parking spaces, access to HOV-style lanes and expedited permitting processes as examples of these incentives.[13] As outlined in the Project Get Ready Casebook and profiled in other similar studies, many cities have taken steps toward EV-ready development and the creation of an EV-friendly regulatory environment.

In the case of any type of regulation, EV readiness can be interpreted at a minimum as the removal of barriers to easy, safe and cost-effective EVSE installation. At maximum, codes can be utilized to impact the scope of EVSE deployment in a given jurisdiction.

In general, EVSE-ready policy does not necessarily require installation of charging stations, but instead takes the approach that future technology and consumer preferences may change. In this way, EV readiness can include up-front planning for current and future infrastructure needs while remaining conscious of costs. In several of the model jurisdictions profiled in this report, such planning initiatives range from limiting the cost and time associated with permitting and inspections to mandating a certain percentage of new construction parking spaces be pre-wired for future EVSE installation.

Stakeholders consulted for this report widely agree that EVSE policy and planning should not tie hands at the local level. As with most regulatory and governance issues, there is no one-size-fits-all plan of action for creating the ideal scenario for EVSE deployment. The jurisdictions profiled in this report have been actively engaging in initiatives that have the goal of accelerating EV adoption. These case studies demonstrate that while different localities have a range of goals, such as reducing greenhouse gas (GHG) emissions or petroleum imports, the use of state or

---

[12] National Fire Protection Association, "Article 625 – Electric Vehicle Charging System Equipment," in *NFPA 70 National Electrical Code* (Quincy, MA: National Fire Protection Association, May 2001), http://www.nfpa.org/assets/files/pdf/A625-675.pdf.

[13] Electric Vehicles Initiative, *EV City Casebook* (Paris: International Energy Agency/Boulder, CO: Organization for Economic Cooperation and Development, 2012), www.rmi.org/Content/Files/EV_City_Casebook_2012_1.2.pdf.

local codes to promote EV readiness is an effective tool to achieve differing goals and can take several approaches.

1.4. Code Modifications are Just One Tool at a Jurisdiction's Disposal

This report finds that the scope of best practices for EV readiness includes codes in two important ways: (1) establishing minimum parking requirements, and (2) addressing permitting or other administrative processes. Each of the jurisdictions profiled for this report has enacted its provisions for EVSE relatively recently (with some changes pending: Los Angeles County and the City of Vancouver will vote on new mandatory measures in August 2012).[14]

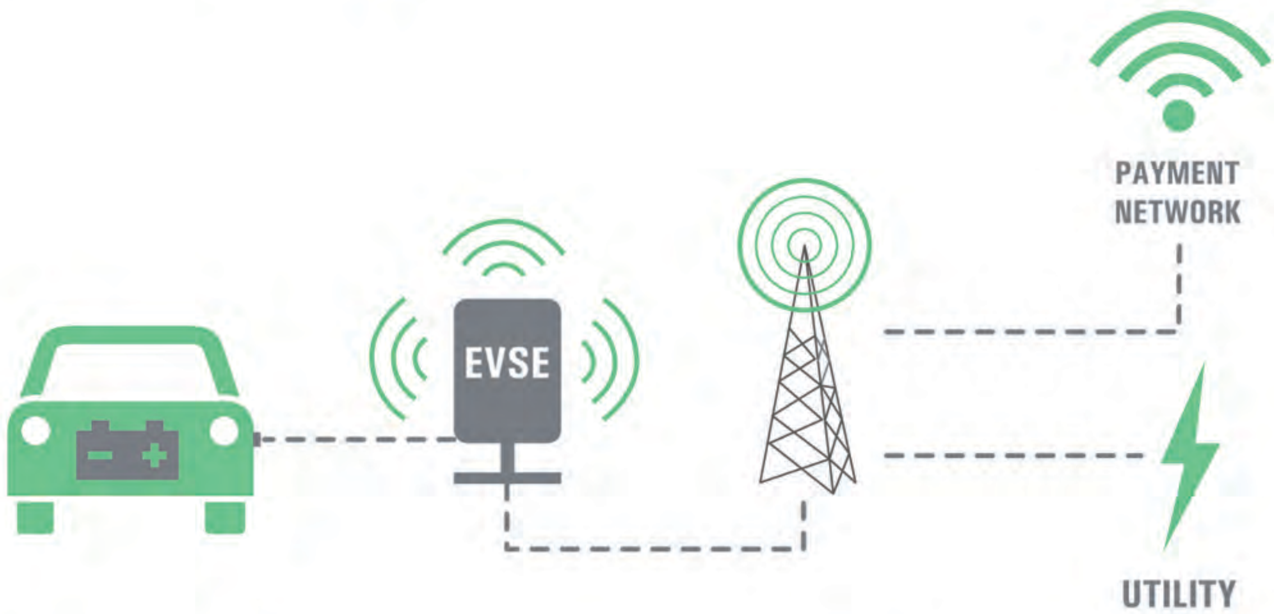
Modification of the state or local structural codes to encourage and incentivize EVSE installation is a direct action that enables jurisdictions to establish a pro-EV regulatory environment, either alone or in concert with state-level legislation; simplification of the administrative permitting process and changes to zoning and parking ordinances,

The national and local relationships to the model code development process are outlined in Section 2 of this report; case studies profiling EV-ready code actions taken by jurisdictions at different levels and lessons learned can be found in Section 3. This document provides a primer on the relevant structural codes and processes, as well as on opportunities and challenges for states and local jurisdictions seeking to regulate for and to encourage EVSE deployment.

---

[14] Beth Neaman (Southern California Edison), interview; Malcolm Shield (City of Vancouver), interview, July 18, 2012.

Codes and Standards Topics for EV and EVSE



VEHICLE DOMAIN	INFRASTRUCTURE DOMAIN	
Power Rating	**Electric Vehicle Supply Equipment**	**Infrastructure Communications**
Battery Safety Testing Storage Recycling	Charging Stations Power Quality Charging Levels/Modes Off-Board Chargers EV Couplers	Utility Metering Sub-Metering Load Balancing
Crash Tests/Safety	Vehicle as Supply	Charge Network Service Provider Payment Accessibility and Locating EVSE User Information Exchange Notification
On-Board Wiring	Alternative Power Sources	
Emissions	**Infrastructure Installation**	
User Interface Graphic Symbols	Site/Power Capacity Assessment Loads and Circuitry Ventilation - multiple vehicles	
	Urban Planning and Design Parking and Siting Environmental and Use Conditions Accessibility	
	Administration Permitting Inspection	

Figure 1: Code Issues for EVSE

1.5. Objectives and Methodology

The aim of this report is to aid local and state practitioners in developing an understanding of what, if any, barriers to EV readiness exist in the current codes, what code provisions would encourage a basic or advanced level of EV readiness and how model codes are created and translated from national or international policy to locally administered regulations.

The primary objectives of this report are the following:

- To help the municipal, state or regional planner understand and expand on the high-level implications of codes and related policies that regulate EVSE
- To establish the role of state and local jurisdictions and legislatures, private industry and interest groups in setting and implementing codes in the EV infrastructure domain
- To describe the general process and potential associated with amending and adopting building and electrical codes as well as the specific lessons learned from jurisdictions that have adopted EVSE-related amendments
- To distill best practices and formulate initial recommendations for EVSE-friendly codes and the generation of consistent regional infrastructure networks

Expert interviews formed the basis of this report and included in-depth consultation with EV and EVSE specialists at the nation's primary code-setting organizations, the ICC and the NFPA, which develop and publish the IBC and the NEC, respectively. For the purposes of this high-level review, the project team focused on engaging code experts at the national level and in model cities and states, but it should be noted that every state and many municipalities have agencies and/or departments that oversee the adoption, implementation and enforcement of state building and electrical codes. These experts in local policy and implementation should be consulted in further detail as well.

In-depth expert and stakeholder interviews with planning and transportation practitioners, policy makers, EVSE installers and licensed electricians and other stakeholders from the Northeast and Mid-Atlantic Clean Cities' communities and beyond were conducted between June and August of 2012.

This work is supported by secondary analysis and literature review of reports and existing studies, market-based analysis and mapping.

Through case studies of model jurisdictions, this report examines the efforts of, and lessons learned by, jurisdictions at state and local levels to incorporate EVSE-specific provisions into the building code, and considers lessons learned for model code development. Case studies include the following:

- Municipal planning in Vancouver, British Columbia, Canada
- State-level planning in Oregon
- Regional approaches linking city, county and utility planning in Los Angeles, California

These case studies were selected based on an analysis of new and existing research and recommendations by the U.S. Department of Energy (DOE) Clean Cities Coalitions, the Transportation and Climate Initiative (TCI) regional stakeholder group and ANSI, among others. These case studies profile options and opportunities at different levels of government in order to illustrate challenges and choices from various perspectives.

Criteria for case study selection included the following:

- The jurisdiction must have an implemented code change specific to EVSE
- Examples were sought to provide insight at multiple levels of government

- Case study localities should have addressed issues of jurisdictional boundaries
- Depth of local experience with EVSE and EVs
- Examples should offer breadth with respect to potential lessons learned

The case studies were selected based on an analysis of new and existing research and recommendations by the DOE Clean Cities Coalitions, the TCI regional stakeholder group and the American National Standards Institute (ANSI),[15] among others. These case studies profile options and opportunities at different levels of government in order to illustrate challenges and strategies from multiple perspectives.

The report offers brief recommendations to multiple stakeholder categories for the codes modification process and for critical, related elements of local infrastructure planning that should accompany and inform jurisdictional or state-level change.

1.6. Report Structure

Section 1: Introduction

Section 2: Codes in Policy and Practice: National Landscape
This section develops an understanding of and expands on the national code-setting system and how codes apply to EVSE deployment.

Section 3: Local Codes from Model States and Municipalities
This section examines the efforts of jurisdictions at state and local levels to incorporate EVSE-specific provisions into the building codes, and considers lessons learned for model code development.

Section 4: Summary and Next Steps
This section synthesizes implications of case study jurisdictions' efforts and outcomes on the code-setting process for permitting (administration) and siting (design and zoning), and suggests next steps in the form of key recommendations and future study.

Appendices

---

[15] ANSI is a standards-setting organization that published a critical reference for codes relevant to EV and EVSE. The EVSE Standardization Roadmap for Electric Vehicles, published in April 2012, is available at: http://publicaa.ansi.org/sites/apdl/evsp/ANSI_EVSP_Roadmap_April_2012.pdf.

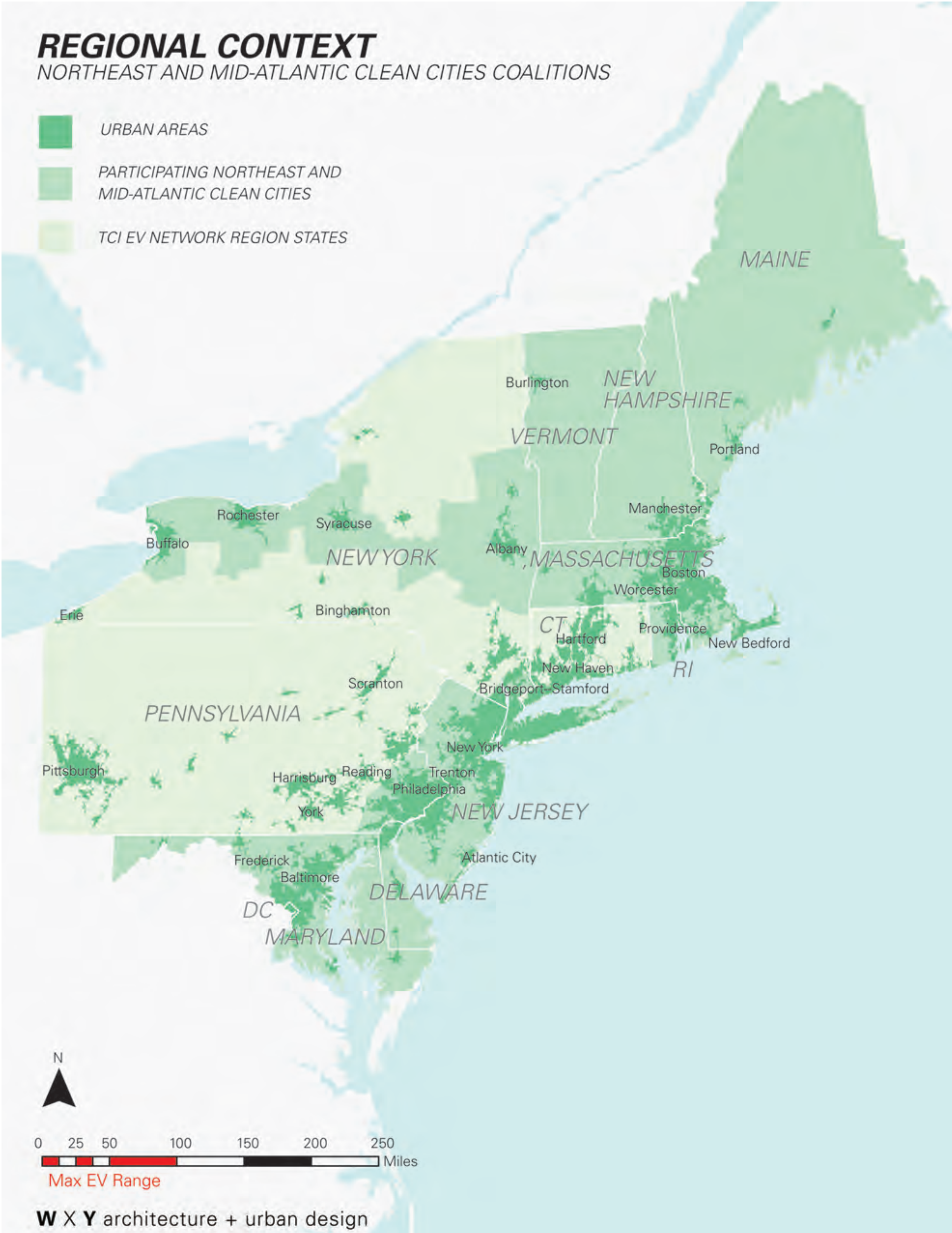


Figure 2: TCI Region Map. Sources: Transportation & Climate Initiative and U.S. Census Bureau via ESRI

2. CODES IN POLICY AND PRACTICE: NATIONAL LANDSCAPE

Section 2 of this report takes a general approach to understanding the purpose of codes, their role in regulating EVSE-specific issues and the respective roles of various stakeholders: federal, state and local governments as well as code-setting entities and businesses in the EV sector. Understanding the theoretical underpinnings and processes behind the establishment of the primary model codes will aid states and local jurisdictions in their decision-making processes regarding if and how to make amendments to include EVSE-specific provisions to their respective regulatory processes.

2.1. What are Codes and Standards?

Codes are systematic statements of a body of law, especially one given statutory force.[16] According to the NFPA,

> *A **code** is a model, a set of rules that knowledgeable people recommend for others to follow. It is not a law, but can be adopted into law. A **standard** tends be a more detailed elaboration, the nuts and bolts of meeting a code.* [17]

At the most basic level, codes provide the minimum requirements to ensure public health, safety and welfare, and constitute the administrative framework through which governments extend safety protections. There are model codes—those that are developed at the national level for adoption by states and local jurisdictions—for every aspect of the built environment. For this report, the code discussion is focused on the NEC and the IBC, created by the NFPA and the ICC, respectively. Both of these are model codes, adopted in all 50 states and the District of Columbia.[18]

If codes provide the "what," standards often provide the "how." Standards are benchmarks that can provide descriptive language indicating accepted ways of doing things. They are rules, conditions, guidelines or characteristics for products, processes, production methods and management system practices.[19] Within the regulatory environment, codes and standards work together to create a framework of safety requirements and best practices; codes typically reference consensus standards developed by standards-developing organizations. As such, standards play an important role, "enabling technological innovation by defining and establishing common foundations upon which product differentiation, innovative technology development

---

[16] "Code," Merriam Webster, copyright 2012, http://www.merriam-webster.com/dictionary/code.
[17] "About Codes and Standards," National Fire Protection Association, accessed October 23, 2012, www.nfpa.org/itemDetail.asp?categoryID=1332&itemID=31068&URL=Press%20Room/A%20Reporter's%20Guide%20to%20Fire%20and%20the%20NFPA/About%20codes%20and%20standards.
[18] While adoption of a building or electrical code is not required by federal law, the IBC is adopted or in use in 50 states and Washington, DC. The NEC is adopted similarly and has the distinction of being the least-amended model code. Some jurisdictions, notably New York City, have or have previously written their own building provisions, oftentimes to deal with local complexities, such as New York City's high-density population.
[19] "OMB Circular A-119," Standards.gov, accessed October 23, 2012, http://standards.gov/a119.cfm.

and other value-added services" are developed and are "essential for enabling seamless interoperability across products and systems."[20]

The American standardization system relies on private-sector involvement led by nongovernmental code-setting entities, and it is supplemented by federal involvement, in particular regarding regulatory processes.[21] In the United States, codes and standards are developed in an advisory capacity at a national scale—for example, the model codes created by organizations such as the ICC and the NFPA, which develop the IBC and NEC, respectively.

2.1.1. Model Codes Adopted by States and Local Jurisdictions

When this report references codes, it will refer to both *model* codes and *adopted* codes. Model codes are those created at the national or international level. Model codes are adopted by states and local jurisdictions through the legislative process. Adopted codes are the version of the model code approved at the state or local level, enforced by the local administrative agency having jurisdiction.

The IBC and NEC are adopted in their entirety or with amendments into law by the states; states further stipulate whether local jurisdictions are then permitted or required to adopt local amendments. Statewide adopting authorities, policies and procedures differ greatly from state to state, and again from local jurisdiction to jurisdiction, regardless of whether the state or jurisdiction is adopting a code as is or with amendments.[22] In part, this is a consequence of a limited federal role.

All codes are voluntary, carrying no legal status until they are adopted by states and/or local governments. Only adopted codes have the force of law. In this way, code-setting organizations are effectively responsible for developing and revising policy documents that advocate for public safety and consistency within the industries covered by the given code. When a jurisdiction adopts a model code or standard, it becomes enforceable under state or local law through the administrative process of the authority having jurisdiction, which may be a state, county or municipal government—and typically regulation requires action at multiple levels. Local amendments spell out code enforcement in the language of the code itself. Furthermore, code appendices offer optional compliance requirements that, when adopted, provide flexibility for jurisdictions to meet the demands of local conditions.

In the United States, conformance with electrical and building codes relies on four interrelated mechanisms: (1) product safety standards and certification, (2) plan approval, (3) application of installation codes and standards and 4) inspection. [23]

---

[20] Subcommittee on Standards, *Federal Engagement in Standards Activities to Address National Priorities: Background and Proposed Policy Recommendation* (Washington, DC: National Science and Technology Council, October 2012), http://standards.gov/upload/Federal_Engagement_in_Standards_Activities_October12_final.pdf.
[21] Office of Management and Budget, "Circular No. A-119 Revised," The White House, February 10, 1998, http://www.whitehouse.gov/omb/circulars_a119.
[22] International Code Council, "Code Adoption Process by State," (Washington, DC: International Code Council, n.d.), http://www.iccsafe.org/gr/Documents/AdoptionToolkit/HowStatesAdopt_I-Codes.pdf.
[23] See note 13.

2.1.2. Pathway to Local Codes

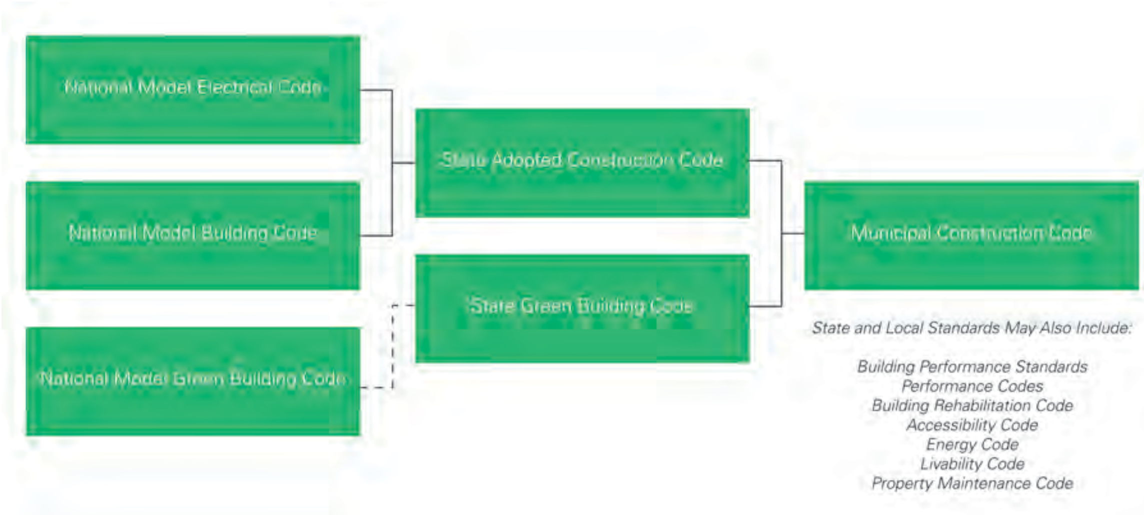


Figure 3: Hypothetical Code Adoption Pathway

2.1.3. Safety Considerations are Central to Codes

Codes ensure user safety and the long-term durability of EVSE hardware and its connection to the power source. There are three widely recognized elements to the safe installation of electrical equipment, including EVSE:

- The use of certified and listed equipment
- Development of clear building and installation plans
- Enforcement through permitting and inspection

EV infrastructure will be installed in a variety of different conditions, such as in single-family homes, on-street parking and public parking lots.[24] In each individual electrical installation, both electrical and building codes will dictate clear processes and procedures for site planning and electrical installation. While a great majority (an estimated 90%) of the charging infrastructure installations will be in residential settings, EVSE will be present in public and shared spaces as well, introducing potential safety hazards into the public realm. Although charging stations most closely resemble such innocuous household appliances as a dishwasher or clothes dryer, safety for all those who come in contact with powered appliances is paramount for the organizations that develop codes and the agencies and inspectors who administer them.[25]

---

[24] Washington State passed legislation requiring jurisdictions throughout the state to specifically allow EVSE, including battery swapping, by target dates. Washington State's efforts are also explored in the next chapter.

[25] Although not determined to be major code-related concerns, the safety issues associated with typical EVSE designs and site installations that may lead to increased risk of shock or fire due to heightened continuous electrical loads will be discussed further in this report and in the EVSE site design guidelines.

2.1.4. Interoperability

Interoperability refers to the compatibility of products, systems and processes. Interoperability standards increase user value and improve user experience by providing not only a seamless interface but also peace of mind in terms of relying on the long-term viability of a technology investment or consumer purchase. Such standards reduce the risk of large-scale public and private investments in technology becoming prematurely obsolete.[26] More broadly, interoperability standards can also help maximize levels of coordination and compatibility within the EV industry domestically and internationally. This type of standardization contributes to market stability and could help increase adoption rates, supporting growth even in a transitioning marketplace. Interoperability also has an administrative component. From the perspective, for example, of permitting processes, the amendment of codes at the state level can make charging infrastructure more seamless to install and inspect, as well as to plug in to.

Finally, interoperability standards also relate to uniform signage, easy-to-use site design and other systems that ensure universal access and a safe user experience.

2.1.5. Adaptability

Changes in technologies and infrastructure in terms of the linkage of the EV with the electrical grid are invariable, and it is paramount that these new processes occur in a way that protects the environment.[27] In order to ensure a smooth transition to a future where the EVs are a widespread transportation option, a range of changes in regulatory environments will be necessary.

International consistency will underpin trade between the global automotive industry and local markets as well as compatibility of the charging infrastructure.[28] Compatibility of products in an international marketplace is a critical aspect of reducing production costs. Furthermore, the United States EV industry has the opportunity to advocate for the acceptance of its own standards at the international level, aiding in the competitiveness of U.S.-designed or U.S.-made products. EVSE manufacturers and network service providers see their role in setting standards as changing the marketplace and setting a path for the industry.[29]

---

[26] "Memorandum for the Heads of Executive Departments and Agencies: Principles for Federal Engagement in Standards Activities to Address National Priorities," The White House January 17, 2012, http://www.whitehouse.gov/sites/default/files/omb/memoranda/2012/m-12-08_1.pdf.
[27] Stephen Brown, David Pyke and Paul Steenhof, "Electric Vehicles: The Role and Importance of Standards in an Emerging Market," *Energy Policy* 38, no. 7 (July 2010): 3797–3806, http://www.sciencedirect.com/science/article/pii/S0301421510001631.
[28] Ibid.
[29] Steven Dorresteijn, "Epyon: Your Partner in Fast Charging Solutions" (presentation, March 2011).

2.1.6. Code-Related Goals and Applicable Codes by Type

Issue	Code Type	Model Code
Structural Safety	Building Code	IBC, International Residential Code (IRC), International Green Construction Code (IgCC)
Fire Safety	Electrical and Building Code	IBC, IRC, NEC
New Technology	Electrical Code, Installation Standards	NEC, National Electrical Installation Standards (NEIS)[30]
Energy Efficiency	Building Code, Installation Standards	IgCC, NEIS
Scoping Requirements	Building Code	IBC, IRC, IgCC
Administrative Streamlining	Electrical and Building Code	IBC, IRC, IgCC, NEC

2.2. National Codes and the Federal Role

The U.S. federal government plays no official role in developing model codes or setting national standards, although it occasionally utilizes these documents to guide legislation and policy. In a 1997 article, University of Washington professor Peter J. May notes, "With the notable exception of building provisions for the disabled, the federal role is largely restricted to funding research programs in areas such as energy efficiency."[31] Instead, there is extensive reliance on private-sector code-setting bodies for the development of relevant standards.[32] The National Technology Transfer and Advancement Act (NTTAA) requires federal agencies to rely on standards developed by the private sector for regulatory or procurement processes unless there is impetus to do otherwise.[33] The NTTAA directs the National Institute of Standards and Technology to bring together federal, state and local agencies and governments to achieve greater reliance on voluntary standards, such as nationally accepted model codes, and decrease dependence on in-house single-agency standards.[34] The purpose of such legislation is to achieve openness, transparency and multi-stakeholder engagement through the engagement of the private sector in government process.[35]

---

[30] NEIS provides quality and performance standards for electrical construction work that go beyond the NEC. As standards, they are beyond the scope of this document's analysis. However, it is important to note that NEIS has developed helpful EVSE-specific guideline materials for licensed electricians, and it is engaged in instructing technical courses to familiarize professionals with higher-level requirements and best practices associated with EVSE than required in the NEC's minimum installation safety standards. For more information, see: www.neca-neis.org.
[31] Peter J. May, "State Regulatory Roles: Choices in the Regulation of Building Safety," *State & Local Government Review* 29, no. 2 (Spring 1997):70–80.
[32] Ibid.
[33] See note 8.
[34] Standards.gov homepage, accessed July 24, 2012, http://standards.gov/.
[35] See note 28.

Many national policies intend to increase clean energy and EV use and their associated markets. President Obama's initiative to increase the number of EVs on U.S. highways to 1 million vehicles by 2015 includes the proposition that vehicles, parts, support equipment, batteries and other components will be made and serviced in the United States. Clean energy goals represent another area where the federal government is currently making significant policy and financial investments, and in which there is potential opportunity for the federal government to accelerate standards development activities in the process of promoting market-based innovation and competitive market outcomes.[36]

The national framework has also included funding, such as through the American Recovery and Reinvestment Act (ARRA) or DOE, which has been channeled into such related initiatives as the EV Project, a $230 million investment in EV infrastructure deployment and data collection that offers EV owners access to charging stations free of cost, as a means of both incentivizing uptake and evaluating the effectiveness of the charging infrastructure and network business models.[37]

However, it is the states and local jurisdictions that will directly confront feasibility, market development, application for and allocation of transportation and energy grant funding and evaluation of costs and benefits of public EVSE infrastructure programs.

2.2.1. Private-Sector Participation Links Code-Setting Process to Local Development

There is extensive reliance on private-sector code-setting bodies for the development of relevant standards.[38] Model codes are developed by private-sector not-for-profit membership organizations that unite concerns for public safety with those of industry. It is the role of these organizations to carry out the process through which the model building and electrical codes are created.[39]

This process features a high level of industry representation with a clear market component and is "informed by market needs…play[ing] a foundational role in facilitating competition, innovation and global trade."[40] Codes and standards are thus keystones of EV-ready economic development policies and practices. From the international level to the local level, government decision making surrounding the EV and EVSE industries and EV and EVSE deployment will react to changes in technology and markets—stimulating market uptake of new products, technologies and services; increasing safety to assure for consumer; increasing interoperability for affordability and consumer access; and making strides in innovation for creation of new business models and job growth potential. Code-making bodies and standards organizations effectively broker the transaction between industry interests and government interests in the intersecting arenas of economics and public safety.

2.3. Overview of National Model Codes and their Purview

Understanding the respective purviews of the various code-setting bodies and the range of potential goals and outcomes associated with code modifications points to the ways in which local changes can inform model codes in the future. For the purposes of this report, the ICC and NFPA will be considered the primary code-setting bodies, due to their focus on infrastructure. Their standards govern the built environment from structural and electrical perspectives and provide the critical link between vehicles and the power grid.

---

[36] Ibid.
[37] "Overview," The EV Project, accessed October 23, 2012, http://www.theevproject.com/overview.php/.
[38] See note 33.
[39] See note 9.
[40] See note 42.

2.3.1. NFPA and the NEC[41]

The NFPA is an international nonprofit organization focused on reducing the risk and damage from fire and other hazards through research, training and the development of codes and standards. The NEC is the infrastructure standard for electrical construction in the United States, developed by the NFPA and in use since 1897. The primary concern of the NFPA is electrical safety.[42] The NEC provides requirements for typical hard-wired connections for all types of electrical installations, including wiring methods, equipment construction, grounding and protection and equipment location to prevent exposure to energized live parts. The scope of the NEC with respect to EV infrastructure[43] includes the relevant conductors and equipment external to the vehicle, the connection of the EVSE to the electricity supply, the conductive or inductive means required to make the connection and the installation process itself.[44] The electrical code will deal exclusively with the installation of the infrastructure, including electrical safety provisions that impact siting and design, such as minimum heights and maximum cord lengths, and should be amended for electrical safety purposes only, such as those that pertain to local environmental conditions.[45]

NEC Article 625 provides specific requirements for the following:

- Placement of unit (height from ground)
- Length of cable (25 feet max)
- Number of cables per unit
- Connections and couplers
- Rating (level of charge)
- Markings
- Overcurrent protection
- Personnel protection
- Interactive systems
- Ventilation
- Supply circuits
- Indoor versus outdoor installations

EVSE Provisions

The NFPA introduced EVSE in the 1996 edition of the NEC, a response to the expected release of a number of EV models by large original equipment manufacturers to meet the initial phase of the zero emission vehicle mandate. Revisions have been included in the 1999, 2002, 2005, 2008 and 2011 editions of the NEC based on changes and evolution in battery, automobile and supply equipment technology, along with other industry and user-based needs.[46] The NEC also acknowledges EVs and charging infrastructure in Article 625 of the code.[47]

---

[41] NEC consists of an introduction and nine chapters. Chapters 1–4 of the NEC cover general requirements that are widely applicable to electrical wiring and installations of all kinds. These first chapters set up the fundamental rules and cover specific technical installation requirements for electrical installations; later chapters in the code establish more specific thematic rules that regulate installations by topic, for example, EVSE. Chapters 5–7 cover special occupancies, equipment and conditions, and supplement the regulations set out in the first part of the code. The remaining chapters cover communications systems, reference tables and appendices. These last chapters are only requirements when specifically referenced in other parts of the code; otherwise they are for informational purposes.

[42] Mark Earley (NFPA), interview, July 18, 2012.

[43] NFPA NEC 70 Article 625 defines EVs as those that are highway-worthy autos. It additionally distinguishes between battery electric vehicles, plug-in hybrid electric vehicles and hybrid electric vehicles.

[44] See note 15. Inlets and corresponding couplers are currently standardized not by the NEC, but by the SAE J1772 standard.

[45] The NEC deals with the consumer side of the electrical installation, while a separate code developed by the Institute for Electrical and Electronics Engineers (IEEE) called the National Electrical Safety Code deals with the manufacturer side.

[46] Donny Cook, "Electric Vehicles and Electric Vehicle Charging" (presentation).

[47] Furthermore, Article 626 regulates electrical systems on freight trucks.

Electrical Loads and EVSE Safety

Because the NEC is exclusively concerned with electrical installation, the model code only directly determines design parameters that dictate safety requirements related to circuitry design.[48] Even the lower-voltage level 1 charger generates system impacts due to the fact that the eight or more hours required to charge a vehicle represent a unique instance for residential applications because such installations do not typically generate continuous loads of more than three hours.[49] Continuous electrical loads generate more heat in the local system, which is a cause for concern, and have implications for the utility grid. The continuous loads of EV charging stations present the central challenge to efficient and safe ongoing use, both in the home and on local transformers. Alternating current (AC) levels 1 and 2 are considered continuous-duty loads; that is, they are on for more than three hours. The NEC provides minimum requirements for performing site assessments.[50]

Although the cumulative effects of EV battery charging on both the circuitry at the point of installation and at the local network scale is outside the scope of this report, and at present EVSE is or could be considered minor work in many jurisdictions, these effects should still be taken into account. The safety implications that may arise from either overloading household circuits or local transformers, or collectively burdening utilities with increased loads at prime charging hours, may become issues for homeowners and for the utility grid. In general, the NEC provides guidelines for overload protection and load calculations, as do the EVSE installation standards published by professional organizations and interest groups.[51] Jurisdictions are also taking steps toward increasing requirements for reporting EVSE installation to local utilities.

NFPA views system capacity issues related to EV charging loads as central to the EVSE installation discussion because a homeowner or developer—or even a municipality—installing EVSE does not want to "surprise" the utility. For new installations (new construction with EVSE or EVSE-ready installation), the load issue will come to light through the permit application or inspection process where one exists. However, for existing installations (the addition of EVSE to a previously constructed circuit), this issue is not addressed by the current code.[52] While ideally this is an issue that could be addressed locally through relationship-building between utilities and local or state governments, it is the case in most TCI region states (e.g., New Jersey and Rhode Island) that the privacy issues associated with notifying utilities of an EV purchase or EVSE home charging units remain an ongoing concern that, without legislation mandating EV reporting (Maryland), has yet to be solved.

Expected NEC 2014 Revisions

The NEC is currently in the middle of the development cycle for its updated 2014 edition, which is scheduled for publication in fall 2013. Significant work is underway on Article 625, pertaining to EVs. In addition, revisions of the sections pertaining to alternative energy are expected. There is a need for the code to more specifically recognize some new DC-related technologies, even

---

[48] See note 44.

[49] According to NFPA expert Mark Early and utility representative and EVSE program manager Beth Neaman at SCE, other household appliances, such as refrigerators or air conditioning units, draw a similar amount of power in cycles. The cyclical nature of the electrical loads associated with virtually all other standard household electrical equipment makes the 6–8 hour continuous charge a substantial power drain on a typical household system.

[50] See note 15. Specifically, articles 210, 215 and 220, which include rules related to calculations/loading of services, feeders and branch circuits in all occupancies. Annex D of the NEC provides load calculations in examples that include several EVSE scenarios including multifamily dwellings, store buildings, multi-structure industrial facilities and single-family residences.

[51] For example, see Advanced Energy's guide: http://www.advancedenergy.org/transportation/evse/Charging%20Station%20Handbook%20Rev2011.pdf and the National Electrical Contractors Association EVSE installation guide: http://www.necanet.org/index.cfm?fa=newsAboutNecaItem&articleID=5536.

[52] See note 44.

though DC has been addressed in the NEC since its first edition in 1897. The DC initiative underway is primarily focused on low-voltage DC as well as updating general DC requirements throughout the code.[53] A key factor in all of these articles is interactivity. A new article is in development that will cover energy management in interactive electrical systems that are capable of storing and supplying energy back to the grid. Energy management systems can be used in a variety of applications, but for EVSE they provide a means by which the charging infrastructure and vehicle battery can help store and supply power in a way that reduces peak demand.[54]

2.3.2. The ICC and the IBC

The ICC is a member-based association that works to help the building safety community and construction industry provide safe and sustainable construction through the development of codes and standards that apply to the design, construction and compliance process.[55] The IBC is used around the world.[56] As publisher of the IBC, the International Residential Code for One- and Two-Family Dwellings (IRC), the International Fire Code, which is used in 43 states as the fire code and the International Green Construction Code, the ICC has a significant role in establishing standards for much of the built environment.

For simple, plug-and-play outdoor EVSE installations, the building code is not a major consideration. For certain built environment conditions, such as inside a garage, it is presumed that the applicable version of the building code will have required all that is necessary from a fire safety standpoint.[57]

IRC: Purview and Challenges

The IRC governs construction for single-family homes of up to three stories. The residential code is written for the designer and builder of a single-family home who may not necessarily be a licensed architect; as such, it attempts to be entirely self contained, meaning that it does not require the designer or builder to reference any additional standards or codes.[58] The commercial code (the IBC) refers to other standards, including the NEC, based on the assumption that licensed professionals who are well versed in the standards and their applications will be carrying out the work.

Residential installations will compose an estimated 80%–90%[59] of the EV charging stations installed, followed in number by office locations and then by publicly accessible charging.[60] One of the most significant opportunities for improvement to the model building code thereby comes from the IRC–for single-family home installations in jurisdictions where the IRC has been adopted and where the local code does not require an electrician to perform work on a private residence. The typical homeowner is likely not going to be concerned with or knowledgeable of the capacity of his home's electrical system. A homeowner installing a charging station purchased independently and without consulting the local utility may create safety hazards due to additional and continuous loads associated with EV charging.[61] It is particularly critical to be wary of these

---

[53] See note 10.
[54] "NFPA 70 National Electric Code," National Fire Protection Association, www.nfpa.org/70.
[55] Although ICC is an accredited ANSI standards developer, ICC develops its code using its own "Governmental Consensus Process" (added by David Karmol).
[56] See note 8. Despite the fact that the model IBC is adopted in all 50 states and Washington, DC, it is not considered an American National Standard due to the fact that the IBC is not vetted through the American National Standards accreditation process (see next section).
[57] See note 44.
[58] Bruce Spiewak, phone interview, July 20, 2012.
[59] See note 5.
[60] Brian Kiley, interview July 27, 2012; See note 17.
[61] Kiley, interview.

safety hazards in homes built in the 1960s and before, which would benefit from a service upgrade for safety purposes. Although the number of installations fitting this particular scenario may represent a small amount of total residential EVSE, it is a clear area for potential improvement.

2.3.3. ANSI

ANSI is a member-based nonprofit organization that plays many interrelated roles within the world of standardization. In general, ANSI acts as the administrator and coordinator of the U.S. private-sector system of voluntary standardization, overseeing the creation, promulgation and use of thousands of guidelines that apply to many economic sectors. The organization provides accreditation services whereby standard-setting bodies can be recognized as conforming to due process procedures for standards development, and certification programs can be recognized as complying with national and international norms. In its role as accreditor of standards developers, ANSI does not participate in a discourse on the technical merits of a given standard, but rather approves standards if the process followed by the standard-creating organization adheres to ANSI's essential requirements for due process. ANSI's membership comprises government agencies, organizations and companies from the private sector, international bodies and individuals.

ANSI is itself the official representative member from the United States to the International Organization for Standardization and, via the U.S. National Committee, the International Electrotechnical Commission, both of which are involved in the development of international standards related to EVs and charging infrastructure manufacturing.[62] As a member of these international organizations, ANSI represents the interests of its own members and their respective standards across a variety of industries in the international realm, and it serves those interests by advocating where requested for the adoption of U.S. standards as the international norm.[63]

ANSI's general interest as a standards umbrella organization in optimizing processes and harmonizing standards and codes created by multiple organizations has spurred action on the front of EVs and charging infrastructure. Inspired by standards' roadmaps created by both Germany and the European Union, ANSI established an organizational arm to address this emerging area of work. The ANSI Electric Vehicles Standards Panel (ANSI EVSP) is a cross-sector coordinating body within ANSI whose objective is to foster coordination and collaboration on standards to enable the safe, mass deployment of EVs and EVSE, engaging stakeholders to generate international-level coordination, adaptability and engagement.[64] Key stakeholders include the automotive industry, utilities and power authorities, electrotechnical manufacturers and other standards organizations. The primary product of the ANSI EVSP has been a roadmap document (*ANSI EVSP Standardization Roadmap for Electric Vehicles)* released in spring 2012. The roadmap catalogs all relevant entities operating in the EV standards space, identifies central issues to EV and EVSE standardization and codes, discusses product and infrastructure standards related to EVs and identifies existing needs and gaps as well as existing efforts at harmonization. The analysis provided by the roadmap is a critical review of existing codes and standards across all aspects of EVs and EVSE, and the roadmap will be an important resource for the field and EV-ready planning going forward.[65] One of the key takeaways from the roadmap

---

[62] "About ANSI Overview," American National Standards Institute, accessed October 23, 2012, http://www.ansi.org/about_ansi/overview/overview.aspx?menuid=1.
[63] See note 8.
[64] "Electric Vehicles Standards Panel," American National Standards Institute, accessed October 23, 2012, www.ansi.org/evsp.
[65] See note 13.

exercise is the confirmation that for EVSE installation, safety issues are largely accounted for in current standards and model codes.[66]

2.3.4. The Code Revision Process

Codes and standards are updated regularly in set cycles with the intent to incorporate new science, lessons learned from disasters and new technologies and products.[67] Both the ICC and the NFPA operate on a three-year code revision cycle, with designated periods for proposals from the industry and public for additions or amendments to the code. Following the proposal period, the proposed changes are made publicly available for comment and review.[68] The relevant committees within each organization then determine which, if any, of the proposals will enter the next version of the model code.

The process by which model codes are developed and revised is open to input from the public, which includes all concerned parties ranging from industry to local government to concerned practitioners, as well as from internal committees in the case of the NFPA. The ICC receives code change proposals from its members and from the public, but it does not generate changes within the organization. Similarly, a majority of code change proposals for the NFPA originate as public proposals, although the NFPA's internal committees and working groups generate new code concepts as well.[69]

The NFPA's committee-based proposal allowance permits the organization's members to become more proactive in the code cycle; task forces and technical committees, comprising NFPA members, examine the technology landscape to ensure all relevant safety concerns are addressed in the next revised model code.

It is important to consider impacts and rank priorities for code changes. Cost barriers that impede local jurisdictions, even states, from updating the code on the standard three-year cycle are real and reflect a larger economic situation more than disinterest in pursuing the adoption of the most up-to-date standards.[70] The added costs of training and staff time should be taken into consideration, even with temporary amendments or interim changes to the code. The NFPA permits interim changes in the event that the organization becomes aware of a significant new technology that poses immediate safety concern. Such changes are referred to as "tentative interim amendments."[71]

The key to developing and proposing successful model code changes is not only the development of a widely applicable rule or process, but the language used in writing the proposed changes; code language must provide clear guidance but be generic with regard to projects or products.[72]

---

[66] See notes 10 and 13.
[67] "NFPA, ICC Create Coalition to Advance Public Safety in the Built Environment," National Fire Protection Association, June 5, 2012, http://www.nfpa.org/newsReleaseDetails.asp?categoryid=488&itemId=57256&utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+nfpacodesandstandards+%28NFPA+codes+and+standards%29.
[68] As of writing, both the NEC and IBC are in the public review phase for the next edition of the codes, which will be available in 2013.
[69] See note 44.
[70] See note 60.
[71] See note 44.
[72] See note 9.

2.4. New Technology Outlook

Innovations will define the technological and electrical components that relate to evolving safety and infrastructure issues in EVSE installation. Codes and standards must be forward-thinking as policy and planning tools to anticipate the need to cover changing infrastructure technology. However, while it is critical that interface and infrastructure standardization are undertaken so as to anticipate and be compatible with future technological advancements in EV electrotechnical systems, safety and environmental sustainability, it is widely accepted that codes should support existing technology rather than attempt to anticipate the next innovation.[73] The development of such standards and their inclusion in model codes is a work in progress. Upcoming innovations and areas for consideration can be divided into several key categories: updates to the stations themselves, innovation in power sources and connection to the utility grid. In all of these areas, public education will be critical component of future success.

2.4.1. Charging Stations, Design and Networked Communications

There are gaps regarding emerging issues, including standards for DC fast charging.

- DC fast charging will be useful for long-distance travel and public charging stations and in commercial applications
- Future standards in connector design should take into account current how-to-use issues. International energy technology firm Efacec, one of the leading DC fast-charging manufacturers in the U.S. market,[74] reports that 90% of the calls to the company's customer service line are regarding how to plug in the DC connector, which has not yet been standardized.[75]

Currently, no standards exist to cover wireless charging.

- Inductive or in-ground wireless charging presents another interesting future advancement and codes challenge.
- This topic is presently being addressed under SAE 2954 and Underwriters Laboratory (UL) 2750, but not in the NEC or the IBC.

No international standards exist to address battery swapping safety and interoperability.

- The ANSI EVSP roadmap has identified this gap as a priority.
- Washington State has referenced battery swapping stations in a proposal for local zoning ordinances to address EVSE.
- Battery banks will be addressed in a current code proposal for NEC section 625.4 to include power sources of up to 600 volts DC.

Communications standards are lacking and will impact site design and construction best practices.

- Smart grids, communications systems that connect the EV driver's mobile device to the vehicle, such as through mobile technology, or the vehicle to the grid, such as through

[73] See notes 17 and 29.
[74] "Transportation," Efacec, accessed October 23, 2012, www.efacecusa.com/Transportation.aspx.
[75] Mario C. Santos, EPRI Infrastructure Working Council on Electric Transportation meeting, Chicago, IL (presentation), June 28, 2012

charge point monitoring software, are areas of communications-related standards that require additional work.[76]

- No standards currently exist to provide for generic locating and reserving of public charging stations, the interconnectivity (e.g., through roaming) of EVs between EVSE service providers, offline access control at private charging stations or communications from EV meters to the vehicle or sub-metering scenarios.[77]

Electrical loads and alternative power standards that address reverse power flow, both communications and safety aspects, are still in development.

- Sections of the relevant codes from SAE need to be completed to include this information, although existing standards cover information design, use cases and safety aspects for reverse power flow.[78]
- Codes relating to the load balancing required for energy storage systems are another potential area of development.

Alternative power sources represent an interesting future option for generating power, and while many areas and companies are experimenting with this technology, model and local codes have not yet seen the need to address it.[79] Generally this area is already covered by standards, but there remain areas on which to improve:

- The NEC does not specifically address the integration of EV/EVSE with a facility high-voltage DC power distribution system for either charging or reverse power flow.
- NEC requirements are needed for high-voltage DC power distribution systems and the integration of DC loads within the system.
- Solar is addressed by ANSI/UL 1703 and NEC article 690 for safety of photovoltaic equipment, and small wind systems are covered in NEC article 694.
- Communication with various state utility commissions should take place to make sure that vehicle-to-grid technology can be used as a part of a state's distributed power system. Distributed power can be an effective tool for leveling the spikes in power requirements.

---

[76] The National Institute of Standards (NIST) has released a February 2012 document: "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0." In that document, there is a complete summary of the efforts to date on the development of plug-in electric vehicle interoperability standards (http://www.nist.gov/smartgrid/framework-022812.cfm).

[77] See note 13.

[78] Ibid.

[79] Ibid.

3. LOCAL CODES FROM MODEL STATES AND MUNICIPALITIES

3.1. Local Planning for a Regional Infrastructure Network

A key strategy for capturing the many benefits of EVs will be the development of policies and programs that aim to deploy EVSE infrastructure to meet today's charging needs and prepare cities, towns and regional corridors for growing EV use. Every jurisdiction is different, yet there are select, key factors necessary in order to successfully advance policy, legislation and ordinances pertaining to EV infrastructure. The building and electrical codes examined in this study represent just one tool available to governments, and may or may not be the ideal solution to regulate EV-charging infrastructure deployment everywhere. EV-ready planning should include consideration of the following goals:

- Ensuring that new construction is wired for EVSE
- Clearing administrative pathways for residential service upgrades and EVSE retrofit
- Guaranteeing safe, consistent and accessible infrastructure installations and implementing good site planning and design
- Ensuring that new construction can support a higher pull on the utility grid, with the potential of adding future vehicle battery charging capacity and eventually energy storage devices
- Aligning EVSE deployment with policy and environmental mandates to achieve emissions reductions, air quality improvements, transportation technology advances and energy independence

Each of these goals will require actions by state and local governments and authorities, private-sector stakeholder, nonprofit EV proponents and other EVSE stakeholder groups. In planning for EV readiness, the question is what jurisdictions or agencies can do to enhance EV readiness. For example, zoning and parking ordinances, along with permitting, comprise potential approaches at the local level that can work alone or in combination with the structural codes for the implementation of EV-ready policies. These are just a few of the policy levers available to jurisdictions. Legislation, environmental benchmarks, economic development planning, real estate incentives or advocacy-based outreach and education are also critical approaches that were determined as a result of this report's research. These policies should be noted as areas for further study as a part of the emerging EVSE ecosystem.

Considering the limitations in current EV battery technology and the range anxiety associated with a vehicle's battery, the primary existing infrastructure need is the development of a consistent, accessible charging network. However, for EVs, infrastructure begins at home. Ensuring safe, accessible and cost-effective EVSE installation in a variety of vehicle home contexts—the places that vehicles will receive their regular charge—represents the first step in EV-ready planning. Connecting home charging to other charging scenarios would enable EV owners to increase the effective range of their vehicles by making it possible to charge at home, at work and in commercial and public locations, thus extending vehicle reliability over longer trips and better integrating EVs into regional transportation networks. Effectively doing this requires cooperation among jurisdictions, and interviews and case studies also indicate the importance of a high-level, flexible EVSE code framework at the state or regional level designed to encourage local adaptability.

Timing and Costs Complicate Code Regulation

Irregular timing of technology development and rates of EV adoption combine with a wide variation in administration and local conditions—such as extreme weather or high population density—and may encourage localities to amend national model codes to better suit the safety and public welfare requirements necessary. Many states across the country have passed environmental or other related laws that may include provisions or language that require changes to the state-level codes in order for the included jurisdictions to be in compliance with the full spectrum of regulation.[80] There are also high costs associated with changing codes—from staff time to inspector training—and many states and local jurisdictions opt to amend codes once every six years rather than three.[81] Finally, the staggered timelines for revision by code-setting bodies and for review at the local level means that the local jurisdictions adopting codes are often simply behind the times, if being up-to-date is viewed from the perspective of adopting the most recent edition of the code. Together, these factors create a high degree of inadvertent variation across jurisdictional boundaries.

Acknowledging the high costs to local jurisdictions, this report does not at this time recommend changes to the local code revision cycle that would require states or municipalities to update their codes more regularly.

3.1.1. Opportunities to Harmonize Regulations and Promote EV Adoption

Some sources suggest that states or other local jurisdictions should have no reason to deviate from a national model code unless there are provisions written into the applicable state or local laws that require the jurisdiction to do so.[82] Yet federal, state and local laws can lead jurisdictions to amend national model codes. Legislation is typically the incentive to act on codes, and it may include goals related to economic opportunity, environmental conditions or local factors.

There is no one-size-fits-all policy approach to increase EV readiness and serve EV users—or to achieve environmental benefits. Each state or local jurisdiction needs to evaluate the objectives (compliance, economics, and environment) behind any potential policy, code or other change, and follow a path that best suits the available and appropriate menu of options for that jurisdiction. Code modifications can help municipalities, states and regions to promote EV adoption by raising the bar on infrastructure development requirements.

There are implications for the administrative enforcement of local codes that, in turn, impact anyone interested in installing EVSE. Perhaps most significantly, inconsistent business or regulatory environments create complications for those entities providing EVSE infrastructure, from developers to charge networks. Administrative timelines and costs vary widely, and infrastructure providers must navigate a new system with every infrastructure deployment.

Tackling these issues will require cooperation and advocacy. Creating regulatory consistency will be a dual function of the ongoing work of code-setting organizations to incorporate EV- and EVSE-specific provisions, and of the place-based efforts made by the jurisdictions with authority over state and local codes.

The case studies in this section discuss several scenarios in which local and state codes require amendments that arise for particular policy reasons, such as the following examples:

- State or local code changes may be required in order to comply with environmental, transportation or clean energy target legislation established at the federal or state level.

---

[80] See note 60.
[81] Ibid.
[82] See note 8.

- The building code can include scoping requirements, enabling jurisdictions to self-tailor regulations through a selection of the most appropriate mandatory and optional provisions.

3.1.2. Model Jurisdictions: Case Study Overview

The purpose of the following case studies is to profile different approaches, scales and outcomes to changing building codes to more seamlessly allow the incorporation of EVSE infrastructure. The three case studies focus on process and outcomes, highlight best practices for implementation and seek to understand benefits of "EV-ready" codes. The purpose is not necessarily to provide a standard format for writing local codes—ideally greater harmonization will continue to happen at the international and national levels.[83] Instead, the case studies attempt to show the process and outcomes of changing codes to be more EVSE-friendly under different circumstances. What are the key components of EV-readiness? What experiences are replicable? What are the lessons learned from state and local processes for encouraging EVSE deployment?

The case studies in this section elaborate on ways that jurisdictions are currently modifying existing model codes in order to create and implement improved local codes that speak to the needs of jurisdictional authority. Although there is wide variance among local jurisdictions, the process of revising codes is available to states and local authorities and also provides flexibility that leaves room for state-level interpretation. Within a framework of consistent guidelines, this flexibility could be utilized to generate more uniform codes, and determine when and where states and jurisdictions choose to adopt them.

The case studies also outline scenarios in which economic drivers (such as a local EV-related manufacturing base, a desire to generate high-tech jobs or a desire to improve quality of life to attract residents and workers) are relevant, particularly in the way they interact with local conditions (such as the relative economic and environmental cost associated with the local energy supply).

---

[83] See note 5.

VANCOUVER, BRITISH COLUMBIA, CANADA

Summary
Vancouver is the first North American city to require EV charging station connection points for EVs in all new homes and developments.

Focus
Municipal building code

Code Outcomes
Modification of the city's building by-laws to require EVSE-ready wiring in new single-family and multifamily residential construction. Twenty percent of multifamily new construction and 100% of single-family new construction must be built EVSE-ready.

New code updates for 2012 will increase the residential service request to 220 volts to accommodate uniform level 2 charging, and will introduce a 10% EVSE-ready parking requirement to new commercial construction.

3.2. Vancouver: An EV-Ready Building Code

Vancouver, BC, in Canada is known as one of the most forward-thinking cities with respect to its transportation electrification policies and efforts. Yet the city staff stresses that the city is ahead of the curve not because the city is somehow better or more knowledgeable, but because the municipality had the opportunity to move ahead quickly with EVSE planning. EV infrastructure plans and pilots have only just launched in BC. By incorporating EVSE into long-range goals for buildings, transportation and economic planning, the city has taken a holistic approach to EV infrastructure deployment. At the center of Vancouver's strategy is the city's building by-law—the city's building code.

Above and Beyond Approval

The original proposal for a by-law amendment required 10% of the parking stalls within multifamily residential developments to be wired for EVSE installation. Vancouver's City Council approved the by-law amendment and doubled the required amount of parking stalls to be wired for EVSE to 20%.

Unique Considerations

Along with Halifax, Vancouver is one of just two Canadian cities with jurisdictional authority to modify its building by-laws at the municipal level.

Utility

BC Hydro, a Crown corporation, provides much of BC with clean hydropower, with 93% of the electricity in the province generated by clean or renewable resources, meaning that EVs have the potential to dramatically reduce GHG emissions in a local well-to-wheel analysis in addition to eliminating them at the tailpipe.[84]

Pilot Funding

The city of Vancouver secured $800,000 (Canadian) for an EV infrastructure pilot project. Project financing includes funds in the amount of $120,000 from BC Hydro, the Vancouver power authority. A portion of the total funding also came from the provincial government (a partial allocation of an approximately $14.6 million BC-wide EVSE project that will install 1,000 charging stations throughout the province—570 public, 400 in multiunit residential buildings and 30 DC fast chargers on the Canadian spur of the Pacific Coast Electric Highway). A minimum of 67 charging stations will be part of the Vancouver pilot.[85]

3.2.1. Cutting-Edge Code Policy Supports EV-Ready Green Buildings

In July 2008, as a part of the Green Homes Program, the Vancouver Council enacted new regulations in the building by-law[86] aimed at reducing the environmental impacts of new one- and two-family homes; the amendments to the code made the Vancouver building by-law one of the "greenest" residential codes in the world.[87] With the successful implementation of the Green Homes Program goals, and to move forward with provisions in the city's EcoDensity Charter,[88] the Vancouver Council passed a second building by-law amendment to require the electrification of a portion of residential parking stalls in all new buildings containing three or more dwelling units; the provisions were required for all new projects applying for permits after April 20, 2011.[89] The by-law required a minimum of 20% of parking stalls associated with multifamily dwellings to be outfitted with an electrical inlet and conduit/panel capacity to accommodate level 2 EVSE installation, and stated that it is the responsibility of the electrical engineer of record to assess the electrical system capacity required. Further, in buildings with an electrical room containing a transformer, the room is required to contain enough physical space capacity to accommodate future installation of the equipment necessary to provide charging stations at 100% of the building's parking stalls.[90]

3.2.2. Location Advantages: Vancouver's EV Suitability

Vancouver is a compact, high-density city with a population of about 600,000 people in roughly 114 square kilometers (44 square miles).[91] Demographics support the EV market, indicated by the high level of alternative vehicle technology uptake (in Vancouver and in BC, the Toyota Prius sold at more than twice the national rate). In a city with a relatively small land area, about 95% of car trips are less than 30 kilometers (19 miles) and about 70% of car trips are less than 10 kilometers (6 miles), making EVs highly viable for daily transportation. Furthermore, Vancouver's power supply is unique for two reasons. First, less than 10% of the province's power comes from non-renewable sources (natural gas); like much of the Pacific Northwest, BC has a supply of

---

[84] "Plug-In Vehicles," BC Hydro, accessed October 24, 2012, http://www.bchydro.com/about/sustainability/climate_action/plugin_vehicles.html.
[85] See note 17.
[86] City of Vancouver, By-Law No. 9691 (Building By-Law, January 30, 2007), http://former.vancouver.ca/blStorage/9691.PDF.
[87] City of Vancouver Committee on Planning and Environment, *Green Rezoning Policy Report* (February 4, 2009).
[88] http://vancouverpublicspace.ca/index.php?page=ecodensity-liveability.
[89] City of Vancouver By-Law No. 9936.
[90] City of Vancouver Community Services Group, Bulletin 2011-002-BU/EL, March 17, 2011.
[91] With a population density of approximately 13,000 residents per square mile, Vancouver compares most closely to Boston or Chicago among major U.S. cities. In land area, Vancouver is comparable to Boston and San Francisco.

clean, renewable energy, largely hydropower. As a result, a transition to EV use would represent an approximate 98% reduction in carbon dioxide emissions.[92] Second, Vancouver has the largest price differential between gas and electricity in North America.[93] Together, these factors exponentially increase the environmental and economic benefits of EV adoption, providing serious policy and financial incentives for the city to invest in studying and deploying EV charging infrastructure.

In addition to these incentives, Vancouver has the advantage of already being known as one of the world's most livable cities.[94] The benefits of the "Pacific Northwest mindset" and 40 years of forward-thinking local policy from the Vancouver City Council also contributed to the ease of adoption of the Building By-law amendments.

These factors should not be seen as setting Vancouver apart as an anomaly; every city is unique in its combination of economic, energy and planning policies and agendas; real estate development industry; political will; stakeholder buy-in and realistic action items. Instead, other cities should look to a broad range of market, environmental and political factors to consider the feasibility of a particular path to EV readiness in their communities.

3.2.3. Policy Origins

In March 2005, Vancouver's Council approved a Community Climate Change Action Plan to reduce GHG emissions to 6% below 1990 levels by 2012, and two years later, in March 2007, the City Council passed a motion directing city staff to plan for significant, long-term GHG reductions with the goal of carbon neutrality. In May of the same year, the Vancouver Council adopted a building by-law that included environmental protection objectives, opening the door to the facilitation of future development of the city's Green Building Strategy.[95]

BC Plug-In Electric Working Group

In response to these city-wide goals, a working group emerged from an early partnership started by the former Climate Programs Engineer for the city of Vancouver, the power authority BC Hydro and the BC provincial government, when it was realized early on that three people—or even three agencies—could not guide the entire planning process. Ultimately, the BC Plug-In Electric Working Group was composed of 10–12 carefully selected institutional members representing different levels and agencies within the provincial and city governments, nongovernmental organizations, the electrical utility and academia. In its bimonthly meetings, the working group sought to understand the large-scale questions in the context of what small steps could be taken.[96]

The first of those steps was recognizing the ability of the province to secure EVs for sale in the local market. BC signed memoranda of understanding (MOUs) with vehicle manufacturers, notably receiving early shipments of the Mitsubishi i-MiEVs. After establishing that getting the vehicles to the area for sale was the first step, the city and province, through the working group, began to consider the required infrastructure.

---

[92] See note 17.
[93] See note 5.
[94] Consistently ranked highly by *The Economist*, *Monocle* and *Mercer*: http://www.mercer.com/press-releases/quality-of-living-report-2011#City-Rankings.
[95] "Policy Report on Development and Building" (Vancouver: City of Vancouver, June 9, 2008), http://www.docstoc.com/docs/5427511/CITY-OF-VANCOUVER-POLICY-REPORT-DEVELOPMENT-AND-BUILDING-Report.
[96] See note 17.

The BC Plug-In Electric Working Group united interests and expertise from local and provincial government, utilities and energy resources and academia around creating a comprehensive EV-ready and infrastructure deployment strategy.

Building Code Amendments[97]

The BC Plug-In Electric Working Group looked to areas that the city could control; that is, the regulatory tools available that would have the ability to build awareness and interest as well as hard infrastructure for EV charging.[98] With the working group and other stakeholders, the city's Office of Sustainability, Planning, Development and Engineering, the office responsible for making final recommendations, realized that a primary challenge is the ability of the EV owner to install or access a charging station at his home.[99] In 2008, Vancouver began working on its building code, or building by-laws. The ability of the city to do so is unique (with Halifax being another exception to the rule) in Canada; municipalities typically do not have jurisdictional authority over the building code. The building code rose to the top as the most critical option for city policy changes to drive EV development because of its ability to garner larger interest, policy buy-in and market uptake.[100]

In Vancouver, amending the building by-laws for the EV provision was not a process that differed from amending the code for other reasons. Essentially, there is a standard approach and process that must be followed for such an amendment. Because the potential change would necessarily impact real estate developers—from whom the city can expect a certain degree of push back on proposed changes that will increase construction costs— BC Plug-In Electric Working Group attempted to craft a standard that would keep any cost increase below 2% of total construction costs.[101] This 2% maximum construction cost increase limits the scope of any building code amendment in the city.

The amendments included the following:

- Single-Family Dwellings: Vancouver Building By-law No. 9691 (2008), which requires each dwelling unit to be constructed with a cable raceway capable of supporting level 2 charging infrastructure.
- Multifamily Dwellings: Vancouver Building By-law No. 9936 (2009), which requires 20% of the parking stalls in multifamily construction (three or more dwelling units) to be equipped with a receptacle to accommodate EVSE use.

For the city, addressing the residential building code was a "clear decision area."[102] Not only does it fall clearly within the jurisdiction of the city and the code, but the city took the position that a majority of future EV charging will be done at home. In planning for infrastructure deployment with a limited budget,[103] it was critical for Vancouver's planners and the BC Plug-In Electric Working Group to consider the tools available that could create the maximum impact.

---

[97] See Appendix D for code language from Vancouver.
[98] See note 17.
[99] See note 98.
[100] See note 17.
[101] Vancouver's 2% figure is standard for any building by-law amendment, largely due to the fact that such a minimal overall increase is effectively lost in the project details. Additional development costs are not always passed on directly. Vancouver's current Climate Programs Engineer, Malcolm Shield, explains that the total development value is based on a combination of developer profit, hard costs, soft costs and land costs. Considering that the price to the buyer is fixed by the market value of the unit—the developer will not shift its profit margin—and that hard and soft costs are effectively fixed, the increased cost associated with EV-ready construction will be reflected in the one remaining variable: land price.
[102] See note 17.
[103] CAD 800,000 for the infrastructure deployment program.

3.2.4. A Measured, Holistic Approach

Another key element to Vancouver's planning approach is the holistic nature of the issues and actions considered by the Vancouver City Council and the BC Plug-In Electric Working Group. The city's relatively limited resources created a need to plan very carefully due to smaller project budgets than those available for similar projects in U.S. cities.

However, the combination of working in a number of related but distinct areas to advance the city's EV readiness contributes to the broad perception of Vancouver's success and leadership in the EV field. In reality, Vancouver has just six public charging stations owned and run by the city. By the end of 2012, this number will increase by between 20 and 25 stations as a part of the publicly funded pilot.[104]

Next steps for the city will prioritize rolling out the charging infrastructure trial, assessing sites and understanding the best locations for EVSE location. Steps forward will also include continued innovation through industry partnerships and a focus on understanding EVs as an aspect of multimodal transportation planning. In many ways, Vancouver's approach to EVSE deployment demonstrates that the proof is not in the numbers, but in the creation of a strategy that leads to a more favorable EV market.

Vancouver, BC, Stakeholder Outreach by Category

Category	Action
Business Partners	car2go car sharing partnered with the city to share a fleet vehicle, kept in a high-visibility parking spot. The vehicle is designated for public use during the day and is available to car2go customers during non-business hours.
Business Partners	TELUS has designed concepts for integrated EV and cellular infrastructure that will be deployed in Vancouver parks.
Utility Relations	Development of energy price structures BC Hydro acts as consumer resource for EV and EVSE
EV-Ready Roadmap	Project Get Ready/Rocky Mountain Institute created a plan for an EV-ready Vancouver, including a menu of EV-ready action items.

3.2.5. Key Takeaways

Summary:

- Foster continued growth of EV policy and working groups
- Implement small-scale change for big results in the long-term
- Encourage flexibility at the municipal level to adapt to markets and local conditions
- Link clean power sources to EV planning efforts, maximizing environmental impacts

In **Vancouver**, a municipality created a collaborative working group to develop EV-readiness strategies with the intent of meeting long-range GHG reduction goals. Because of the ready availability of clean hydropower, the replacement of gas engine vehicles with EVs was

[104] See note 17.

determined to have a disproportionately dramatic effect on GHG emissions, making the stimulation of the EV market a smart choice for the area. In meeting the anticipated needs of future EV owners, the Vancouver City Council took advantage of its unique ability among Canadian cities to modify its building codes in order to require a substantial percentage of parking stalls in new construction to be EV-ready. At little added cost to developers, amending the scope of the local building code to include mandatory minimum requirements for the future electrical installation of charging stations illustrates a relatively simple, feasible solution to a complex problem. In doing so, Vancouver became the first North American city to require EVSE connection in all new development.

In the **TCI region**, fostering continued growth of EV policy and working groups created by states, municipalities and regional planning organizations is a very important step. Working groups can look to Vancouver's successes in negotiating with the development community to recommend EV-ready strategies that are considerate of economic development as well as public benefits associated with transportation electrification.

Another important lesson learned from Vancouver's sustainability planning in the EV arena is the understanding that the "low-hanging" fruit, in this case the building codes, can have large-scale impacts. Moving ahead on one focused policy can create a ripple-effect once acceptance has been achieved and benefits understood in one area.

Vancouver has the unique ability to amend building codes at the municipal level. Each US state has the ability to draft code amendments, and can include provisions that set broad policies and standards, but allow flexibility to municipalities to accommodate local conditions and markets, much like in British Columbia and Vancouver.

The predominant use of hydropower in Vancouver and throughout the Pacific Northwest makes the relative impact of reducing tailpipe emissions including GHGs and CO_2 a dramatic one. However, jurisdictions in the TCI region have the opportunity to take advantage of the extended benefits of cleaner power sources as well. Nearly every electrical utility is now providing consumers with the option to choose clean or renewable power sources. While anticipation of the expansion of this type of service in the TCI region is outside the scope of this report, the potential to continue to link EV charging and clean power through utility participation in policy and planning is an important consideration to pursue. In the interim, state and municipal officials can refer to the existing literature (e.g. impact studies produced by local utility companies) to estimate the relative positive benefit of introducing EV charging to the local grid.

LOS ANGELES, CALIFORNIA

Summary
High statewide standards required by CALGreen, the California State Green Building Code, and local amendments work in concert with utility-led efforts to plan for EV readiness across complex jurisdictional boundaries.

Focus
State and local Green Building Code and utility infrastructure and service planning.

Code Outcomes
CALGreen includes mandatory provisions and optional appendices. The city of Los Angeles takes a more restrictive approach and requires EV-ready construction of all new single-family and multifamily dwellings and of commercial properties. Los Angeles County is considering mandatory measures that will create greater harmony among the region's many individual jurisdictions.

3.3. Los Angeles: Green Construction Codes and Utility Planning

Best practices from the city of Los Angeles, Los Angeles County and the surrounding metropolitan area illustrate the importance of multi-agency cooperation across jurisdictional boundaries and demonstrate that there are multiple potential leaders among EV and EV infrastructure stakeholders.

In southern California, emission reduction goals and working with aging energy infrastructure are central concerns relating to the regulatory environment surrounding EVSE. However, regulation of any kind in Los Angeles is a complex process because the county's many jurisdictions are not only irregularly bounded, but they also have the opportunity to adopt their own codes.

Measures specific to EVSE included in the state's mandatory green building code, called CALGreen, in concert with utility-led work on infrastructure in the Los Angeles metropolitan area, have created a standard framework for incorporating charging infrastructure into the built environment in the form of a mandatory state green building code and two tiers of voluntary appendices. These appendices include a set of universal choices and requirements for EVSE for jurisdictions choosing a more stringent route. State-level work on codes has resulted in unique local opportunities to enforce or mandate more restrictive codes. Jurisdictions voluntarily adopt right-sized regulations to meet local needs, but the details of optional code appendices have been set out in advance, creating a consistent typology across the state. The city of Los Angeles is one example of a jurisdiction seeking a higher degree of regulation and EV readiness; it already requires EV-ready wiring in one- and two-family homes, and it is in the process of reviewing a proposal to adopt the extended voluntary CALGreen appendix covering EVSE into the mandatory code at the county level.

The intersection of local and state code-based strategies and the unifying activities of utility service providers give rise to an EV-friendly environment that crosses jurisdictional boundaries.

3.3.1. California Green Code

The new California Green Building Code, governed by the California Building Code Commission, is unique.[105] The new standard was introduced in 2008, with the mandatory measures included therein enforceable as of January 2010. Currently, the EV- and EVSE-related codes are included as voluntary appendices, available for adoption by local jurisdictions by amendment via the local code adoption ordinance.[106] A key feature of the CALGreen code and appendices is a two-tiered system that is designed to allow jurisdictions to adopt codes that go beyond the state's mandatory provisions.[107] The tiers enable standard options for local jurisdictions that choose to adopt more stringent regulations.

The intent of the optional, or voluntary, approach was to allow the industry and enforcement agencies to prepare for the new code before it became mandatory. However, several jurisdictions immediately adopted the 2008 code as mandatory. A process of revision based on further stakeholder conversations, working groups and feedback on the implementation of the 2008 edition of CALGreen enabled improvements at the state level prior to the introduction of the 2010 mandatory code. [108]

CALGreen addresses the issue of compliance and training by incorporating the new code into existing code enforcement infrastructure and requiring public agencies to incorporate the new provisions into their inspection process.[109] Unlike some state building codes, California's Green Code is available online, increasing access to new standards. In addition, the state's Building Standards Commission is pursuing training related to the code through partnerships throughout the state.[110] As in Vancouver, the state of California's new regulations only increase the construction costs associated with a new home by a minimal amount.[111]

CALGreen requires the designation of parking stalls for zero-emission vehicles as an aspect of the nonresidential mandatory measures.[112]

EV Charging in State and City Codes

CALGreen's 2010 edition contains voluntary measures for nonresidential construction that require 10% (tier 1) and 12% (tier 2) of total parking spaces be designated for zero-emission or fuel-efficient vehicles. Further, EV supply wiring is required for EV charging stations for between one and four parking spaces, depending on the lot or garage capacity.[113]

---

[105] CALGreen is available online at: http://www.documents.dgs.ca.gov/bsc/CALGreen/2010_CA_Green_Bldg.pdf.

[106] The voluntary appendices A4 and A5 of the California Green Building Code thus depend on the choice of builders in each jurisdiction to execute. That is, the appendices make guidelines for EVSE available if and when a developer chooses to incorporate such infrastructure into a project.

[107] "The 2010 California Green Building Standards Code" (California Buildings Standards Commission, n.d.), http://www.documents.dgs.ca.gov/bsc/CALGreen/The-CALGreen-Story.pdf.

[108] Ibid.

[109] Ibid.

[110] Ibid.

[111] The California Building Standards Commission estimates that all new green building regulations, not just EVSE, will increase the average cost of home construction by about $1,500.

[112] California Building Standards Commission, *Guide to the (Non-Residential) California Green Building Standards Code*, Second Edition (Sacramento, CA: November 2010), chapter 5.2, http://www.documents.dgs.ca.gov/bsc/CALGreen/Master-CALGreen-Non-Res-Guide2010-sec-ed-final-3-1-11.pdf.

[113] CALGreen Nonresidential Voluntary Measures A5.106.5.3 requires one 120 VAC 20 amp and one 208/240 V 40 amp, grounded AC outlets or panel capacity and conduit installed for future outlets.

As of January 1, 2011, all single-family residences, multifamily dwellings and commercial properties constructed in the city of Los Angeles will have EV-specific requirements.[114] EV supply wiring is mandatory for residential construction as per Article 9, Division 4 of the city's adopted version of CALGreen. The city ordinance requires a minimum of one 208/240 V 40 amp, grounded AC outlet for each dwelling unit or the panel capacity and conduit for future EVSE installation for each unit. For multifamily occupancies or single-family attached occupancies with shared parking, Los Angeles currently requires a minimum of 5% of total parking spaces to be wired with EVSE capacity and requires EV readiness through additional service capacity.

Currently, Los Angeles County is discussing the mandatory adoption of the non-residential CALGreen appendix, a proposal that, if passed, would include an amendment of the State Green Code to require new commercial construction of 10,000 square feet or more to be EVSE-ready, representing a decrease in the minimum building size to trigger EV-ready electrical systems.[115] This proposal would include more construction and building typologies.

3.3.2. State Policy Origins

California aims to reduce its GHG emissions by 33% by 2020. In 2004, then Governor Arnold Schwarzenegger signed an executive order to create the "Green Building Action Team" to address efficiency for state-owned buildings. Another order the following year established the "Climate Action Team," which called for the overall reduction of GHG emissions in the state. The emission reduction goals were solidified in law with landmark legislation AB32. CALGreen standards were developed in cooperation with the California Air Resources Board, the Department of Housing and Community Development, the Division of the State Architect and the Office of Statewide Health Planning and Development.[116]

In California, a West Coast sustainability mentality meets a high dependence on personal transportation. Emissions can be broken down into the activities that produce them. The state's on-road emissions from the transportation sector represent the largest source of California's gross inventory of emissions (more than 35%).[117] By contrast, the California Air Resources Board found that emissions from commercial and residential buildings remained steady from 2000–2009, even as the number of housing units and commercial and institutional floor space grew substantially. Observation of steady emissions despite increasing building area indicates that fuel use per unit of consumption has actually declined.[118] A serious policy discussion of what measures could achieve GHG emission reductions goals pointed to the building code, where an existing willingness to adopt green building practices became an opportunity to incentivize EV adoption.

The mandatory standards adopted in 2010 were initially introduced as voluntary measures two years prior. CALGreen, adopted unanimously by the California Building Standards Commission, allows cities with more stringent green building codes to retain their existing standards—or to modify them further to be more restrictive.[119]

---

[114] See note 17.
[115] Ibid.
[116] See note 110.
[117] Air Resources Board, "Trends in California Greenhouse Gas Emissions for 2000 to 2009" (Sacramento, CA: California Environmental Protection Agency, December 2011), http://www.arb.ca.gov/cc/inventory/pubs/reports/ghg_inventory_00-09_trends.pdf.
[118] Ibid.
[119] Kristina Shevory, "California Adopts Green Building Codes," *The New York Times*, October 24, 2012, http://green.blogs.nytimes.com/2010/01/15/california-adopts-green-building-codes/.

EVs in Southern California

Home to early adopters in clean energy technologies, the Los Angeles metropolitan area is anticipating a surge in consumer and municipal uptake of EVs based on market forecasts utilized by Southern California Edison (SCE).[120]

California already has several decades of experience working with and planning for EVs. While this has proved beneficial, it also generates unique challenges: in Los Angeles and throughout the state there are hundreds of existing low-technology charging stations from the first release of EVs in the state, dating to the mid-1990s. The state's experience has resulted in an existing inclusion of EVs within the motor-vehicle-related occupancies section of the California Building Code, section 406.7, which provides the minimum EV-related code requirements referenced in the Green Building Code.

3.3.3. Challenges Related to Jurisdictional Boundaries

Cooperative efforts in EV readiness across the Los Angeles metropolitan area are not limited to the county and city of the same name. There are 88 incorporated cities, numerous unincorporated areas and almost 10 million residents within Los Angeles County, and the irregular municipal boundaries of the city of Los Angeles envelop or abut many of these. This arrangement produces an astonishing number of city officials: there are more than 450 mayors and city council members in the county.[121]

Furthermore, there is a strong home-rule tradition in California that has impacts on collaboration around energy and infrastructure—and nearly everything else.[122] However, there is also an established tradition of regional planning, area Councils of Governments and Metropolitan Planning Organizations playing roles in large-scale plans.

A recent report on the government structure of Los Angeles summarizes the difficulties that surround representation, regulation and enforcement in the metropolitan area:

> *Los Angeles is a different kind of city. It is huge in land area, decentralized in living arrangements, marked by an individualistic culture that pays little attention to politics and government. Many residents of Los Angeles have never seen an actual map of Los Angeles. Others are not certain whether they live in Los Angeles City, in another smaller city, or in an unincorporated county territory. While public officials are important and powerful, they do not have the visibility that marks public office in eastern and Midwestern cities like New York City and Chicago.*[123]

This poses specific political and administrative challenges for designing strategies relating to EV readiness that can help the region achieve more uniformity and smooth its transition to a more EV-friendly environment.

3.3.4. California Utilities and Energy Market Impacts on EV Readiness

The Los Angeles area has produced one possible solution to the challenges created by fragmented jurisdictional governance, although not by government actors: intense involvement of the utilities in programming and training, research and upgrading and monitoring the electrical

---

[120] See note 17.
[121] "Mayors and City Councils Cities of Los Angeles County," accessed October 24, 2012, http://www.laalmanac.com/government/gl10.htm.
[122] Conor Friedersdorf, "Los Angeles is 88 Cities, Many of Them Corrupt," *The Atlantic*, April 28, 2011, http://www.theatlantic.com/national/archive/2011/04/los-angeles-is-88-cities-many-of-them-corrupt/237980/.
[123] Raphael J. Sonenshein, "Los Angeles: Structure of a City Government" (Los Angeles: The League of Women Voters of Los Angeles, 2006), http://www.lwvlosangeles.org/files/Structure_of_a_City.pdf.

service. This report will focus on SCE, an investor-held utility with a wide-reaching territory covering much of the Los Angeles mega-region, and touch briefly on initiatives of the Los Angeles (City) Department of Water and Power. SCE is the primary utility service provider for the county as a whole, but the city of Los Angeles has its own, fully integrated utility that performs power generation, transmission and distribution for the city only.

A full discussion of the recent history of energy deregulation and supply in California is complex and beyond the scope of this document. However, it is worth mentioning that the California energy crisis of the early 2000s has had direct effects on the current state of EV infrastructure planning in the state. A settlement reached in the spring of 2012 between the California Public Utility Commission, the agency responsible for the regulation of investor-owned utilities in the state, and NRG Energy, a subsidiary of Dynegy Inc., which was found to have manipulated the energy market during the post de-regulation crisis a decade ago, will generate an investment of $100 million dedicated to EV charging infrastructure throughout the state.[124] More than half of this settlement funding will go toward the installation of 200 commercial charging stations.[125] Despite some industry concerns over the energy company effectively being granted the monopoly-like benefits of a competitive advantage as a "first mover" in the DC fast charging market,[126] the outcome for EV users, the utility grid and the built environment will be the introduction of a significant (nearly 200%) increase in fast-charging stations in the state. The NRG settlement will include an additional $40 million toward wiring of homes, multi-unit dwellings (MUDs) and public locations for EV readiness.

Best Practices for Utility-Led Infrastructure Planning

SCE takes a pro-active approach to EV readiness. Particularly with the introduction of more widespread fast charging, the need to approach EV-ready infrastructure from the perspective of the energy grid is clear, as it becomes increasingly important for utilities and power authorities to be knowledgeable of the required service capacity within their respective territories.

Currently, SCE is involved with many organizations, pursuing a comprehensive stakeholder outreach initiative that includes other utilities, auto manufacturers, state and local governments, nonprofit entities working on EV readiness, consumer groups and community-based organizations. The primary goal behind the utility's outreach programs is the creation of a uniform message about EVs and EV charging infrastructure. The mission of the utility is to provide safe and reliable electrical service; this is the reason behind SCE's involvement in the EV infrastructure space. This relates specifically to the utility's ongoing role in upgrading the grid throughout its service area.

A unique need in California is the upgrading of existing charging infrastructure dating from the first wave of EV use in the 1990s; hundreds of older charging stations are due for an upgrade. In order to approach infrastructure upgrades in a cost-effective manner, the utilities are seeking to prioritize upgrades in the areas that are most critical. This is an issue that impacts both the distribution infrastructure (power generation and other parts of "the grid") and residential systems. The coastal climate of Los Angeles (which has not typically required residential electrical system capacity for air conditioning), combined with an aging building stock means that the capacity of many area homes may only be 40 amps—not quite able to accommodate a level 2 charger with a four- to six-hour continuous load.[127] The purchase of EV charging stations from home renovation retailers such as Home Depot for self installation—regardless of whether it is allowable in the residential building code—represents a "concern" for utilities. Part of this

---

[124] For a timeline of the 2000–2001 energy crisis, see: http://www.pbs.org/wgbh/pages/frontline/shows/blackout/california/timeline.html.
[125] http://www.forbes.com/sites/pikeresearch/2012/04/27/nrg-settlement-far-from-settled/.
[126] See: http://ecotality.com/wp-content/uploads/2012/04/Motion-for-Public-Review-of-NRG-Settlement.pdf.
[127] See note 17.

concern arises out of the technology use of EV early adopters; these are often households that have already adopted other new technology that already drains home system capacity, such as plasma televisions.[128]

Monitoring EVSE deployment happens from the utility perspective in several ways: through cooperation with the auto manufacturers and dealers to obtain data on EV orders within the service area, cooperation with EV charging service providers that sell or lease charging stations and via notification systems such as permits issued for EVSE installation or for electrical service upgrades. Failing access to that type of data, the utility monitors and assesses spikes in energy use as a general practice.[129]

Additional incentives from the utility address rates, research and outreach. SCE provides an option for dedicated metering, including special EV rates. The EVSE is metered separately on a dedicated line, billed using a time-of-use rate. The installation of a separate meter does not present a code or permitting issue and is typically easy to execute. Finally, SCE leads and partners in energy-related research. Recent projects include an unreleased study assessing the charging and driving patterns of EV drivers in the SCE service territory. Working with the University of California, Los Angeles and the University of California, Santa Barbara on public infrastructure research, SCE has produced a number of research documents, the dissemination of which has occurred through transportation and regional planning organizations such as area councils of government and metropolitan planning organizations.[130]

3.3.5. Key Takeaways

Summary:

- Encourage environmental benefits in the transportation sector through regulating the built environment
- Create consistent code options for local jurisdictions by offering tiered requirements
- Work with and expand the role of utility companies in planning for EVs

In the **Los Angeles** metropolitan region, city, county and state governments have taken innovative approaches to greening buildings and the transportation sector. These efforts have been complemented by the proactive stance taken by the major electrical utility providers in the Los Angeles region. CALGreen, as the nation's first mandatory green building code, sets a high bar. The code's overall goals deal directly with the state's mandate to reduce GHG emissions, and an EV-ready policy included in the code recognizes that regulation in one high-emissions sector (buildings) can impact and incentivize greener consumer behavior in another sector (transportation). The state's approach to phasing in the code's mandatory provisions sheds light on the ways in which other jurisdictions might adopt similar code amendments, and the inclusion of "tiers" of compliance in the voluntary appendices makes it possible for the adopting jurisdiction to choose the level of deployment and enforcement most appropriate for the local market and community. Los Angeles is leading the shift to mandatory EVSE codes; both city and county have or will likely soon pass and upgrade the requirements for EV-ready construction. For a metropolitan area with an incredible number of local jurisdictions, a top-down but flexible approach such as CALGreen is a good solution. In addition, the utilities, such as Southern California Edison, are finding a niche role as a stakeholder and coordinator for EV-ready action that spans jurisdictions.

In the **TCI region**, codes that make buildings greener can create environmental benefits for the transportation sector as well, e.g. through the inclusion of dedicated EV parking spaces. The top-

---

[128] See note 17.
[129] Ibid.
[130] Ibid.

down, flexible approach to setting standards by using tiers and voluntary code appendices is a best practice that could be translated to state building codes throughout the TCI region. Indeed, like California, many east coast states have a wide range of population densities across highly populous and dense urban areas and rural and agricultural areas. Codes become a tool that lets local jurisdictions assess local conditions by opting in or out of certain levels of regulation, while offering a consistency in requirements and developer and consumer expectations across a state.

Further, the focus of the reduction of transportation sector emissions is not something unique to the west coast, nor is the potential adoption of environmental standards that have originated in west coast states. Another related California initiative, Title 13 of the California Code of Regulations, sets standards for low emission vehicles, and these standards have been adopted into law by TCI region states and jurisdictions, including Washington, DC, Maryland, New Jersey, New York, Pennsylvania, Connecticut, Massachusetts and Vermont.[131]

The opportunity for expanding utility companies' roles in EV planning is illustrated by SCE's various initiatives. Considering the importance of utilities as partners and stakeholders (e.g. in EV working groups or councils) is an important step in any jurisdiction toward EV readiness. Many of the issues that TCI stakeholders cited in initial project outreach are concerns of the utilities, for example: peak rates and electricity pricing per kilowatt hour, the inclusion of dedicated (split) or smart meters that can aid EVSE installations in multi-family housing, reporting of EV purchases or EVSE installations to manage loads on local transformers.

[131] State-by-state references to California's Low Emission Vehicle standards can be found through the U.S. DOE: http://www.afdc.energy.gov/laws/search

OREGON

Summary
The Oregon Building Codes Division has developed new administrative rules to streamline permitting and inspection protocols for EVSE installation statewide.

Focus
Electrical code amendment facilitates permitting process

Code Outcomes
New, streamlined permit and inspection protocols apply uniformly throughout the state. These include Oregon's minor label program. Code changes currently address levels 1 and 2.

3.4. Oregon: State-Level Electrical Code Amendments

The state of Oregon is known as a national leader in sustainability, and as such this case study addresses state-level efforts to amend the regulatory environment governing EV infrastructure. As a sustainability leader, Oregon is home to a few unique considerations relevant to this discussion. First, as a region included in ECOtality's EV Project, Oregon has received substantial EVSE-related funding through ARRA.[132] Second, Oregon has a concentration of existing EV automotive component producers in niche manufacturing.[133] Both points are evidence of existing understanding of the value of growing the EV market.

Another distinction worth noting is actually common throughout the Pacific Northwest; more than half of the state's energy comes from hydropower. Portland General Electric (PGE), Idaho Power Company and Pacific Power provide electricity throughout the state, in addition to numerous smaller providers. As Portland's power supplier, PGE is particularly engaged in expanding EV adoption, raising awareness and generating industry economic opportunity in partnership with public and private organizations.[134]

Cooperation has been at the center of Oregon's EVSE efforts. The Governor's Alternative Fuel Vehicle Infrastructure Working Group has guided research and policy approaches for the state, recommending code changes to the Building Codes Division (BCD). BCD worked with PGE on a pilot program to install an initial five-charge point pilot project in Portland and Salem beginning in 2008. In 2010, the working group created the Transportation Electrification Executive Council in order to address the need to coordinate public, private and civic leadership in the area of EVs and

---

[132] An EV Project report on EVSE deployment for the Portland, OR, and Salem, OR, areas can be found here: http://www.theevproject.com/downloads/documents/Electric%20Vehicle%20Charging%20Infrastructure%20Deployment%20Guidelines%20Oregon%2015%20Metro%20Areas%20Ver%203.2.pdf.
[133] *Report of the Alternative Fuel Vehicle Infrastructure Working Group* (Portland, OR: Multnomah County, January 2010), http://www.psrc.org/assets/3751/W_OregonReport_2010.pdf.
[134] "Electric Vehicles in Oregon," Portland General Electric, accessed October 24, 2012, http://www.portlandgeneral.com/community_environment/initiatives/electric_vehicles/evs_in_oregon/default.aspx.

EVSE. As mentioned above, cooperative efforts extend to the private sector. A coalition of Oregon cities are participants in the EV Project, a public-private partnership administered by DOE and funded by ARRA and the private investment of ECOtality, Inc. The EV Project has facilitated cooperation among public and private organizations, utilities, financial partners and the EV industry.[135]

Lessons from Oregon demonstrate how legislative effort and relatively simple electrical code changes can help specify an EV-ready policy that speaks to overall emissions reduction and sustainability goals through a safety-focused policy. The code change process has also focused on establishing best practices in the permitting and administrative arena that have made these processes more uniform and dramatically reduced the cost of permits for EVSE installation.

3.4.1. Electrical Code Change Aimed at Expediting Permitting and Inspections

Oregon's participation in the EV Project provided funding and introduced vehicles into the market, as well as accelerated demand for charging infrastructure. The state of Oregon's approach to streamlining the permitting and inspection process addresses this relatively high-demand condition. Overall, Oregon is actively coordinating a range of activities to facilitate widespread EV and EVSE deployment.

Targeting the structural codes presented unique opportunities and challenges for the State of Oregon. The state's building codes are different from most other states; codes adopted at the state level set both the minimum requirements for construction statewide and the maximum requirements that local jurisdictions can enforce. In effect, state-level building code changes would establish a uniform policy for all new construction across the entire state, much like Vancouver's Building By-laws, but over an inefficiently large geographic area, causing cost burdens in many areas, particularly those outside the urbanized Pacific coast corridors. The working group concluded that while building code changes would reduce the construction costs associated with retrofitting buildings to be EVSE-ready in the future, the increased costs for developers at the present moment would be premature.[136]

In this light, finding a way of ensuring a positive user experience, reducing the administrative costs and ensuring a path for emerging technology and its safe installation without adapting the scope or structural aspects of the building code was a challenge to the state in its approach to supporting EVSE. The solution was to ask BCD to develop a home EVSE installation process that could be completed within just a few days of purchase.

3.4.2. Minor Label Program

In 2008, BCD adopted statewide permit and inspection protocols through a rule that establishes the types and number of permits and inspections required to install EVSE. One of the central aspects of Oregon's code change is the inclusion of EVSE in the state's minor label program. Oregon's statewide process speeds simple EVSE installations by enabling licensed electricians to pre-purchase permitting minor installation "labels" online and inspecting only 1 out of 10 EVSE installations.

The electrical minor label program was developed and implemented in the late 1980s to allow electrical contractors to use labels in lieu of individual permits for limited, simple installations, repair and maintenance. Previously, these installations were limited to 30 amps at 40 volts; however, in examining EVSE, BCD determined that the installation of a simple 40 amp circuit in a

---

[135] "Oregon EV Companies," EVRoadmap.com, accessed October 24, 20120, http://www.evroadmap.com/orevcompanies.html.
[136] See note 135.

residential setting could also fall into this same scope of work.[137] Under the minor label program, a licensed electrician can purchase booklets of 10 minor installation labels for $140; each label allows for standard EVSE installations. The program defines standard EVSE installations as those installations that are within sight of the electrical panel supplying the charging unit, have a branch circuit that does not exceed 40 amps/240 volts and are not located in a damp place.[138] Under this program, just 1 in 10 of the electrician's completed jobs is inspected by BCD. An additional benefit of the program addresses some concerns raised by the electrical safety community around lack of control over residential installation under the IRC: only licensed professionals are permitted to purchase minor labels.

The inclusion of EVSE in the state's minor label program can be considered a best practice. Reducing the cost to the state in terms of inspections and to the EV owner makes the installation of at-home charging infrastructure that much more accessible—each permit for a basic installation costs $14, compared to permitting costs that still reach up to $700 in some areas of the Los Angeles region. The Oregon code amendment does not contradict the conclusion that the NEC provisions sufficiently cover existing technology needs; instead, it emphasizes the potential for states or local jurisdictions to amend the code to create a more pro-EVSE regulatory environment.

In addition, local jurisdictions that participate in BCD's ePermitting services are able to offer the required feeder permit for EVSE online, simplifying the process even further.[139]

3.4.3. Policy Origins: Alternative Vehicle Evolution

Consistent, predictable standards provide guidance to cities and counties on the issues surrounding emerging technologies, according to BDC.[140] In order to assist in the creation of consistent standards at the state level, the state of Oregon has adopted and continued to revise new standards that establish permitting and inspection requirements for EVSE that apply in every county and city across the state.

BCD is housed within the State Department of Consumer and Business Services, which is the state's business regulatory and consumer protection agency. The Codes Division provides code development, administration, inspection, plan review, licensing and permit services to the construction industry.[141]

The EVSE-related standards are one in a series of steps taken by BDC's Green Building Services section toward positioning Oregon as a green building innovation center; prior activities included the approval of new water conservation methods and the development of amendments to the building code to allow for greater energy efficiency.

The Oregon code amendment does not contradict the conclusion that the NEC provisions sufficiently cover existing technology needs; instead it emphasizes the potential for states or local jurisdictions to amend the code to create a more pro-EVSE regulatory environment.

Oregon has supported alternative fuel vehicles since 1991, when the state established an alternative fuel vehicle tax credit program, the precursor to the contemporary strategy of

---

[137] Dennis Clements, personal correspondence, July 27, 2012.
[138] Alternative Fuels Data Center, "Oregon Deploys Plug-In Vehicles and Charging Infrastructure," U.S. Department of Energy, April 25, 2011, http://www.afdc.energy.gov/case/1000?print.
[139] See note 135.
[140] "New Building Codes Standards Support Electric Vehicle Growth," Oregon Department of Consumer and Business Services, October 14, 2008, http://www.cbs.state.or.us/bcd/notices/electric_vehicles_nr.pdf.
[141] Ibid.

focusing on GHG reduction.[142] The focus on the transportation sector seems to be a natural fit, given the relatively clean sources of electricity in the state (more than 50% of the state's electricity is generated by hydropower) and that statewide, about 38% of the GHG emissions come from transportation.[143] In September 2008, Oregon Governor Ted Kulongoski signed Executive Order 08-24, creating the Governor's Alternative Fuel Vehicle Infrastructure Working Group, which is charged with developing policies and infrastructure for Oregon to "attract car manufacturers seeking to bring the next generation of electric and alternative fuel vehicles to market in North America."[144]

Oregon: Goals and Strategies Supporting Code Changes

Goal	Strategy
Reduce Emissions	Reach GHG emissions targets of 10% below 1990 levels by 2020 and 75% below 1990 levels by 2050
Capture Energy Expenditures	Recapture a portion of the 90% of non-tax dollars spent on fuel by Oregon residents that leave the state. Oregon spends $8 billion annually on gasoline
Maximize Clean Energy	Oregon has relatively clean (low GHG) electricity sources, including hydropower
Develop Industry	Investment for Oregon's concentration of businesses in the EV sector

The working group seeks to marry emissions reductions goals with economic ones, encouraging EV adoption rates while fostering local and statewide job growth in the electrified transportation sector.[145]

In addition to the 2008 Executive Order, Oregon passed earlier enabling legislation that targeted emerging technologies and included provisions for swift regulatory action by BDC where such action is necessary to support emerging technology adoption. A follow-up executive order in 2010 established a panel to assist in creating an agenda for EV and infrastructure deployment and related services throughout the state.[146] This panel, called the Governor's Transportation Electrification Executive Council, is meant to address the "need to focus and coordinate public, private and civic leadership in ensuring that Oregon is well-positioned to capitalize on the economic benefits of transportation electrification," in addition to enhance strategic infrastructure deployment, identify opportunities and barriers to EV adoption and facilitating outreach, among other areas of related work.[147]

3.4.4. Local Plans in a Restrictive State Framework

According to the Oregon Department of Transportation (ODOT), Oregon residents in metropolitan areas travel an average of just 17.5 miles per capita per day—well within the range of any EV on the market today.[148] Portland, Oregon, has created complementary municipal policy. Although local jurisdictions are not able to create more rigorous building or electrical codes or

---

[142] See note 140.
[143] See note 135.
[144] See note 142.
[145] City of Portland and Multnomah County, "Climate Action Plan 2009 - Year Two Progress Report" (Portland, OR: Office of Sustainability, April 2011), http://www.portlandoregon.gov/bps/article/393345.
[146] Office of the Governor, "Executive Order 10-09" (Salem, OR: State of Oregon, September 22, 2010), http://cms.oregon.gov/Gov/pdf/eo_1009.pdf.
[147] Ibid.
[148] See note 135.

standards, they are able to pursue other strategies to increase their EV market share and capitalize on the environmental benefits of transportation electrification. To this end, Portland has established more vigorous, but harmonious GHG standards: the Portland City Council created policies that support the city's effort to meet the emission-reduction goals of its 2011 Climate Action Plan.[149] The plan estimates that in order to meet city goals, 13% of all non-commercial vehicle miles traveled on Portland roads in 2030 will need to be traveled by EVs.

Portland has pursued a strategy of showcasing technology in partnership with Portland State University and Portland General Electric, opening "Electric Avenue" in 2011. The City of Portland has 11 (Multnomah County has four) electric fleet vehicles.

3.4.5. Innovative Partnerships Programs Channel Funding

Oregon demonstrates policy and practice integration across state and local levels. ODOT and the state's Office of Innovative Partnerships and Alternative Funding have worked with industry and government partners on EV projects and pilots, including ECOtality's EV Project, facilitating the West Coast Green Highway and administering a Tiger II EV infrastructure grant.

In September 2010, ODOT received $700,000 in federal stimulus funding to install up to eight fast-charging stations in southern Oregon. In October of the same year, ODOT was awarded an additional $2 million from the TIGER II program in order to enable the state to build necessary infrastructure to support and expand the range of existing EVs.[150] The stations "will be placed no more than 50 miles apart on highways outside of metro areas to create a continuous network."[151]

Transportation Corridor Planning: The EV Corridor Connectivity Project

These partnership programs have focused to a great extent on expanding infrastructure along major transit corridors, building and extending what is known as the West Coast Electric Highway, a tri-state network of EV DC fast charging stations along Interstate 5, connecting Northern California to British Columbia. The goal of developing a regional transportation corridor framework creates the need to address the installation scenarios with a quick and easy process. This means that partnerships must extend to collaboration among state departments of transportation—this west coast corridor project should be taken as a model for connecting Northeast and Mid-Atlantic states, where smaller land areas will require cooperation among even more interstate agencies.

Utility Role

Consistent processes are also required in a state where, in contrast to British Columbia's sole power authority, retail electricity service is offered by numerous different utilities. These include three investor-owned public electric companies, 19 electric cooperatives, six peoples' utility districts and 13 municipal utility districts.[152] In this business environment, it may be desirable for the state to pursue minimum electrical requirements that must be enforced across these boundaries.

---

[149] Christina Williams, "Portland Passes Wide-Ranging Electric Vehicle Policy," Sustainable Business Oregon, July 20, 2010, http://www.sustainablebusinessoregon.com/articles/2010/07/portland_to_adopt_electric_vehicle_policy.html.

[150] Washington State was awarded a similar grant of more than $1.3 million. For more information, see: http://westcoastgreenhighway.com/projects.htm.

[151] "U.S. Transportation Secretary LaHood Announces Agreement for Electric Vehicle Charging Stations in Northwest Oregon," U.S. Department of Transportation, April 8, 2011, http://www.fhwa.dot.gov/pressroom/fhwa1114.htm.

[152] See note 135.

Future Actions

In 2010, the working group recommended that BCD revisit the appropriateness of building code amendments requiring a dedicated EV conduit in new construction. Similar to Vancouver's calculation of a 2% increase in construction costs, Oregon assumes a market trigger of about 5% new EV market sales to justify the additional expenses of a non-health or safety building code requirement.[153]

3.4.6. Key Takeaways

Summary

- Reduce real consumer costs of EV adoption by addressing the extreme variation in permitting fees and lowering fees for residential installations
- Consider the demographic and economic impacts for urban, suburban and rural communities when choosing state-level routes to EV readiness
- Incorporate EVSE into existing regulations where possible
- Codes are complemented by other types of EV-ready planning

Oregon amended the electrical code to reflect a need to address EV charging infrastructure in a market with many early adopters concentrated in specific geographic areas and corridors. Because the state's building codes set the minimum and maximum requirements enforceable by local jurisdictions, the geographic concentration of the population along the Pacific coast would make mandatory EV-ready building policies economically inefficient in much of the state. However, a clear need to reduce costs and ease the transition to increased EV use led state officials to recommend an expedited and inexpensive permitting process. Further, two municipal and corridor planning efforts—Portland's EV priorities in its Climate Action Plan and the West Coast Green Highway—illustrate the ability of local jurisdictions and state authorities to complement code-specific policies by setting environmental and transportation-oriented goals. In addition, the inclusion of EVSE in the state's minor label program reduces costs to the state and to the EV owner, making installation of at-home charging infrastructure that much more accessible—each permit for a basic installation costs $14.00.[154] The Oregon code amendment does not contradict the conclusion that the NEC provisions sufficiently cover existing technology needs; instead, it emphasizes the potential for states or local jurisdictions to amend the code to create a more pro-EVSE regulatory environment.

The **TCI region** can use the electrical code to focus on reducing costs of permitting and installing most EVSE, particularly in situations where the electrical work is routine. Stakeholders throughout the region, as well as those interviewed from other jurisdictions for this report, cited wide variation in and often high cost of permitting as a barrier for EV adoption. Establishing a flat and consistent fee for residential EVSE installation at the state level is a clear step toward regulatory consistency that has real results for individual EV owners.

The ability of the state of Oregon to establish in the state level building code the minimum and maximum requirements for construction across the state, state officials determined that route not to be the most cost effective, instead choosing to pursue electrical code changes to reduce costs. TCI region states should first assess the costs and benefits associated with pursuing a particular code policy change, considering the uniqueness of their state's regulations.

Furthermore, Oregon's regulation is exemplary in its simplicity. While the organization, goal setting, and other aspects of state-level planning discussed in this case study are important and

---

[153] Ibid.

[154] A minor label program designates certain simple electrical construction work as "minor work." Permits are still required, but costs and timelines are reduced. Oregon's program for EVSE is discussed further in section 3.4.

essential steps, the conclusion to include EVSE in an established state permitting program provided a reasonable solution easily adopted by local permitting authorities throughout the state.

Finally, Oregon's electrical code changes occurred within a larger framework of EV-ready planning that has ensured compatibility/co-development of plans for municipalities, such as Portland's use of EV planning in meeting emissions goals for the city, and for regional efforts, such as the West Coast Green Highway. TCI region states can look to examples like Oregon to see that EV-ready initiatives are not mutually exclusive, and that code changes can support one aspect of encouraging EV adoption, while partnerships, local plans and initiatives in other sectors can complement work done to amend codes by extending access and ownership throughout the state.

4. SUMMARY AND NEXT STEPS

4.1. Case Studies in Summary

The case studies included in this report highlight three approaches to metropolitan area and regional cooperation to address the regulatory framework that supports and monitors EV infrastructure deployment. Looking at advanced efforts at the state, metropolitan area and municipal levels in forward-thinking jurisdictions, several common factors emerge regarding the successful creation of policy and regulation supportive of EV infrastructure:

- Each jurisdiction took specific and multifaceted steps to encourage use of EVs.
- Each jurisdiction considered opportunities and challenges associated with regulation at multiple levels of government, or with multiple layers of agency, authority or private-sector participation, demonstrating the wide range of possibility in working with codes and other components of the regulatory environment.
- Actors in each jurisdiction identified and overcame potential regulatory barriers.

In **Vancouver**, a municipality created a collaborative working group to develop EV-readiness strategies with the intent of meeting long-range GHG reduction goals. Because of the ready availability of clean hydropower, the replacement of gas engine vehicles EVs was determined to have a disproportionately dramatic effect on GHG emissions, making the stimulation of the EV market a smart choice for the area. In meeting the anticipated needs of future EV owners, the Vancouver City Council took advantage of its unique ability among Canadian cities to modify its building codes in order to require a substantial percentage of parking stalls in new construction to be made EV-ready. At little added cost to developers, amending the scope of the local building code to include mandatory minimum requirements for the future electrical installation of charging stations illustrates a relatively simple, feasible solution to a complex problem.

In **Los Angeles**, the city, county and state have taken innovative approaches to greening buildings and the transportation sector. These efforts have been complemented by the proactive stance taken by the major utility companies that provide service to the Los Angeles region. CALGreen, as the nation's first mandatory green building code, sets a high bar. The code's overall goals deal directly with the state's mandate to reduce GHG emissions, and an EV-ready policy included in the code recognizes that regulation in one high-emissions area (buildings) can impact and incentivize greener consumer behavior in another (transportation). The state's approach to phasing in the code's mandatory provisions sheds light on the ways in which other jurisdictions might adopt similar code amendments, and the inclusion of "tiers" of compliance in the voluntary appendices makes it possible for the adopting jurisdiction to choose the level of deployment and enforcement most appropriate for the local market and community. Los Angeles is leading the shift to mandatory EVSE codes; both city and county have or will likely soon pass and upgrade the requirements for EV-ready construction. For a metropolitan area with an incredible number of local jurisdictions, a top-down but flexible approach such as CALGreen is a good solution. In addition, the utilities, such as SCE, are finding a niche role as a stakeholder and coordinator for EV-ready action that spans jurisdictions.

Oregon amended the electrical code to reflect a need to address EV charging infrastructure in a market with many early adopters concentrated in specific geographic areas and corridors. Because the state's building codes set the minimum and maximum requirements enforceable by local jurisdictions, the geographic concentration of the population along the Pacific coast would make mandatory EV-ready building policies economically inefficient in much of the state.

However, a clear need to reduce costs and ease the transition to increased EV use led state officials to recommend an expedited and inexpensive permitting process. Further, two municipal and corridor planning efforts—Portland's EV priorities in its Climate Action Plan and the Green/Electric Highway—illustrate the ability of local jurisdictions and state authorities to complement code-specific policies by setting environmental and transportation-oriented goals

The inclusion of EVSE in the state's minor label program reduces costs to the state and to the EV owner, making installation of at-home charging infrastructure that much more accessible—each permit for a basic installation costs $14. The Oregon code amendment does not contradict the conclusion that the NEC provisions sufficiently cover existing technology needs; instead, it emphasizes the potential for states or local jurisdictions to amend the code to create a more pro-EVSE regulatory environment.

4.2. Central Themes and Preliminary Recommendations

Considering complexities in the state and local decision-making process of evaluating EV-ready options, there are opportunities that can be created to encourage consistent EVSE deployment planning. Structural codes do not operate alone in the local regulatory environment; they are one tool available on the regulatory menu for jurisdictions seeking to govern infrastructure deployment. Despite the environmental benefits and growing EV market in many areas across the United States and throughout the region, each state and local jurisdiction will need to assess the costs and benefits associated with its own goals pursuant to energy efficiency, transportation electrification, green construction, air quality and economic development in order to effectively prioritize EV-readiness steps.

4.2.1. Existing Codes Present No Significant Barriers to EVSE Deployment

While there are no specific barriers to EVSE installation embedded in the existing national model building and electrical codes, there is room within the codes as adopted by the states to more clearly encourage EV readiness. Despite differences between jurisdictions, the codes themselves—model and adopted—cover existing safety concerns related to existing automotive and charging technology and permit or facilitate conditions under which EVSE can be installed.

Neither level 1 nor 2 EVSE requires significant electrical work so long as the existing circuitry supports the electrical load and connection. Each installation presents unique wiring and construction challenges that can increase costs, but they are typically accounted for by the existing structural codes and standards.

For existing technology, at present there are no specific structural codes issues cited by the stakeholders, code experts or model jurisdictions interviewed for this report that prevent or inhibit EVSE installation. However, challenges to consistency and safety may arise out of a lack of familiarity with EVSE equipment, complex commercial installations (such as with DC fast-charge installations, or where loads exceed circuit or service capacity) or the single-family residential code (the IRC), because not all jurisdictions require homeowners to hire a licensed electrician to perform electrical work.

Recommendations

- Consistent with their respective missions, code-setting bodies must continue to engage stakeholders in a participatory process geared toward bringing new technologies and implementation strategies to the fore as new industry standards. Organizations such as the ICC and NFPA, for example, should further engage in outreach, actively seeking best practices from local jurisdictions.

- States that do not have some form of mandatory inspection program for construction permitted under the IRC or similar local single-family construction code should institute a more comprehensive process.
- Education and training programs for inspectors and installers have become the norm as an early evaluative step in EV-readiness planning. States seeking to evaluate the need of codes and permitting processes should initiate EVSE training for professionals in related fields.[155]

4.2.2. Codes Can Help Achieve EV Readiness and Regional Cohesion

There are specific reasons to consider changing codes at the local, state and national levels. Because code amendments are one of several interrelated strategies to encourage EVSE deployment, in considering changes, it is important to consider what codes can accomplish:

- Codes can specify scoping requirements of numerical goals or limits for certain features in new construction (e.g., percentage of required parking to be built EVSE-ready).
- Codes can provide new permitting or inspection protocols and encourage the reduction of associated administrative costs.
- Codes are revised regularly and will be adapted at the national level to meet new structural or fire safety concerns, such as those related to new and emerging technologies.

The TCI region can achieve a level of cohesive EV readiness through the building and electrical codes if similar efforts are made across the region. Local conditions will factor heavily into the decision to regulate for EVSE based on codes. Variations across the TCI region will mean that states will make different choices. States such as New Jersey, for example, with a relatively evenly distributed, dense population and centrally located transportation corridors, may find scoping requirements in the building code to be a good solution. By contrast, Maine's lack of population density and residential concentration around key urban centers may suggest a different approach.

In addition to state and local governments, Clean Cities' Coalitions and other similar groups can play a central advocacy role in this assessment at the jurisdictional scale. In Vancouver, the EV Working Group became an important source of information sharing and program development. Within the TCI region, there are examples of several similar initiatives. Maryland has created by law the Maryland State Electric Vehicle Council, housed within the state's Department of Transportation.[156]

Incentivize EVSE Parking

A hypothetical proposal for a new optional appendix to the model building code could include in its scope provisions requiring 10% of parking spaces in new construction residential garages to be EVSE-ready, creating a uniform approach across jurisdictions that adopt that regulation.

---

[155] Stakeholders have indicated that while training is a clear component of ongoing successful EVSE installations, the training is more educational than technical; once an installing licensed electrician is aware of the EVSE device and components, it will be clear how to proceed with the installation. One exception is the level 3 or direct current (DC) fast-charging units, which are newer to the market and therefore have not yet been specifically addressed by these primary standards. However, even the new technology currently on the market is regulated for safety.
[156] The Maryland EV Council is discussed in detail in the companion to this report, the *EVSE Toolkit: Administrative and Planning Strategies for Local Jurisdictions*.

Over the long term, state code and local amendments and regulatory changes may influence the language of the model codes.[157] Regulation at the state level may provide the greatest consistency to metropolitan areas and corridors. The case of California illustrates the benefit of consistent, voluntary options.

Recommendations:

- Following the lead of states such as Oregon and New Jersey, each of the TCI states should conduct a review of its codes and policies to determine if residential EVSE installation can be classified as "minor label" or "minor work."
- Incentivize and encourage incorporation of EVSE by modifying building codes when appropriate to require that a percentage of accessory parking associated with new development to be pre-wired for EVSE (for example, 20%), providing flexibility for future capacity.
- Enable state and local participation in a forum for interstate cooperation.

4.2.3. EVSE Deployment as Economic Development

Codes, and the requirements that they set out, factor into economic development planning. EVs and EVSE deployment influences such disparate areas as maintaining housing affordability, providing equitable access to transportation infrastructure, creating green jobs and marketing metropolitan areas to attract new businesses, residents and institutions.

Cost Reductions

For the development and construction community, there is a need to keep costs of EVSE installation low enough to be easily absorbed into overall project costs.

Another aspect of economic development for EVSE is that jurisdictions encouraging EV readiness will likely gain growth in industry associated with EVs and charging infrastructure. The presence or stimulation of markets for EV and EV charging has primed the pump in early adopting jurisdictions. For example, Vancouver's signing of MOUs with auto manufacturers highlights an approach to capture a portion of the EV market. In most localities, however, EV readiness will bring additional electrical and green energy jobs and other economic opportunities.

Decisions to pursue an EV-focused GHG emissions reduction strategy partly through code amendments may, as it did in Los Angeles, result in additional economic benefits. With a municipally owned utility in the mix (Los Angeles Department of Water and Power), Los Angeles' support of EVs not only reduces the 43% of GHG emissions associated with on-road vehicle travel, but money previously spent on imported fuel and energy sources can stay in the city and region.[158] In this instance, local administrative action has the benefit of reducing consumer costs,

Incorporate EVSE Infrastructure Planning into Urban Development Strategies

For a downtown revitalization plan, the incorporation of EV charging stations can aid marketing strategies. Portland's Electric Avenue highlights the potential of bringing a unique amenity to Main Street.

[157] See note 62. State and model code revisions may take up to 12 years, depending on the jurisdiction's code cycle and date of proposed change.
[158] See note 16.
[3] "Renewable Energy Financing District/Solar Energy Improvement Special Assessments," Energy.gov, July 1, 2009, http://energy.gov/savings/local-option-renewable-energy-financing-districtsolar-energy-improvement-special-assessments.
[4] "Special Purpose Districts in Washington," Municipal Research and Services Center of Washington, accessed October 24, 2012, http://www.mrsc.org/subjects/governance/spd/spdmain.aspx.

capturing dollars through locally based services and improving air quality.

Raising Awareness and Profiles

Local jurisdictions also have the opportunity to create or alter perceptions of the EV market. The importance of securing vehicles has been illustrated anecdotally throughout this research process. A stakeholder described an attempt to add EVSE provisions into the parking calculations for zoning requirements in Dover, New Hampshire, that involved a similar approach to mandating parking through the building code.[159] The stakeholder's proposal suggested that developers make 2% of all parking spaces EVSE-ready for all developments exceeding 50 spaces; when the local planning board voted on the provision, the reason cited for not establishing a mandatory requirement was that there were no EVs registered in the area yet.[160] From this example, an awareness of use creates trust that administrative efforts will be worthwhile.

Portland, Oregon, has created a prominent strip of EV parking in a busy downtown area, giving prominence to EVs and creating a unique addition to the urban environment at the same time. Such profile-raising strategies show that in many places across the country local governments consider EVs a valuable commodity. Provisions for EVSE deployment can be seen as an amenity that allies the locality with green branding that can aid in attracting businesses and residents, while setting legitimate goals for sustainable energy, buildings and job growth. The question remains for new EV markets as to how the West Coast states' and provinces' approaches can be translated to the East Coast.

Finally, while codes can influence markets to some extent, codes should not be used to predict the future of EVSE infrastructure. Instead, they should be written so as to freely adapt to any installation or new technology scenario. The fact that DC fast charging and wireless charging are not yet fully accounted for in the national codes is not alarming; rather, it indicates a lack of prescriptive regulations that can negatively impact innovation and growth in the sector.

Recommendations:

- Incorporate or acknowledge EVSE deployment through TCI-region state-level economic development strategy.
- Fund further research and program assessment specific to the TCI region to enable local jurisdictions to make informed decisions about costs and benefits associated with public expenditures for EVSE, and to guide development of public-private partnerships.
- Fund ongoing demonstration programs, particularly those that focus on innovation and new technology.

4.2.4. High-Level Flexibility Creates Meaningful Local Options

EVSE policy and planning should not tie hands at the local level. California's CALGreen is an excellent example of the ability of codes to create a high-level planning framework while retaining flexibility at the local level. Codes ideally provide consistent regulation by making changes at the highest level of government reasonable.

Compliance is a Local Issue

Significantly, a local jurisdiction's codes must comply with state-level legislation, meaning state laws play a central role in establishing the range and impact of local regulatory requirements. Challenges in this arena include the creation of seamless and simple regulations using consistent language in state and local laws that limit code revision necessary to comply.

---

[159] James Poisson (Master Electrician, New Hampshire Department of Environmental Services. TCI Regional Stakeholder), phone call, June 29, 2012.
[160] Ibid.

Codes can offer an a la carte menu of options, standardized at the state level but adopted through tiered systems and/or on a voluntary basis by the local jurisdiction. CALGreen, for example, lets jurisdictions prioritize code changes by providing a clear menu of options. Well-written codes may also offer phased provisions or optional parameters, maximizing adoptability and efficacy of local regulations. A pilot phase may precede mandatory enforcement of new code provisions, allowing local governments and other stakeholders to adjust to new requirements.

Outreach is a Local Obligation

In addition, jurisdictions motivated to adopt EVSE-specific codes can take on an advocacy role through local awareness building and outreach about EV benefits. The process of revising model codes at the national and international levels is open to public proposals, and local jurisdictions that have adopted EVSE code modifications have the opportunity to directly influence national EVSE policy through the proposal of changes to national model codes.

Improving upon the existing EV and EVSE knowledge base in many jurisdictions represents an important step for government officials, industry and utility stakeholders and the public. Development of an understanding of how structural codes, permitting processes and zoning ordinances relate both separately and together to EV-ready planning will require awareness building and updated training for installers, inspectors and state and municipal officials. Stakeholders, including interested members of the public, should have equal access to important EV and EVSE information and be permitted to participate in or otherwise approve of local and state-level changes.

Recommendations:

- Adopt code appendices containing voluntary scoping and implementation options, further including code phasing and tiers.
- Make consistent information and technical support available to officials across state and local agencies through the Clean Cities' Coalitions.
- State agencies having jurisdiction should introduce locally vetted modifications to the discussion of national model codes in the next possible code cycle (2015).

EV Readiness: Phasing and Tiers

Voluntary/Mandatory: Requirements included as an optional appendix; voluntary requirements create consistency among jurisdictions that choose to adopt.

Local and Developer Burdens: Code language should be enforceable in the local jurisdiction and not cause undue local burdens.

Tiered Codes: Optional appendices to the building code should be structured with additional options, or tiers, that set standards for increasing levels of participation and enforcement.

Pilot Phases: Test new codes and allow contractors, inspectors and other local stakeholders to develop a knowledge base prior to full enforcement of any new code.

4.2.5. Partnerships Guide Infrastructure Deployment across Boundaries

Successful local plans for EVSE rollout have been comprehensive in scope; because codes are one part of the local regulatory environment, they must work in concert with other legislative rules, economic policies, local planning and regulatory processes. Key factors must be in place to successfully advance policy, legislation and ordinances pertaining to EV infrastructure, and several central themes rise to the top.

Highly significant among these themes is a forum for cooperation. The reduction of barriers to EVSE deployment will not come from code amendments, but rather from the collaborative efforts that can produce such amendments as part of a comprehensive deployment strategy.

Large-scale and multi-agency coalitions and working groups, public-private partnerships and work with academic and research institutions have contributed to a broad-based understanding of intersections among local and regional goals in model jurisdictions. Partnerships are central to comprehensive planning efforts, and academia, utilities, power authorities and a range of government agencies and nonprofit groups should be involved in the planning process regardless of scale.

A key enabler for EV infrastructure deployment and installation is the local electric utility. Utilities are possibly the single most important stakeholder in the EVSE conversation and should be involved extensively. Utility companies can be privately held or public authorities.

The role of the private sector can be just as important as that of the public sector in preparing the region for more comprehensive EVSE deployment. Federal and state funding has been channeled to private infrastructure developers (ECOtality's EV Project, for example) to gather data, test business models and pilot high-visibility EV charging. Private-sector outcomes and developing business models will determine many aspects of EVSE and EV adoption.

Recommendations:

- Enable the creation of special purpose clean energy districts to connect interests and regulatory processes in the TCI region.
- Enable data exchange and access to EV ownership and EVSE installation to improve utility performance and enhance utility involvement in local and regional planning.
- Create and/or engage EVSE working groups housed within the appropriate agency in each state to leverage TCI regional stakeholder information and influence and to promote high-level cooperation.

Special-Purpose Clean Energy Districts

Special-purpose districts are independent governmental units that exist separately from general purpose government districts—states, counties, and municipalities—and deliver public services within that area. Special-purpose districts can cross jurisdictional boundaries, including states if established by interstate compact. They require state enabling legislation. Power, sewer or water authorities are examples of existing special-purpose districts. Incorporation as a special-purpose district provides benefits associated with policy, governance and the ability to tax, in some cases. Special-purpose districts often do not include cities within their bounds, but they can.

Special-purpose districts that work in concert with the electric utilities serving the jurisdictions included within its boundaries could present an opportunity for local areas with little ability to enforce green construction or other voluntary EVSE-specific provisions to enact sustainability measures at a collective scale.

EVSE-focused Clean Energy Districts would accomplish the following:

- Act as independent government units to connect energy goals across the region.
- Provide jurisdictional authority to include/permit/enforce EVSE-related standards across existing lines.
- Bring energy-related infrastructure regulations to areas outside major metros while uniting the work, goals and resources of multiple jurisdictions across boundaries.
- Access shared or collective resources.

New Mexico has created renewable energy financing districts with the purpose of enabling participating property owners to access financing for the installation of renewable energy technology. [3] Washington State allows air pollution control authorities.[4]

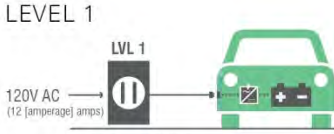
The proper level of focus of the special-purpose district would need further exploration. An EVSE-specific special-purpose district could address regional transportation electrification. Or, a clean energy district could provide a wider range of services and planning on behalf of the underlying zones.

This page intentionally left blank.

APPENDIX A: CHARGING LEVELS

LEVELS OF CHARGE: DIAGRAMS AND ATTRIBUTES

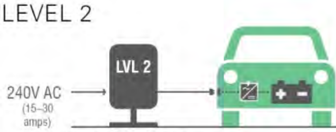
LEVEL 1



ATTRIBUTES:

- A standard outlet can potentially fully recharge an EV battery in 8–12 hours, though larger batteries, such as on the Tesla Model S, would require between 1 and 2 days
- This level is often sufficient for overnight, home charging
- Standard outlets can also provide an option for "peace of mind" charging using onboard equipment on the go
- Uses standard J1772 coupler
- In-vehicle power conversion

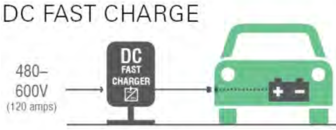
LEVEL 2



ATTRIBUTES:

- Free-standing or hanging charging station units mediate the connection between power outlets and vehicles
- Requires installation of charging equipment and often a dedicated 20–80 amp circuit, and may require utility upgrades
- Well-suited for inside and outside locations, where cars park for only several hours at a time, or when homeowners seek added flexibility of use and a faster recharge
- The public charging network will comprise primarily level 2 charging stations
- Public context requires additional design features, such as payment and provider network interfaces or reservation systems
- Uses standard J1772 coupler
- In-vehicle power conversion, charging speed limited by the onboard charger

DC FAST CHARGE



ATTRIBUTES

- Free-standing units, often higher profile
- Enable rapid charging of EV battery to 80% capacity in as little as 30 minutes
- Electrical conversion occurs in EVSE unit itself
- Relatively high cost compared to level 2 chargers, but new units on the market are more competitively priced
- Draws large amounts of electrical current, requires utility upgrades and dedicated circuits
- Beneficial in heavy-use transit corridors or public fueling stations
- Standard J1772 coupler approved in October 2012

APPENDIX B: SUMMARY OF EVSE STANDARDS

Organization/Code Text	Standard	Description
Society of Automotive Engineers (SAE)	J1772	Electrical and mechanical aspects of the cord set, references Underwriters Laboratory for safety and shock protection and the National Electrical Code for cord and coupler
	J2293	Electric vehicle (EV) energy transfer system
	J2293-1	Functionality requirements, system architecture
	J2293-2	Communication requirements, system architecture
National Fire Protection Association (NFPA)/National Electrical Code (NEC)	NEC 110.11	Deteriorating agents
	NEC 110.28	Enclosure types
	NEC 110.26	Electrical equipment spacing
	NEC 110.26 (A)(2)	Width of working space
	NEC 110.27 (B)	Guarding of live parts to prevent physical damage
	NEC 210.70 (A) (2)	Lighting outlets required, dwelling units
	NEC 300.4	Protection of conductors against physical damage
	NEC 334.15	Exposed work safety requirements
	NEC 334.30	Securing and supporting nonmetallic sheathed cable
	NEC 625.1-625.5	General instructions for electric vehicle supply equipment (EVSE): scope, definitions, other articles, voltage, listed/labeled
	NEC 625.9 (A-F)	Wiring methods for EV coupler
	NEC 625.13-625.19	EVSE equipment construction
	NEC 625.21-625.26	EVSE control and protection
	NEC 625.28-625.30	EVSE supply equipment locations
	NEC 626	Electrified truck parking spaces
Underwriters Laboratory (UL)	UL 62	Flexible cords and cables: required by NEC 625
	UL 2202	EVSE charging station design and construction
	UL 2231	Charging station shock prevention: grounding and ground fault interruption
	UL 2251	Cord design and safety of plug, cord, receptacle, connectors, load rating
	UL 2594	Charging station safety: off-board equipment supplying power to vehicle

APPENDIX C: OTHER LOCAL PLANNING TOOLS

Local governments have five important tools at their disposal that can be used to more successfully and seamlessly integrate electric vehicle supply equipment (EVSE) into the planning and administration of states, cities and towns. Simply put, these tools will ideally achieve the following through electric vehicle (EV)-focused policies:

- Zoning will require EVSE parking in the private realm.
- Parking will enable EVSE in the public realm.
- Codes will require wiring in parking structures and set standards for safety, operation and administrative processes.
- Permitting changes will streamline the administrative process for private installers of EVSE.
- Procurement and partnerships will build consensus and increase awareness for EVSE deployment.

The tools are summarized below and on the following page.

Zoning

Determines where and in what fashion EVSE is allowed, incentivized or required

- Establishes allowable uses based on the municipal zoning code
- Considers deployment of EVSE within the larger context of planning and land use
- Incentive zoning, such as the exchange of development bonuses for the inclusion of EVSE pre-wiring or infrastructure in new development, is a potential area for EVSE deployment, but it remains largely untested
- By setting development standards through zoning ordinances, municipalities can use this tool to shape the scope (how many and where) of EVSE deployment

Parking

Sets the scope and enforcement requirements for parking with state or local laws

- Applies to publicly accessible EVSE, including on-street chargers and units in municipal lots and garages, and is therefore an important part of infrastructure development
- Similar to zoning, parking ordinances provide a way to require a certain number or percentage of spaces and to restrict the use of charging stalls to EVs
- Unlike zoning, parking ordinances are not tied to new development
- Opportunities exist for private parking management

Codes	**Ensure that EVSE installations are safe, and specify the scope of EVSE-ready construction** • Changes to the building and electrical codes are not necessary from a safety standpoint, but they can help make places EV-ready • State and local codes may need to change to meet certain requirements, such as emissions reduction goals. This is an ideal opportunity to incorporate EVSE • Municipalities that are able to adopt their own codes benefit from a highly flexible state code—one that provides different standards for different situations • Building and electrical codes present different EV-ready opportunities
Permitting	**Streamlines the administrative process so that it is uncomplicated, fast and affordable** • Updating and streamlining permitting eases implementation of EVSE and reduces fees to the consumer • Permitting is a local administrative process and, as a result, may be a source of fragmentation across the region, evidenced by wide variations in permit fees • Third-party inspection firms offer opportunities for partnership and inspector training throughout the region
Procurement &	**Work closely with private or quasi-public partners to implement infrastructure in the public realm** • Partnerships include working groups, which can unite government agencies with private industry and experts • Regional planning organizations such as metropolitan planning organizations and councils of government are important for building consensus and getting the word out • Governments can procure EVs for municipal and state fleets to increase awareness and meet sustainability goals • The role of the private sector can be just as, if not more, important in preparing the region for more comprehensive EVSE deployment

APPENDIX D: CODE LANGUAGE DOCUMENTATION

This section includes examples of building and electrical code amendments relevant to electric vehicle supply equipment (EVSE) installation. Amendments relevant to the case studies are included, along with other representative sample codes from jurisdictions in the United States and Canada.

Sample Building Code Amendments for EVSE

Require sufficient area for electrical infrastructure

Meet Future Increased Capacity Needs: Vancouver Building By-law No. 9936 (2009)

Adopted Code Language:

13.2.1.2 Electrical Room

(1) The electrical room in a multi-family building, or in the multi-family component of a mixed use building, that in either case includes three or more dwelling units, must include sufficient space for the future installation of electrical equipment necessary to provide a receptacle to accommodate use by electric charging equipment for 100% of the parking stalls that are for use by owners or occupiers of the building or of the residential component of the building.

Require a percentage of parking stalls to be pre-wired for EVSE

A strategy to encourage electric vehicle (EV) readiness through the pre-wiring of garages and parking stalls at time of construction for current or future installation of charging stations. The goal is to provide future capability for dedicated EVSE in single- and multifamily homes, as well as commercial locations.

Single-Family Dwellings: Vancouver Building By-law No. 9691 (2008)

Adopted Code Language:

12.2.2.10. Cable Raceway

(1) Each dwelling unit shall have a cable raceway leading from the electricity circuit panel to an enclosed outlet box in the garage or carport.

(2) A raceway not smaller than size 21 shall be provided to accommodate future conductors of a separate branch circuit intended to supply a future receptacle for use with the electric vehicle charging system.

(3) An outlet box for the receptacle referred to in Sentence (2) and approved for the purpose shall be provided in a parking space or parking stall of a storage garage or carport intended for use with the electric vehicle charging system.

(4) The raceway described in Sentence (2) shall be installed between the dwelling unit panel board and the outlet box referred to in Sentence (3).

Multifamily Dwellings: Vancouver Building By-law No. 9936 (2009)

In 2008, the Vancouver City Council enacted new regulations in the city's building code that require a portion of the parking stalls in all new multifamily (three or more units) residential construction to accommodate EV charging. The provisions went into effect in April 2011.

Adopted Code Language:

13.2.1.1. Parking Stalls

(1) Each one of 20% of the parking stalls that are for use by owners or occupiers of dwelling units in a multi-family building that includes three or more dwelling units, or in the multi-family component of a mixed use building that includes three or more dwelling units, must include a receptacle to accommodate use by electric vehicle charging equipment.

Single-Family and Multifamily Dwellings: CALGreen, Green Construction Code (Voluntary)[161]

Adopted Code Language:

A5.106.5.3 Electric vehicle charging. Provide facilities meeting Section 406.7 (Electric Vehicle) of the California Building Code as follows:[162]

A5.106.5.3.1 Electric vehicle supply wiring. For each space required in Table A5.106.5.3.1, provide one 12- VAC 20 amp and one 208/240 V 40 amp, grounded AC outlets or panel capacity and conduit installed for future outlets.

Table A5.106.5.3.1

Total Number of Parking Spaces	Number of Required Spaces
0–50	1
51–200	2
201 and over	4

A4.106.5.4 Electric vehicle (EV) charging. Dwellings shall comply with the following requirements for the future installation of electric vehicle supply equipment (EVSE).

A4.106.6.1 One- and two-family dwellings. Install a listed raceway to accommodate a dedicated branch circuit. The raceway shall not be less than trade size 1. The raceway shall be securely fastened at the main service or subpanel and shall terminate in close proximity to the proposed location of the charging system into a listed cabinet, box or enclosure…

---

[161] "Revision Record for the State of California – Supplement" in *2010 California Green Building Standards Code*, Title 24, Part 11 (July 1, 2012), www.iccsafe.org/cs/codes/Errata/State/CA/5570S1002.pdf.

[162] The California Building Code sets out definitions of EVs and installation requirements for ventilation and electrical systems. The code can be found here: https://law.resource.org/pub/us/code/bsc.ca.gov/gov.ca.bsc.2012.02.1.html.

Exception: Other pre-installation methods approved by the local enforcing agency that provide sufficient conductor sizing and service capacity to install Level 1 EVSE.

Note: Utilities and local enforcing agencies may have additional requirements for metering and EVSE installation, and should be consulted during the project design and installation.

A4.106.6.1.1 Labeling requirement. A label stating "EV CAPABLE" shall be posted in a conspicuous place at the service panel or subpanel and next to the raceway termination point.

A4.106.6.2 Multifamily dwellings. At least 3 percent of the total parking spaces, but not less than one, shall be capable of supporting future electric vehicle supply equipment (EVSE)

A4.106.6.2.2 Multiple charging spaces required. When multiple charging spaces are required, plans shall include the location(s) and type of the EVSE, raceway method(s), wiring schematics and electrical calculations to verify that the electrical system has sufficient capacity to simultaneously charge all the electrical vehicles at all designated EV charging spaces at their full rated amperage. Plan design shall be based upon Level 2 EVSE at its maximum operating ampacity. Only underground and related underground equipment are required to be installed at the time of construction.

Required Parking Stalls: Hawaii Senate Bill No. 2747 Relating to Electric Vehicle Parking (2012)[163]

<u>Language of the Adopted Act:</u>

Section 2. Section 291-71, Hawaii Revised Statues, is amended to read as follows:

"291-71 Designation of parking spaces for electric vehicles; charging system.

a) Places of public accommodation with at least one hundred parking spaces available for use by the general public shall have at least one parking space near the building entrance designated exclusively for electric vehicles and equipped with an electric vehicle charging system by July 1, 2012. Spaces shall be designated, clearly marked, and the exclusive designation enforced. Owners of multiple parking facilities within the State may designate and electrify fewer parking spaces than required in one or more of their owned properties; provided that the scheduled requirement is met for the total number of aggregate spaces on all of their owned properties."

Provide flexible, tiered voluntary appendices in the state building code

The California Green Construction Code (2010 edition) includes the following sections, providing for a tiered system of options for local jurisdictions that choose to adopt and enforce codes specific to low-emission vehicles and for EVSE.

---

[163] "SB2747 SD1 HD2," Hawaii State Legislature, accessed October 24, 2012, http://www.capitol.hawaii.gov/measure_indiv.aspx?billtype=sb&billnumber=2747.

Adopted Code Language: CALGreen Green Construction Code[164]

A5.106.5.1 Designated parking for fuel-efficient vehicles. Provide designated parking for any combination of low-emitting, fuel-efficient and carpool/van pool vehicles as shown in Table A5.106.5.1.1 or A5.106.5.1.2.

Provide 10 percent of total designated parking spaces for any combination of low-emitting, fuel-efficient and carpool/van pool vehicles as follows:

Table A5.106.5.1.1 Tier 1 10% of Total Spaces	
Total Number of Parking Spaces	**Number of Required Spaces**
0–9	0
10–25	2
26–50	4
51–75	6
76–100	9
101–150	11
151–200	18
201 and over	At least 10% of total

Table A5.106.5.1.2 Tier 2 10% of Total Spaces	
Total Number of Parking Spaces	**Number of Required Spaces**
0–9	1
10–25	2
26–50	5
51–75	7
76–100	9
101–150	13
151–200	19
201 and over	At least 12% of total

[164] California Building Standards Commission, *2010 California Green Building Standards Code* (Sacramento, CA: California Building Standards Commission, January 1, 2011), www.documents.dgs.ca.gov/bsc/CALGreen/2010_CA_Green_Bldg.pdf.

Write local codes to include multifamily and commercial installation scenarios in addition to single-family scenarios.

Sunnyvale, California[165]

Adopted Code Language:

Building Division Requirements

An electrical permit is required for installation of electric vehicle chargers…

New Residential Construction

- Garages/carports attached to individual dwelling units (typically single-family detached and townhouses) shall be pre-wired for a Level 2 electric vehicle charger.
- Shared parking facilities (typically condominiums and apartments) shall have 12.5% of the required spaces pre-wired for Level 2 electric vehicle chargers.

Non-Residential and Multi-Family Requirements

- The electric vehicle charging spaces may be counted towards the number of required low-emitting/fuel efficient parking in the CALGreen or LEED, as applicable.
- A sign shall be posted at the electric vehicle charging spaces stating "Electric Vehicle Charging Only."

Accessibility Requirements (CBC Chapter 11B)

- In each group of charging stations, one space shall be provided with an accessible loading area (a minimum of 5' wide and 18' in length and striped). These spaces do not need to include signage dedicating them for disabled access use. These spaces shall not be counted as accessible parking spaces, as required by California Building Code.
- Operational controls and receptacles for the charging station controls (i.e. on/off buttons, payment readers, etc.) shall be located between 15" and 48" from finished floor/grade.

Create a more stringent municipal code

For municipalities having jurisdiction, the ability to develop their own or choose voluntary measures provided by the state to create more stringent standards for EVSE may be a good opportunity. In 2011, Los Angeles adopted provisions of the Green Building Code into its municipal code. The city adopted as mandatory provisions of CALGreen, adapting the provisions to require a slightly-higher-than-Tier-1 level of compliance.

Los Angeles Municipal Code (2010)[166]

Adopted Code Language:

99.04.106.6. Electric Vehicle Supply Wiring

---

[165] http://sunnyvale.ca.gov/Portals/0/Sunnyvale/CDD/Residential/Electrical%20Car%20Chargers.pdf.
[166] City of Los Angeles Ordinance No. 181480 (December 15, 2010), http://ladbs.org/LADBSWeb/LADBS_Forms/PlanCheck/2011LAAmendmentforGreenBuildingCode.pdf.

1. For one- or two-family dwellings and townhouses, provide a minimum of:
a. One 208/240 V 40 amp, grounded AC outlet, for each dwelling unit; or
b. Panel capacity and conduit for the future installation of a 208/240 V 40 amp, grounded AC outlet, for each dwelling unit.

The electrical outlet or conduit termination shall be located adjacent to the parking area.

2. For other residential occupancies where there is a common parking area, provide one of the following:
a. A minimum number of 208/240 V 40 amp, grounded AC outlets equal to 5 percent of the total number of parking spaces. The outlets shall be located within the parking area; or
b. Panel capacity and conduit for future installation of electrical outlets. The panel capacity and conduit size shall be designed to accommodate the future installation, and allow the simultaneous charging, of a minimum number of 208/240 V 40 amp, grounded AC outlets, that is equal to 5 percent of the total number of parking spaces. The conduit shall terminate within the parking area; or
c. Additional service capacity, space for future meters, and conduit for future installation of electrical outlets. The service capacity and conduit size shall be designated to accommodate the future installation, and allow simultaneous charging, of a minimum number of 208/240 V 40 amp, grounded AC outlets, that is equal to 5 percent of the total number of parking spaces. The conduit shall terminate within the parking area.

When the application of the 5 percent results in a fractional space, round up to the next whole number.

Article 9, Division 5: For Newly Constructed Nonresidential and High-Rise Residential Buildings

99.05.106.5.2 Designated Parking. Provide designated parking, by means of permanent marking or a sign, for any combination of low-emitting, fuel-efficient, and carpool/van pool vehicles as follows:

Table 5.106.5.2
Tier 2
10% of Total Spaces

Total Number Of Parking Spaces	Number Of Required Spaces
0–9	0
10–25	1
26–50	3
51–75	6
76–100	8
101–150	11
151–200	16
201 and over	At least 12% of total

99.05.106.5.3.1. Electric Vehicle Supply Wiring. Provide a minimum number of 208/240 V 40 amp, grounded AC outlet(s), that is equal to 5 percent of the total number of parking spaces, rounded up to the next whole number. The outlet(s) shall be located in the parking area.

Article 9 Division 12: Voluntary Measures for Newly Constructed Nonresidential and High-Rise Residential Buildings

A5.106.5.3.2. Additional Electric Vehicle Supply Wiring. Provide a minimum number of 208/240 V 40 amp, grounded AC outlet(s), that is equal to ten percent, rounded up to the next whole number, of the total number of parking spaces.

Sample Electrical Code Amendments for EVSE

Amend the state electrical code to streamline the permitting process

The Oregon Building Codes Division started developing administrative rules to streamline permit and inspection protocol for the installation of EVSE within the state. The language of the rule below applies to levels 1 and 2 charging.

Oregon Electric Vehicle Charging Station Statewide Permit and Inspection Protocol, 918-311-0065[167]

To ensure a path for the emerging technology and enable the installation of charging stations for electric vehicles, the following permit and inspection protocols will apply throughout the state, notwithstanding contrary provisions contained in the Oregon Electrical Specialty Code.

(1) Building officials and inspectors shall permit and allow installation of an electric vehicle charging station that has a Building Codes Division's special deputy certification label without further testing or certification.

(2) Persons installing an electric vehicle charging station must obtain a permit for a feeder or branch circuit from the inspecting jurisdiction. No other state building code permit is required.

(3) The jurisdiction may perform up to two inspections under the permit issued in subsection (2) above.

(4) Inspection of the installation is limited to examining the feeder or branch circuit for compliance with the following Oregon Electrical Specialty Code provisions:

(a) Overcurrent protection, per articles 225 and 240;

(b) Physical protection of conductors, per article 300;

(c) Separation and sizing of the grounding and neutral conductors, per article 250.20;

(d) Provisions for locking out the breaker for maintenance, per chapter 4.

(5) For the purpose of this rule, the service, feeder or branch circuit, and charging station pedestal will be considered a single structure as defined by the Oregon Electrical Specialty Code. The structure's owner may opt to install a grounding

[167] Electric vehicle charging station installation amendment Stat. Auth: ORS 455.065.

electrode system to supplement lightning protection, but cannot be required to do so.

(6) An electrical contractor employing a general supervising electrician in accordance with OAR 918-282-0010 is authorized to use a minor installation label to install a new branch circuit limited to 40 amps 240 volts for the purpose of installing a wall mounted Electric Vehicle Supply Equipment (EVSE) unit in the garage of one and two family dwellings, and connect a listed wall mounted EVSE unit to that branch circuit. The electrical panel where the circuit originates must be in the garage within sight from the EVSE unit. This provision does not apply to installations in wet or damp locations.

Amend the municipal electrical code

Seattle, Washington

In Seattle, Washington, the 2008 edition of the city's adopted version of the electrical code identified and added some notable changes specific to EVs, with the purpose of making it easier to install home and commercial EVSE. The Seattle Electrical Code (SEC) adds article 625.27 to address required space for physical equipment and space planning in order to install future conduit, panel and disconnect for EVSE. In addition, provisions in the SEC address outlet load calculations for residential EVSE, as well as feeder and conduit specifications for multifamily residential occupancies. Seattle's electrical code modifications speak to the potential to utilize a jurisdiction's electrical codes to meet localized market demands and projections; the city was planning ahead in the 2008 code edition to account for EVSE installation once the first Nissan LEAF vehicles hit the Seattle market in 2010.[168] Article 625.27 of the SEC may offer best practice guidance to local jurisdictions seeking to plan in advance for EVs, and may also inform the National Fire Protection Association's next revision of the national model electrical code. The full SEC is available online.[169]

<u>Adopted Code Language</u>

ARTICLE 625, Electric Vehicle Charging System

625.27 Requirements for Future Installation of Outlets.

To facilitate future installation of electric vehicle outlets in residential occupancies, the following shall be provided:
(1) Space shall be reserved in the electrical service equipment for installation of an overcurrent protective device to serve electric vehicle charging system branch circuits.
(2) A location shall be designated, together with the required working clearances, for the electric vehicle charging system panelboard.
FPN No. 1: See also 220.57, Electrical Vehicle Outlets, for calculating demand loads.
FPN No. 2: Consideration of the location of the future electric vehicle outlets is recommended when designating a location for the electric vehicle outlet panelboard.
FPN No 3: Residential occupancies are defined in Chapter 3 of the Seattle Building Code.

---

[168] "Plug-In Electric Vehicles" (Seattle, WA: City of Seattle, n.d.), https://www.seattle.gov/environment/documents/Electric%20Vehicles%20FAQ_Update_070511.pdf.
[169] Department of Planning and Development, *2008 Seattle Electrical Code Quick Reference*, Ordinance 122970 (Seattle, WA: City of Seattle, June 5, 2009), http://www.seattle.gov/dpd/static/2008%20qr%20complete_latestreleased_dpdp016577.pdf.

U.S. PEV Sales Update

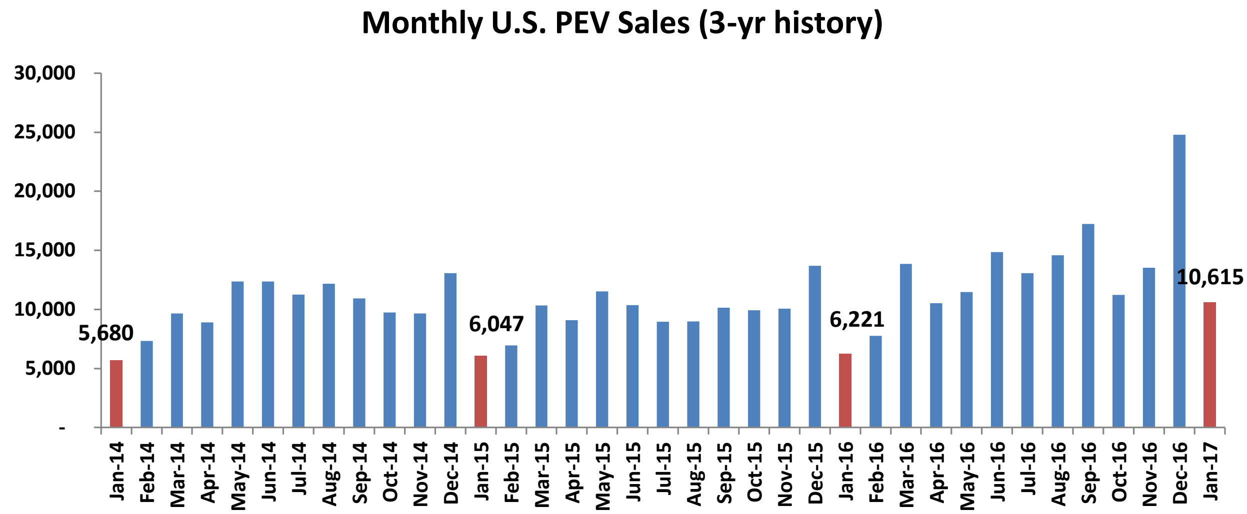
January 2017

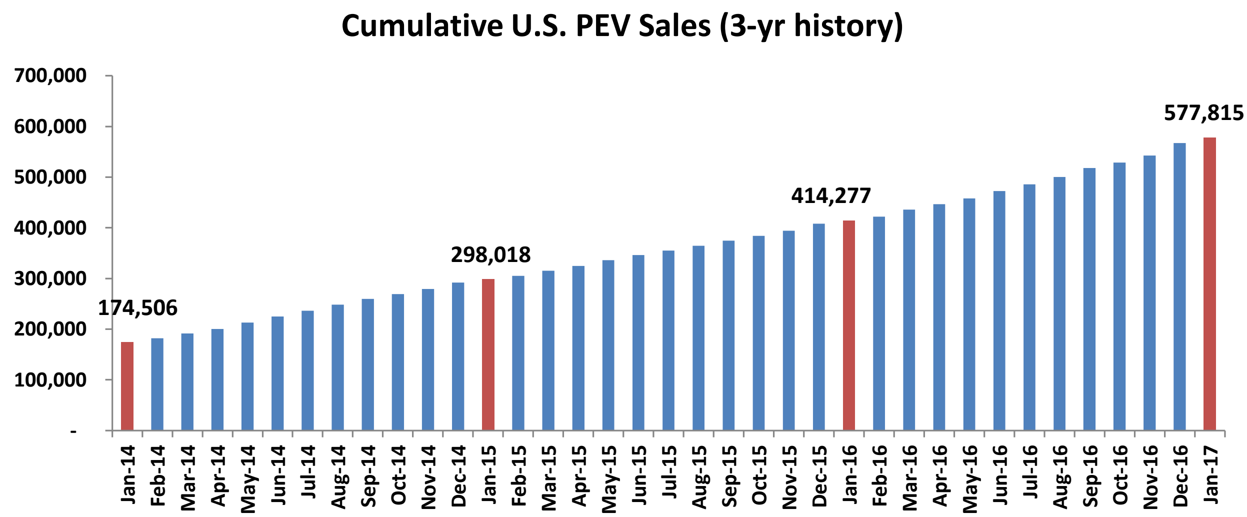
Plug-In Electric Vehicles (PEVs)		Sales Jan-17	Change vs. last month	Change vs. last year	Sales YTD	Change vs. prior YTD
Chevrolet	Volt	1,611	-56%	62%	1,611	62%
Toyota	Prius Prime	1,366	-17%	13560%	1,366	13560%
Chevrolet	Bolt	1,162	101%	n/a	1,162	n/a
Tesla	Model S	900	-85%	6%	900	6%
Nissan	LEAF	772	-59%	2%	772	2%
Tesla	Model X	750	-81%	178%	750	178%
Ford	Fusion Energi	606	-45%	4%	606	4%
Ford	C-MAX Energi	473	-63%	35%	473	35%
Audi	A3 Sportback e-tron	387	-34%	18%	387	18%
BMW	i3	382	-52%	110%	382	110%
Fiat	500e	345	-47%	13%	345	13%
VW	e-Golf	332	-25%	1%	332	1%
BMW	X5 xDrive40e	262	-54%	45%	262	45%
Mercedes-Benz	C350e	210	23%	n/a	210	n/a
Hyundai	Sonata Plug-In Hybrid	190	-42%	9%	190	9%
Porsche	Cayenne S E-Hybrid	177	16%	21%	177	21%
BMW	330e	129	-46%	n/a	129	n/a
Kia	Soul EV	117	-41%	44%	117	44%
Volvo	XC90 T8 Twin Engine	96	-53%	-58%	96	-58%
Ford	Focus Electric	56	-45%	-15%	56	-15%
Mercedes-Benz	S550 Plug-In Hybrid	55	-23%	189%	55	189%
Mercedes-Benz	B250e	53	-2%	-9%	53	-9%
Mercedes-Benz	GLE 550e	52	-37%	n/a	52	n/a
BMW	i8	50	-62%	56%	50	56%
Kia	Optima Plug-In Hybrid	40	n/a	n/a	40	n/a
BMW	740e	18	-22%	n/a	18	n/a
smart	fortwo ED	15	-63%	-69%	15	-69%
Chevrolet	Spark EV	4	-76%	-97%	4	-97%
Cadillac	ELR	3	0%	-96%	3	-96%
Porsche	Panamera S E-Hybrid	2	-33%	-93%	2	-93%
Total PEV Sales		**10,615**	**-57%**	**71%**	**10,615**	**71%**
% all sales		*0.93%*			*0.93%*	

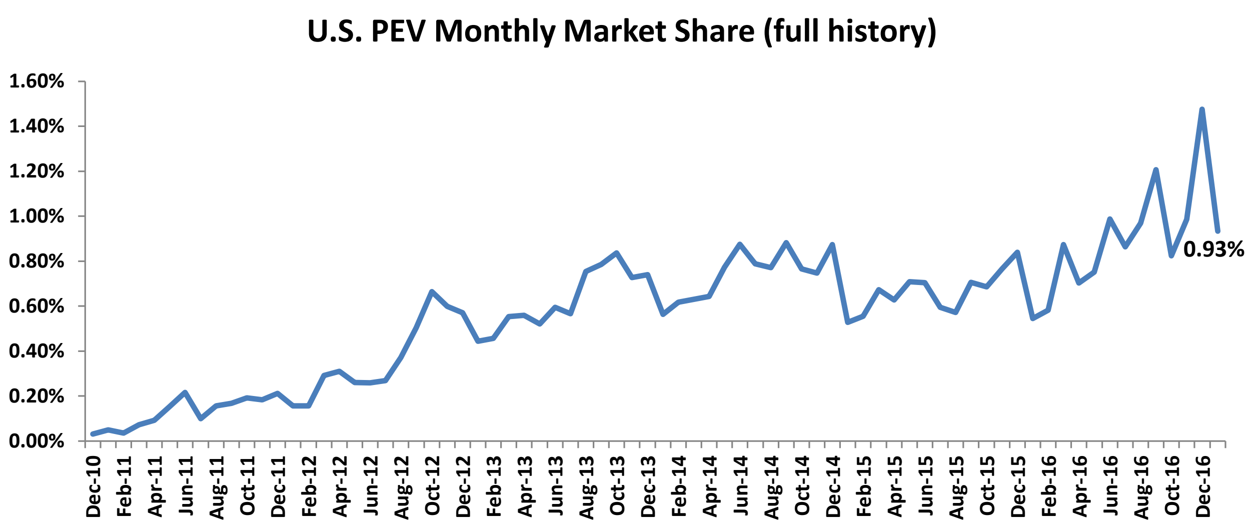
Other Vehicle Sales	Sales Jan-17	Change vs. last month	Change vs. last year	Sales YTD	Change vs. prior YTD
Hybrid Electric Vehicles (HEVs)	22,584	-35%	8%	22,584	8%
% all sales	*1.98%*			*1.98%*	
Fuel Cell Vehicles (FCVs)	127	9%	n/a	127	n/a
% all sales	*0.01%*			*0.01%*	
Diesel Vehicles	5,273	-61%	8%	5,273	8%
% all sales	*0.46%*			*0.46%*	
All Passenger Vehicles	1,137,782	-32%	0%	1,137,782	0%

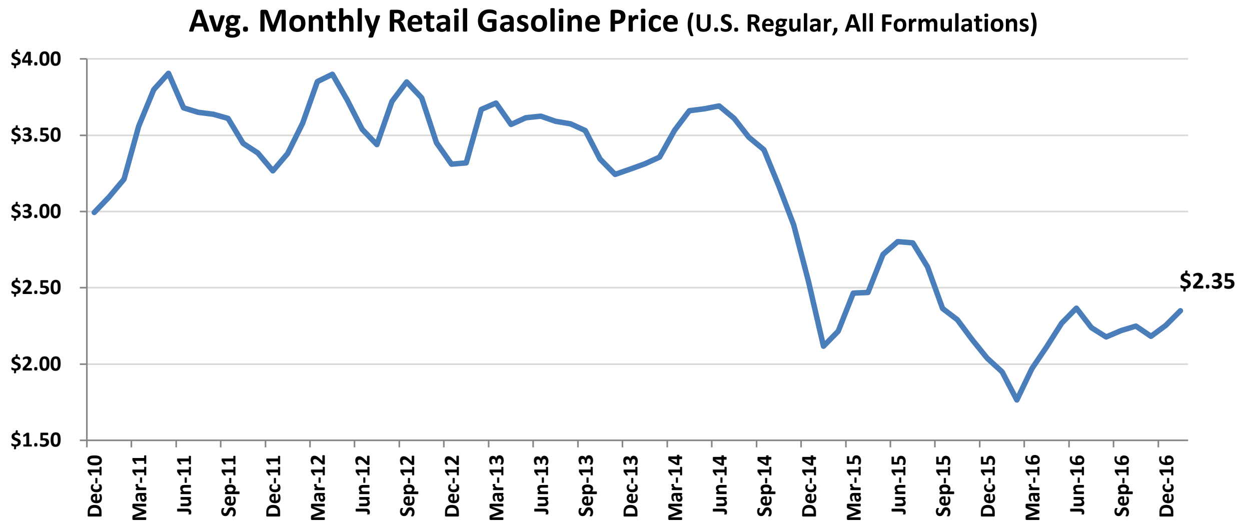
Data provided by HybridCars.com and InsideEVs.com. Tesla, Fiat, and Hyundai sales are unofficial; estimates from InsideEVs are used

U.S. PEV Sales Update *January 2017*









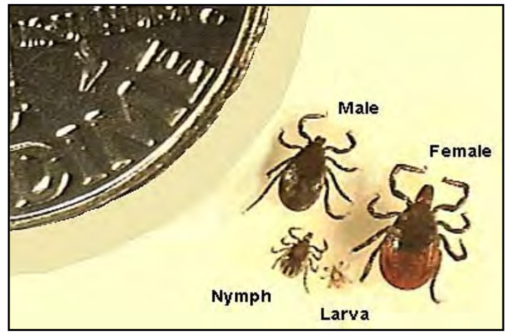
Data provided by EIA

USACHPPM
Readiness thru Health

18-001-1003

Just the Facts…

Tick Control Around the Home



The relative size of *Ixodes scapularis* (blacklegged tick, a.k.a. 'deer tick') as compared to the side of a dime.

First, some basic facts about ticks:

- There are over 800 species of ticks worldwide.
- Ticks must feed on the blood of an animal (the host) in order to grow (molt to different stages) and reproduce (lay thousands of eggs).
- Most ticks go through one inactive stage (egg) and three active stages (larva, then nymph, and finally adult) in their life cycle. The whole life cycle takes 1 to 2 years and the tick must feed (take a blood meal) once at each active stage. A blood meal takes several days to complete.
- Ticks don't fly or jump. Rather, a tick climbs to the ends of blades of grass or weeds and waits quietly with its front legs extended until it can grab onto a passing host.
- Ticks can spread diseases to people, pets, and other animals. Germs that may be present in their saliva are transmitted as they feed on the person or animal. These germs include the bacteria and viruses that cause such serious diseases as Lyme disease, Rocky Mountain spotted fever, and human ehrlichiosis.
- Not all ticks are infected. However, you can't tell if a tick is infected or not just by looking at it. Therefore, it is important to remove any tick that is attached to your skin as soon as possible. Ticks that are just crawling on you cannot transmit diseases.
- Ticks are most common in woods or overgrown places where the ground is covered with leaf litter, thick weeds, or high grass. These are the areas where ticks are not only protected from the harsh drying effects of the sun and wind, but also where their animal hosts (such as mice and deer) live.
- Ticks may sometimes be found on well-mowed lawns, or even inside your home. This is because they drop off of pets or other animals that cross over or enter these areas.

The best way to control ticks is to remove high grass, weeds, leaf litter, and undergrowth from around your home. Chemicals (pesticides) that kill ticks can be applied to your yard as a last resort if large numbers of ticks are present.

- Create 'tick-free' zones around your home by cutting back wooded areas and increasing the size of open lawn.
- Keep your lawn well mowed, to a height of 3 inches or less. This lowers the humidity at ground level, making it difficult for ticks to survive. Also, mice and other small animal hosts avoid these neatly trimmed areas because they cannot easily hide or find food and nesting materials.
- Remove brush, weeds, leaf litter, and other yard debris that attract ticks and their hosts.
- Rake back leaf litter and cut away undergrowth several feet into the edge of any woods that are on or next to your yard.
- Eliminate dense plant beds close to your house, such as ivy and pachysandra.
- Move woodpiles, birdfeeders and birdbaths as far from your house as possible. Mice and chipmunks hide and nest in woodpiles, and eat spilled food from birdfeeders. Birds can spread immature ticks over great distances as they migrate, and they may drop ticks in your yard as they use feeders and birdbaths.
- Keep garbage in tightly closed cans and don't put pet food outside or purposely attract and feed wild animals.
- Reduce the plants in your yard that deer love to eat (such as azaleas, rhododendrons, arborvitae, and crabapple) and increase the plants that they don't like (such as Colorado blue spruce, Scotch pine, boxwood, daffodils and marigolds). Extension agencies and local nurseries can offer more suggestions for your area.

U. S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, Maryland 21010-5403
DSN 584-3613; Commercial (410) 436-3613; FAX -2037

- Consider fencing to keep out larger animals, such as deer, as well as neighborhood pets. Ten-foot high fences may be necessary to completely keep out deer. Using an electrified fence may also be helpful.
- Keep clotheslines high off the ground and out in the open so laundry will not touch vegetation.
- Keep picnic tables and lawn furniture as far from any woods, shrubs, and undergrowth as possible.
- Move children's play areas as far away as possible from woods or other overgrown sites. Consider using fences to keep children from entering tick habitat.
- Create your vegetable and flower gardens in the middle of large areas of open lawn.

It is rare for a tick infestation to occur indoors. However, this can happen if a fully fed female tick falls off a pet and lays its eggs. This may occur in a location like pet bedding, carpeting, furniture upholstery, or crevices in floors and walls. In such a case, vacuum up as many of the ticks as possible, then seal the vacuum bag inside a plastic bag and dispose of it in an outdoor trash can. If possible, first place the sealed bag in the freezer for a couple of days to kill most of the ticks before placing it in the trash. Wash all removable bedding or cloth items in hot, soapy water, and apply an appropriate pesticide to all infested areas (see section on Chemical Control Options). It is best to hire a professional pest controller to perform the pesticide treatment.

More often, a single tick is carried inside on either a pet's fur or a person's clothing. It may then crawl onto another family member, searching for a blood meal.

Inside the home, you can reduce the potential for exposure to ticks by following these suggestions:

- Keep small animals like mice and cute fluffy kittens out of your home by closing up gaps around doors, windows, and other places.
- Check your clothing carefully for ticks before you come inside, and check your whole body once you're indoors.
- Follow this advice if you have pets that go outdoors:
    - Groom them carefully for ticks every time they've been outside.
    - Designate specific sleeping areas for your pets, and check their bedding routinely for ticks that might drop off of them while they sleep.
    - Keep pets off of furniture where ticks can become hidden in the fabric or cushions.
    - Seek your veterinarian's advice before using flea and tick control products on your pet or it's bedding. Remember that exposing your pet to more than one type of treatment (flea and tick collars, dips, baths, or powders) within a short period of time might seriously harm your pet.

Chemical Control Options

Applying pesticides (chemicals that will kill ticks) should be considered only as a last resort. It is best to hire a professional pest control company to do this.

Before deciding to apply pesticides, your property should be sampled for ticks. Your yard may not necessarily contain large numbers of ticks, even if you live in a county or other local area where ticks are numerous, or where there is a high rate of tick-borne disease. Sampling can be accomplished by using a 'tick drag or flag' (white flannel fabric attached to a pole that is dragged across, or poked into, the vegetation. Ticks, if they are present, will cling to the fabric.). If tick levels are high, pesticide treatment may be justified.

Pesticides come in both liquid and granular form. The type of vegetation in your yard and the stage of the ticks that are present will help determine what kind of product is best for your situation. Liquid pesticides will kill ticks that are crawling out in the open. Granular pesticides will penetrate leaf litter to kill ticks that are hatching, molting, or waiting out the cold weather (overwintering). For example, for blacklegged ticks (also known as deer ticks) in the northeastern and mid-Atlantic states, liquid pesticides can be used to kill nymphs in the spring, larvae in the summer, or adults in the fall. Granular pesticides will kill nymphs that are overwintering (in the fall) or larvae that are hatching from eggs (in the early summer). Some pesticides are restricted for use only by licensed pesticide applicators.

Here are some of the safest pesticides that are effective for controlling ticks. All products may not be registered for use in all states.

Class of pesticide	**Examples**
Carbamates	Carbaryl
Pyrethroids	Permethrin, deltamethrin, cyfluthrin
Pyrethrums	Plant extracts called pyrethrins, primarily for use inside the home because they break down so quickly

Personal Protective Measures

Despite your best efforts, it may be impossible to keep your yard entirely free of ticks and their animal hosts. It is therefore important to use personal protective measures. This includes wearing clothing that will prevent ticks from reaching your skin, such as long sleeves and long pants. Tuck your shirt into your pants and your pant cuffs into your socks or boots. Use an insect repellent containing **DEET** (N,N, diethyl-m-toluamide) on your exposed skin (skin that is not covered with clothing). Use an insect repellent containing **permethrin** on your clothing. Always **FOLLOW LABEL DIRECTIONS** when applying repellents. Be sure to check your clothing and body carefully for ticks when you've been outdoors.

LogID 6459

Tick Management Handbook

A integrated guide for homeowners, pest control operators, and public health officials for the prevention of tick-associated disease

Prepared by:

Kirby C. Stafford III
Chief Scientist
The Connecticut Agricultural Experiment Station, New Haven

Produced as part of the Connecticut community-based Lyme disease prevention projects in cooperation with the following Connecticut health agencies:

The Connecticut Department of Public Health
The Westport Weston Health District
The Torrington Area Health District
The Ledge Light Health District

Funding provided by

The Centers for Disease Control and Prevention

The Connecticut Agricultural Experiment Station

This handbook was developed as part of a community-based program for the prevention of tick-borne illness supported through a cooperative agreement with the Centers for Disease Control and Prevention (CDC). The CDC funded publication of this tick handbook. A series of tick and tick-associated disease information sheets first developed by Dr. Kirby Stafford at the Connecticut Agricultural Experiment Station in 1992 and updated and expanded periodically was the original basis for this handbook.

Acknowledgements

Thanks are given to Dr. Joseph Piesman (CDC, Fort Collins, Colorado), Dr. Peter J. Krause (University of Connecticut Health Center, Farmington, Connecticut), Carol Lemmon (CAES, retired), Bradford Robinson (Connecticut Department of Environmental Protection, Pesticide Management Division), Judith Nelson, Director, and the staff of the Westport Weston Health District (CT), Dr. Terry Schulze (NJ), Dr. Gary Maupin (CDC, retired), and Drs. Louis A. Magnarelli and John F. Anderson (CAES) for reviewing parts or all of this handbook. Their comments and suggestions were sincerely appreciated. Thanks are also extended to Vickie Bomba-Lewandoski (CAES) for publication and printing assistance.

Photo Credits

Many of the pictures and illustrations are those of the author or staff at the Connecticut Agricultural Experiment Station (CAES). Sources other than the author are numbered or otherwise noted in captions. Sincere thanks are given to the following for permission to use their photographs or illustrations and federal government sources are also gratefully acknowledged.

Pfizer Central Research (Groton Point Road, Groton, CT): 1, 6, 7, 8, 9, 11, 12, 20, 21, 23, 24, 25, 26, 32, 33, 34, 37, 47, 48.
Centers for Disease Control and Prevention: 13, 14, 16, 17, 19, 27, 28, 29, 30, 36, risk map.
United States Department of Agriculture: Cover (tick), tick morphology figure (adapted from Strickland et al. 1976), 39.
American Lyme Disease Foundation (Somers, NY): 3, 4, 10, 43.
Barnstable County Cooperative Extension (Massachusetts): 40.
Vector-borne Disease Laboratory, Maine Medical Center Research Institute (Portland, ME): 15.
Bayer Environmental Science (Montvale, NJ): 46.
United Industries (Spectrum Brands): 38.
Ric Felton (Goshen, CT; www.semguy.com): 35.
Jim Occi (Cranford, NJ): 5, 18, 45.
Lynne Rhodes (Old Saybrook, CT): 22, 23.
Steven A. Levy, DMV (Durham, CT): 31.
CAES: Jeffrey S. Ward, 2; Uma Ramakrishnan, 41, 42; and Jeffrey Fengler, 44.

Disclaimer

Mention of a product or company is for informational purposes only and does not constitute an endorsement by the Connecticut Agricultural Experiment Station.

Published Summer 2004

Table of Contents

Introduction 1

Ticks of the Northeastern United States 3
- Tick biology and behavior 4
- Tick morphology 6
- Blacklegged tick, *Ixodes scapularis* 7
- American dog tick, *Dermacentor variabilis* 10
- Lone star tick, *Amblyomma americanum* 12
- Other ticks 13

Tick-Associated Diseases 15
- Lyme disease 15
- Southern Tick-Associated Rash Illness 21
- Human Babesiosis 21
- Human Ehrlichiosis 23
- Rocky Mountain Spotted Fever 24
- Tick Paralysis 25
- Tularemia 26
- Powassan Encephalitis 26
- Tick-borne Relapsing Fever 27
- Colorado Tick Fever 27
- Bartonella Infections 27

Lyme Disease in Companion Animals 28

Personal Protection 29
- Tick bite prevention 29
- How a tick bites & feeds 31
- Tick removal 32
- Repellents 34

Integrated Tick Management 37
- Landscape management 39
- Management of host animals 43
- Prevention of tick-associated disease in companion animals 51
- Backyard Wildlife programs and environmentally friendly lawns 52

Area-wide Chemical Control of Ticks 53
- Acaricides used for tick control 54
- Homeowner application of acaricides 55
- Commercial application of acaricides 56
- An acaricide primer 58

Organic Landcare Practices 60

Biological Control 60

Selected Bibliography 61

> To these I must add the wood lice [ticks] with which the forests are so pestered that it is impossible to pass through a bush or to sit down, though the place be ever so pleasant, without having a whole swarm of them on your clothes.
>
> Pehr Kalm, 18 May 1749
> Raccoon [Swedesboro], New Jersey

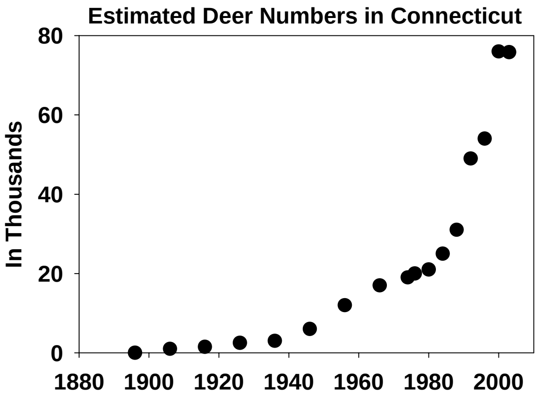
Introduction

Ticks have become an increasing problem to people and animals in the United States. Ticks are obligate blood-feeders that require an animal host to survive and reproduce. They feed on a wide variety of mammals, birds, reptiles, and even amphibians. While most ticks feed on specific host animals and are not considered to be of medical or veterinary importance, several ticks have a wide host range and attack people, pets, or livestock. Ticks can be a nuisance; their bites can cause irritation and, in the case of some ticks, paralysis. Severe infestations on animals can cause anemia, weight loss, and even death from the consumption of large quantities of blood. Ticks can also transmit many human and animal disease pathogens, which include viruses, bacteria, rickettsiae, and protozoa.

1

The association between ticks and disease was first demonstrated when Theobald Smith and Fred Kilbourne proved in 1893 that Texas cattle fever (cattle babesiosis) was caused by a protozoan transmitted by an infected tick. In the late 1800s, Rocky Mountain spotted fever was the first human tick-borne disease identified in the United States and for many years was the major tick-associated disease in this country. Although first recognized from the virulent cases in the Bitterroot Valley of Montana, it eventually became evident that most cases were distributed through the eastern United States. Lyme disease was first recognized as a distinct clinical entity from a group of arthritis patients in the area of Lyme, Connecticut, in 1975, although it became evident that this disease had an extensive history in Europe throughout the twentieth century. Today, Lyme disease is the leading arthropod-associated disease in the United States with over 23,000 human cases reported to the Centers for Disease Control and Prevention (CDC) in 2002. This may represent only about 10% of physician-diagnosed cases. Surveys have found that up to a quarter of residents in Lyme disease endemic areas have been diagnosed with the disease and that many residents perceive the disease as a serious or very serious problem. Without an effective intervention strategy, the steadily increasing trend in Lyme disease case reports is likely to continue.

In the northeastern United States, the emergence of Lyme disease can be linked to changing landscape patterns. A Swedish naturalist named Pehr Kalm recorded in his journal of his travels in the United States in 1748-1750 that ticks were abundant and



annoying. Over a century later in 1872, entomologist Asa Fitch noted that ticks were nearly or quite extinct along the route that Pehr Kalm had traveled. During this time, the land had been cleared for agriculture and white-tailed deer in many areas were drastically reduced or virtually eliminated due to habitat loss and unregulated hunting. With the reestablishment of forested habitat and animal hosts through the latter half of the twentieth century, ticks that may have survived on islands off the southern New England coast were able to increase and spread. The blacklegged tick, *Ixodes scapularis*, which is commonly known as the "deer" tick, and the principal vector for Lyme disease spirochetes, was present on Naushon Island, Massachusetts, in the 1920s and 1930s. Some *I. scapularis* from Montauk Point, Long Island, New York, that were collected in the late 1940s and early 1950s were found infected with Lyme disease bacteria. The risk of human infection increased through the 1960s and 1970s until the recognition of the disease from the cluster of cases in Lyme, Connecticut, in 1975. The rising incidence of Lyme disease is due to a number of factors including:

- Increased tick abundance
- Overabundant deer population
- Increased recognition of the disease
- Establishment of more residences in wooded areas
- Increased the potential for contact with ticks.

An estimated three quarters of all Lyme disease cases are acquired from ticks picked up during activities around the home. With the steady increase in the incidence and geographic spread of Lyme disease, there is a need for homeowners, public health officials, and the pest control industry to learn how to manage or control the tick problem. The withdrawal of the human Lyme disease vaccine (LYMErix™) has essentially brought the control of the disease back to managing tick bites and methods to suppress the local tick population or prevalence of pathogen infection in the ticks. The purpose of this handbook is to provide basic information on ticks and their biology, basic information on the diseases they carry, methods to reduce the risk of exposure to these parasites, and most importantly, information on how to reduce or manage tick populations, and therefore risk of disease, in the residential landscape.

Ticks: the foulest and nastiest creatures that be. Pliny the Elder, 23-79 A.D.

Ticks of the Northeastern United States

Ticks are not insects, but are arthropods more closely related to mites, spiders, scorpions, and daddy-long-legs. There are about 80 species of ticks in the United States (850 species worldwide). However, only about 12 or so in the U.S. are of major public health or veterinary concerns with a few others that occasionally attack humans. The ticks discussed in this handbook belong to the family Ixodidae or hard ticks. The principal hard ticks recovered from humans in the mid-Atlantic and northeastern United States are the blacklegged (i.e., deer) tick, *Ixodes scapularis*, the American dog tick, *Dermacentor variabilis*, and the lone star tick, *Amblyomma americanum*. Other tick species recorded as feeding on humans in the eastern U.S. include *Ixodes cookei*, *Ixodes dentatus*, and the brown dog tick, *Rhipicephalus sanguineus*. The Argasidae or soft ticks form the other major group of ticks. Soft ticks are generally nest inhabitants that are associated with rodents, birds, or bats. Several species of soft ticks attack humans and can transmit disease, mainly in western states, but are not the focus of this handbook. One species, *Carios* (*Ornithodoros) kelleyi*, a bat tick, has been recovered from states in the northeast to at least Connecticut.

Table 1. Important ticks of the northeastern states and some other major ticks of medical importance in the United States.

Tick	Common name	General distribution
Hard Ticks		
Ixodes scapularis	Blacklegged tick	Northeastern & mid-western United States
Ixodes pacificus	Western blacklegged tick	Pacific coast & parts Nevada, Arizona, Utah
Ixodes cookei	A woodchuck tick	Eastern United States & northeast Canada
Ixodes dentatus	A rabbit tick	Eastern United States
Amblyomma americanum	Lone star tick	Southeastern U.S., Texas to New York
Dermacentor variabilis	American dog tick	Eastern U.S. & west coast
Dermacentor andersoni	Rocky Mountain wood tick	Rocky Mountain states south to NM & AZ
Dermacentor albipictus	Winter tick	Canada, United States south to Central America
Rhipicephalus sanguineus	Brown dog tick	All U.S. and worldwide
Soft Ticks		
Ornithodoros species ticks	Relapsing fever ticks	Western United States
Carios kelleyi	A bat tick	Widespread in U.S., north to New York and Connecticut

Scientific Names and a Few Terms

The scientific name of ticks, like other organisms, is given in two parts: genus (capitalized, often abbreviated by the first letter, e.g. *I. scapularis*) and species (not capitalized) sometimes followed by the name of the person who described the organism (given in parenthesis if the genus name is later changed). The name Linneaus is abbreviated L. Common names like deer tick can vary regionally and some organisms may have no common name. The common names used in this guide follow those officially recognized by scientific societies. Several terms are used to define the cycles of animal, tick and pathogen.

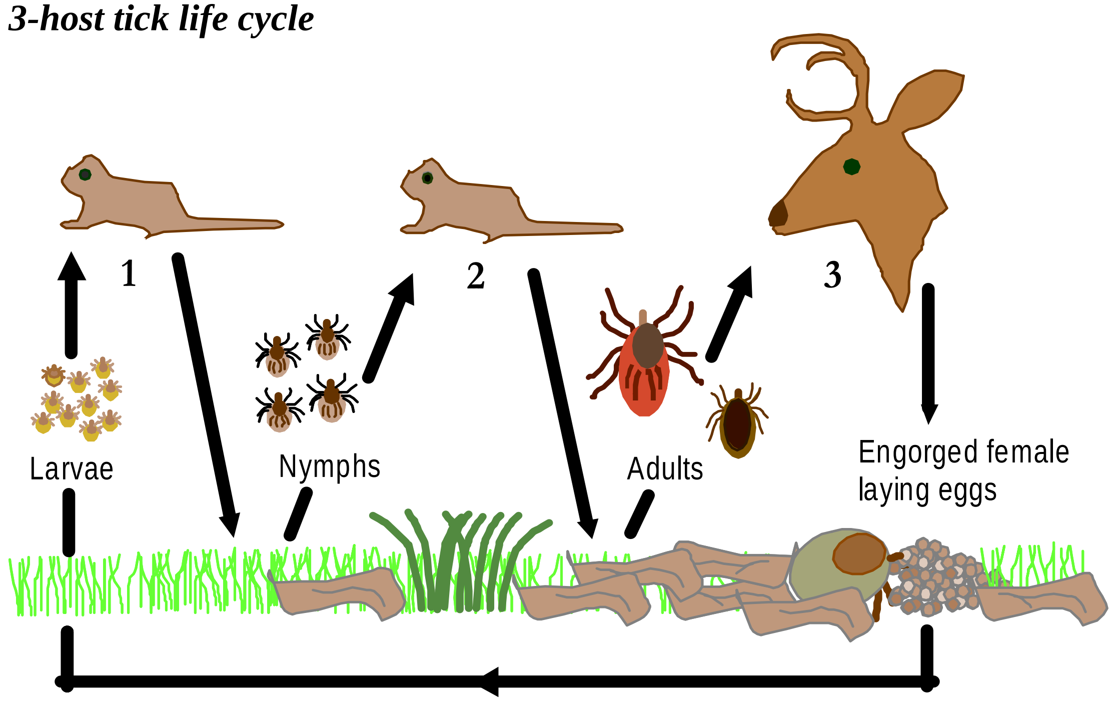
- Pathogen: the microorganism (i.e., virus, bacteria, rickettsia, protozoa, fungus) that may cause disease.

- Parasite: An animal that lives in or on a host for at least part of their life and benefits from the association at the expense of the host (from the Greek, literally para - beside and sitos - food).
- Vector: An insect or other arthropod, like a tick, that carries and transmits a disease pathogen. Diseases associated with pathogens transmitted by a vector are called vector-borne diseases.
- Host: An animal infected by a pathogen or infested with a parasite.
- Reservoir: An animal host that is capable of maintaining a pathogen and serving as a source of infection.
- Zoonoses: A disease caused by a pathogen that is maintained in vertebrate animals that can be transmitted naturally to humans or domestic animals by a vector or through other means (e.g. saliva, feces).
- Endemic disease: A disease that is established and present more or less continuously in a community.

Tick Biology and Behavior

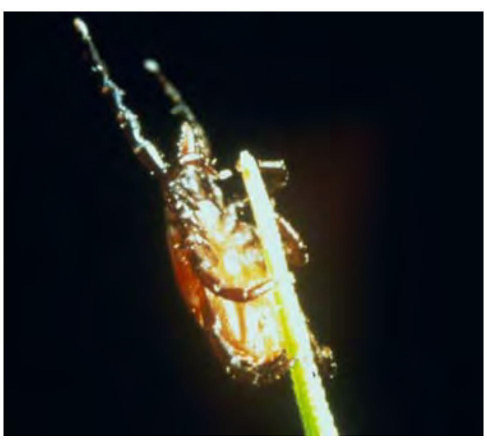
Ticks are essentially mites that have become obligate blood-feeders, requiring a host animal for food and development. Ticks have four stages in their life cycle: egg, the 6-legged larva (seed ticks), and 8-legged nymph and adult (male or female). Larvae and nymphs change to the next stage after digesting a blood meal by molting or shedding the cuticle. Most of the ticks mentioned in this handbook have a 3-host life cycle, whereas each of the three active stages feed on a different individual host animal, taking a single blood meal. Larvae feed to repletion on one animal, drop to the ground and molt to a nymph. The nymphs must find and attach to another animal, engorge, drop to ground and molt to an adult. The adult tick feeds on a third animal. A replete or engorged (blood filled) female tick produces a single large batch of eggs and dies. Depending upon the species of tick, egg mass deposited can range roughly from 1,000 to 18,000 eggs.

3-host tick life cycle



The larvae and nymphs generally feed on small to medium-sized hosts, while adult ticks feed on larger animals. Some ticks may have a one-host (all stages staying and feeding on only one animal host before the female drops off) or other multi-host lifecycles. Depending upon the tick, the life cycle may be completed in 1, 2 or even 3 years, while a one-host tick may have more than one generation per year. Feeding for only a few days, the majority of the life of a tick is spent off the host in the environment either seeking a host, molting or simply passing through an inhospitable season (e.g., hot summers or cold winters). Soft ticks have a multi-host life cycle with multiple nymphal stages; each stage feeds briefly, and adults take multiple small blood meals, laying small egg batches after each feeding. As nest and cave dwellers, often with transient hosts, some argasid ticks may survive many years without a host. However, most hard ticks do not successfully find a host and perish within months or a year or two at best.

3



4

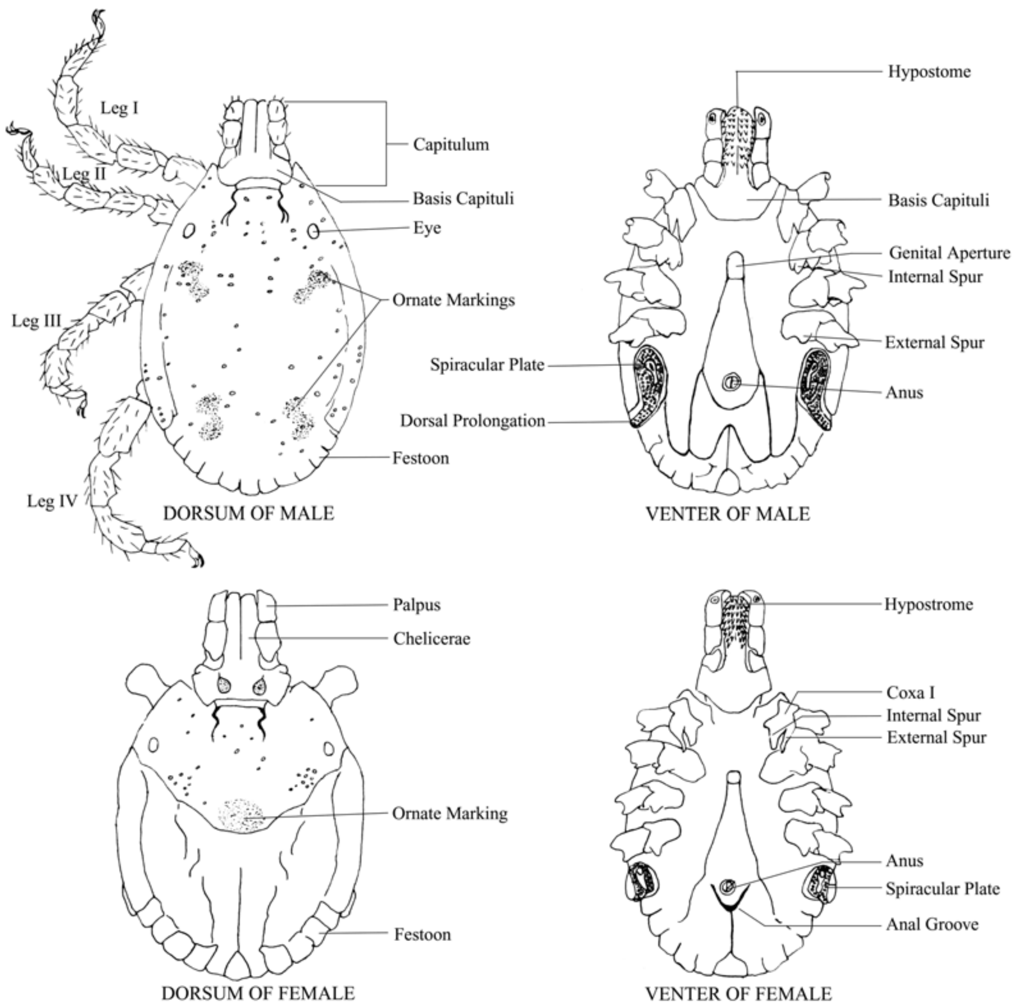
Larval ticks will be clustered on the egg mass after hatching and when ready to feed, ascend blades of grass or similar vegetation to await a host. Ticks assume a questing position by clinging to the leaf litter or vegetation with the back legs, and hold the first pair outstretched. Due to differences in susceptibility to desiccation and host preference, immature ticks generally remain in the low vegetation, while adult ticks may seek a host at a higher level in the vegetation. Ticks detect their hosts through several host odors (including carbon dioxide, ammonia, lactic acid, and other specific body odors), body heat, moisture, vibrations, and for some, visual cues like a shadow. When approached by a potential host, a tick becomes excited - waving the front legs in order to grab the passing host. Ticks cannot fly or jump; they must make direct contact with a host. Once on a host a tick may attach quickly or wander over the host for some time. Some ticks attach only or principally on certain areas like the ear or thin-skinned areas, while other species may attach almost anywhere on the host. Ticks feed slowly, remaining on the host for several to many days, until engorged with blood (see section on feeding in tick bite prevention). Male ticks feed intermittently, take small blood meals, and may remain on a host for weeks. For most ticks mating occurs on the host, as the male tick also requires a blood meal. However, male *Ixodes* ticks do not need to feed prior to mating and mating may occur on or off the host.

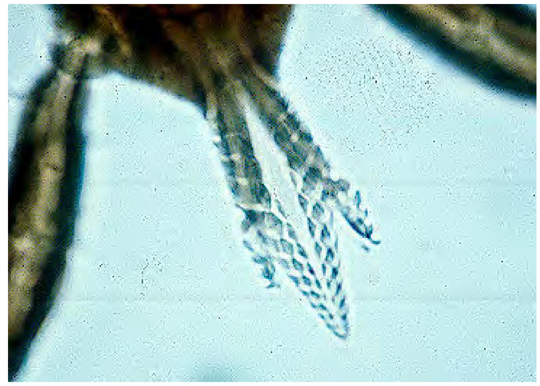
5

Tick Morphology

The body of a tick consists of a “false head” (the capitulum) and a thorax and abdomen fused into a single oval, flattened body. A larval tick has six legs, while nymphs and adults have eight legs present. The basal segment of the leg, the coxa, may have spurs that help in identification. An adult tick will have a genital aperture on the ventral surface, located roughly between the second pair of legs. The respiratory system is evident by spiracular plates located ventrolaterally behind the fourth pair of legs in the nymphs and adults. These plates may be oval, rounded, or comma-shaped. Hard ticks get their name from a tough dorsal shield or plate called the scutum present on all mobile stages of the tick. The scutum on the larva, nymph, and female tick covers the dorsal anterior third to half of the body. By contrast, the scutum on a male tick covers almost the entire dorsal surface and expansion during feeding is very limited. The scutum differs in shape and others characteristics (i.e., presence or absence of simple eyes) between tick genera. In some ticks, ornate or patterned markings may be present that can aid in identification. A distinct semicircular anal groove curves around the front of the anal opening in *Ixodes* ticks. In all other ticks, the anal groove is behind the anus or absent. Many ticks, but not *Ixodes*, have rectangular areas separated by grooves on the posterior margin of the tick body called festoons. Festoons, if present, may not be visible on fully engorged females. Argasid ticks are leathery, wrinkled and grayish in appearance. The capitulum of soft ticks is located on the underside of the body and cannot be seen from above.

Hypothetical Male and Female Ixodidae (Hard Ticks) with Key Characteristics Labeled





The capitulum in hard ticks is visible dorsally in all stages. The capitulum holds the mouthparts consisting of a base (basis capituli), two palps, paired chelicerae, and the median ventral hypostome, which is covered with denticles or recurved teeth. The shape of the basis capituli, length of the palps, number of denticles, and other characteristics of the mouthparts are used to help identify tick genera and species. While the adults of some common ticks can be easily identified with a little training because of distinctive markings or color, the identification of most ticks and the immature stages requires the services of a trained entomologist and the use of keys developed by tick taxonomists. These keys are designed to specifically identify adults, nymphs or larvae.

The Blacklegged Tick or "Deer" Tick, *Ixodes scapularis* Say

6

Above: left to right: larva, nymph, male and female *I. scapularis*. Below top: unfed and engorged female. Below bottom: male, female and engorged female with straight pin.

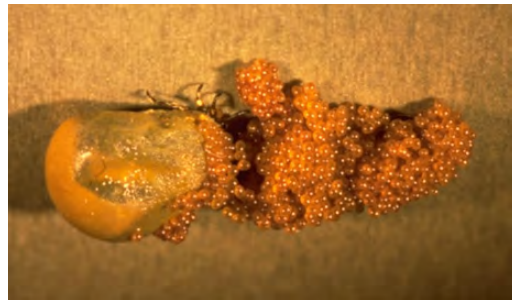
7

8

Blacklegged tick is the correct common name for the tick popularly known as the "deer" tick (the terms are not used together, it is <u>not</u> called the blacklegged deer tick). *Ixodes* (pronounced ix-zod-ease) *scapularis* transmits the causal agents of three diseases; Lyme disease, human babesiosis, and human anaplasmosis. The blacklegged tick is found from some southern portions of Canada and coastal Maine through the mid-Atlantic states into Maryland, Delaware and northern parts of Virginia and in several north central states, particularly Wisconsin and Minnesota, extending down through Illinois and into Indiana. This tick is also found throughout the southeastern United States west to southcentral Texas, Oklahoma, southern Missouri, and eastern Kansas. However, few *I. scapularis* in the southeast have been found infected with the bacterium that causes Lyme disease, the spirochete *Borrelia burgdorferi*. Therefore, the risk for Lyme disease from this tick in the southeastern United States is considered relatively low.

Unfed female *I. scapularis* have a reddish body and a dark brown dorsal scutum (plate) located behind the mouthparts. Length of the female tick from the tip of the palpi to the end of the body is about 3 to 3.7 mm (about 1/10 of an inch). Male *I. scapularis* are smaller (2 – 2.7 mm) than the female and are completely dark brown. Nymphs are 1.3 to 1.7 mm in length, while larvae are only 0.7 to 0.8 mm. Female blacklegged ticks become fairly large when engorged with blood and, consequently, are sometimes confused with engorged female American dog ticks.

Blacklegged ticks feed on a wide variety of mammals and birds, requiring 3-7 days to ingest the blood, depending on the stage of the tick. Larvae and nymphs of *I. scapularis* typically become infected with *B. burgdorferi* when they feed on a reservoir competent host. The white-footed mouse is the principal reservoir (source of infection) for *B. burgdorferi*, the protozoan agent of human babesisois, *Babesia microti*, and can serve as a reservoir for the agent of human granulocytic ehrlichiosis. Birds are also a major host for immature *I. scapularis* and have been implicated in the long-distance dispersal of ticks and *B. burgdorferi*. White-tailed deer, *Odocoileus virginianus* (Zimmerman), are the principal host for the adult stage of the tick, which feeds on a variety of medium- to large-sized mammalian hosts. An engorged female tick may typically lay around 2,000 eggs or more.



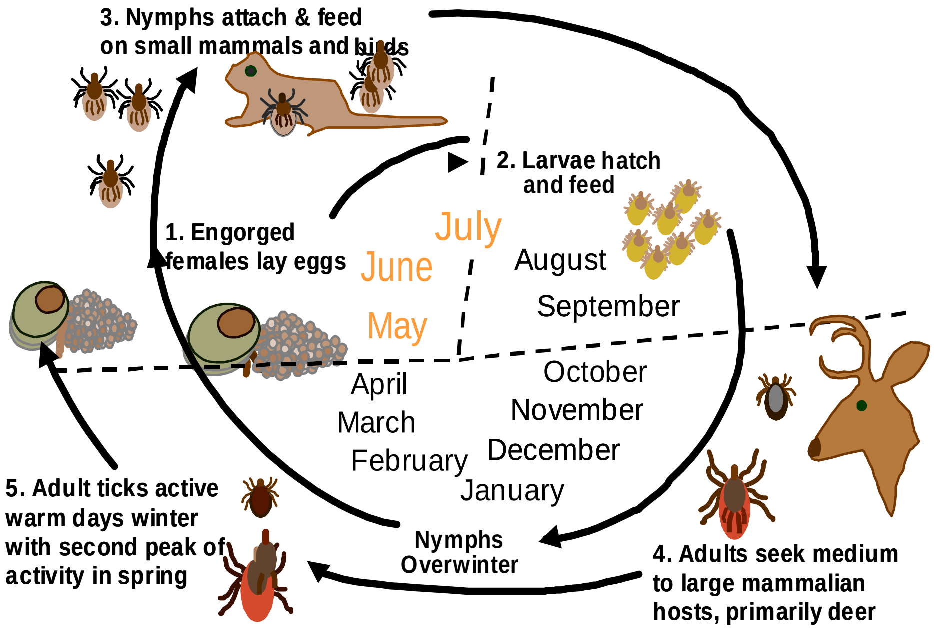
Below clockwise from top left: Nymphal *I. scapularis* in the hand, close-up of an *I. scapularis* nymph (fingerlike projections of the tick mid-gut where the Lyme spirochetes are found are visible through the tick cuticle), female and nymph *I. scapularis* on finger, and nymphal *I. scapularis* on finger.

9

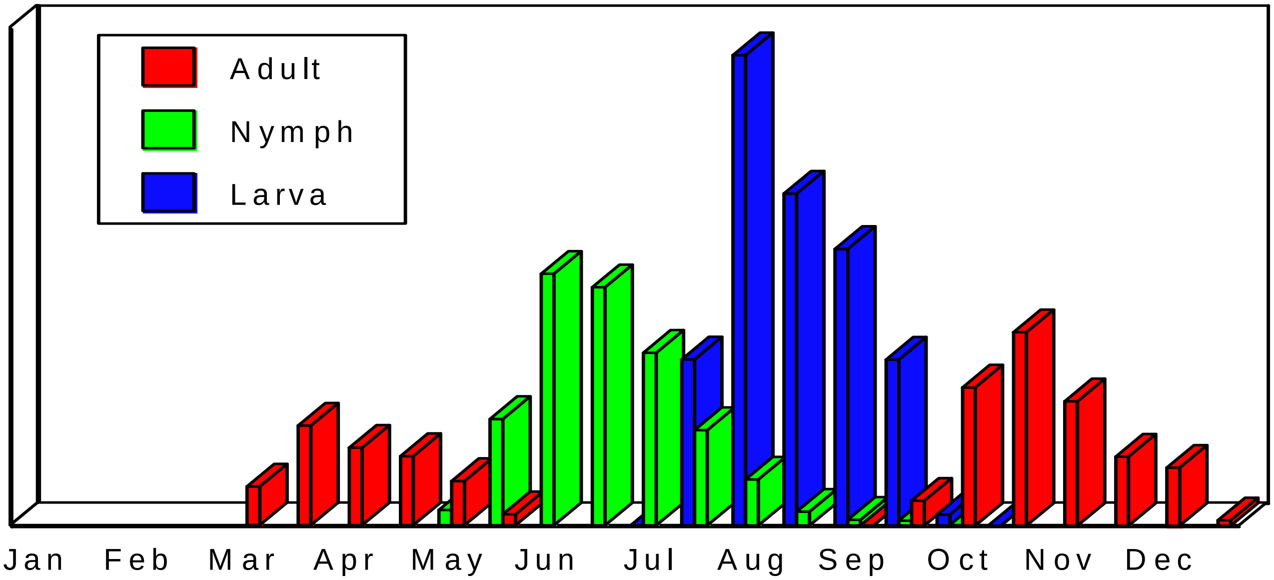
10

The Lyme disease spirochete in northern states is maintained, in part, by the two-year life cycle of the tick. Seasonally, the nymphs precede larvae and infect a new generation of animal hosts. Larvae active later in the summer then become infected when feeding on reservoir host animals. Adults of *I. scapularis* are more commonly infected with *B. burgdorferi* than the nymphs because the tick has had two opportunities to become infected, once as a larva and once as a nymph.

Two-year Life Cycle for *Ixodes scapularis*.



Seasonal activity of *I. scapularis* adults, nymphs, and larvae.



The American Dog Tick, *Dermacentor variabilis* (Say)

The American dog tick, *Dermacentor variabilis*, is the primary vector of the causal agent of Rocky Mountain spotted fever in the eastern United States and is also a vector for the agent of tularemia. This tick does not transmit Lyme disease spirochetes and recent studies have indicated that it is not a vector for the agent of human granulocytic ehrlichiosis. The American dog tick, known by some people as the wood tick, is one of the most widely distributed and common ticks in the eastern and central United States, found from Nova Scotia to the Gulf Coast as far west as Texas, Kansas and the Dakotas. It is also found in parts of California, Oregon, eastern Washington, and northern Idaho. Only adults of the American dog tick feed on people and their pets – records of nymphs from humans are rare. The Rocky Mountain Wood tick, *Dermacentor andersoni*, is found in western North America from British Columbia and Saskatchewan south through North Dakota to northern New Mexico and Arizona and California. This tick is the vector for Rocky Mountain spotted fever and Colorado tick fever in western Canada and the northwestern United States.

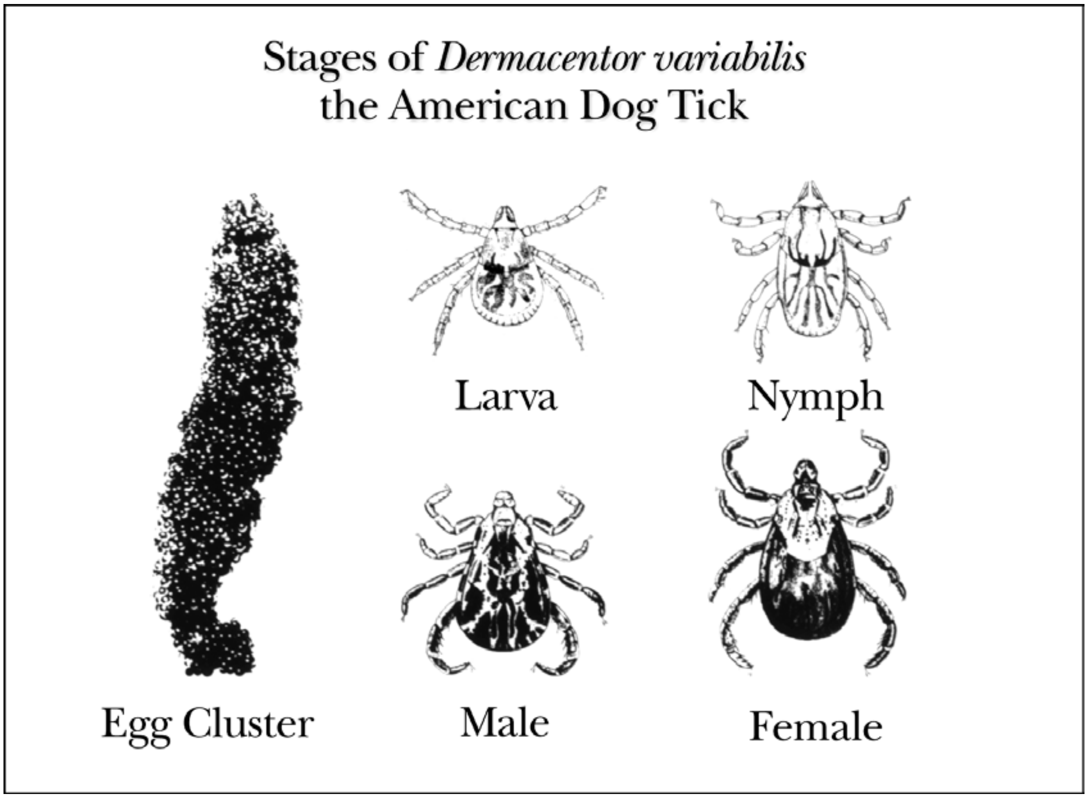
11

12

13

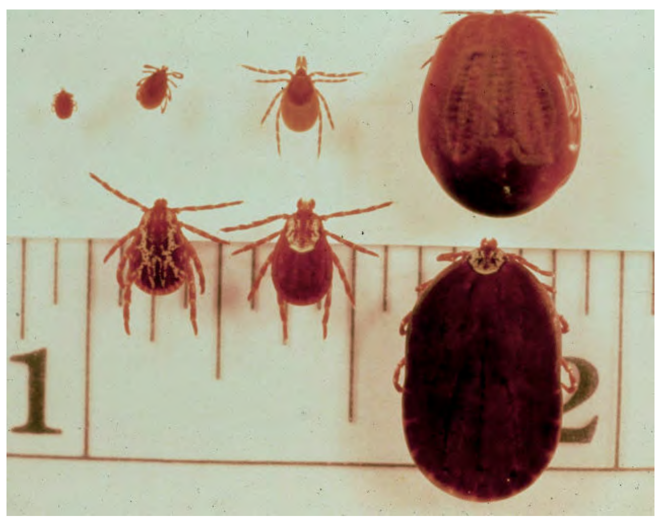
Adult American dog ticks are reddish brown in color with silvery-gray or whitish markings on the back or upper body. They are almost 6.4 mm (¼ inch) in length. The palps are short. The ornate marking are on the scutum of the female and on the male extend over the entire back. Female ticks increase dramatically in size as they obtain their blood meal from a host animal. Fully engorged females may reach ½ inch in length (13 mm long by 10 mm wide) and resemble a dark pinto bean. Male ticks do not change notably in size as they feed. The scutum or plate does not change in size and the white markings are readily visible on a blood-fed tick. Adult dog ticks can be distinguished from adult *I. scapularis* by their larger size and the white markings on the dorsal scutum. In the northeast, adults of both tick species are active during the spring.

Dogs are the preferred hosts of adult ticks, but they also feed readily on other medium to large mammals. These include opossums, raccoons, skunks, fox, coyote, bobcat, squirrel, cattle, sheep, horses and people. Larvae and nymphs of the American dog tick feed on meadow voles (*Microtus pennsylvanicus*), white-footed mice (*Peromyscus leucopus*), and other rodents. In New Jersey, adult ticks are active from mid-March to mid-August. In Connecticut and Massachusetts, adults become active about mid-April to early May, peak in June, and may remain a nuisance until mid-August. Mating occurs on the host. A female tick will feed for 10-12 days. Once she is engorged with blood, she drops off the host, and may deposit about 3,000 to 7,000 eggs (average around 5,000). Males continue to ingest small amounts of blood from the host. In the northeast, the American dog tick probably requires 2 years to complete its life cycle as opposed to one year in the southern parts of its range. American dog ticks can live for extended periods without feeding, more than two years to almost three years, if suitable hosts are not available. Larvae, nymphs, and adults may live up to 540, 584, and 1,053 days, respectively, although typically survival will be much less.



14

American dog ticks are most numerous along roadsides, paths, old fields, marshy areas and trails in brushy woodlands or meadows with tall grass or weeds. Meadow voles are found in fields, pastures, fresh and saltwater marshes and meadows, borders of streams and lakes, and open and wooded swamps. Consequently, large numbers of American dog ticks may be encountered in these areas. People or their pets may bring these ticks from outdoors into the home, where they can survive for many days. However, the tick will not become established indoors. The Brown dog tick (page 13) is the species that may cause household infestations.



15

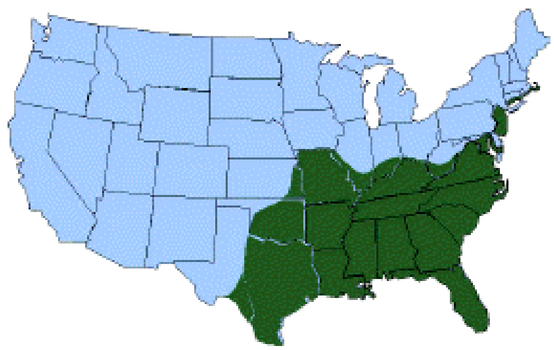
Comparison between the blacklegged tick and American dog tick (above). Top row left to right: nymph, male, female, and engorged female *I. scapularis*. Note engorged female is nearly as large as the engorged female American dog tick. Bottom row left to right: male, female, and engorged female *D. variabilis*. Note the white markings on the scutum of *D. variabilis* can help distinguish between the two engorged ticks (ruler is marked in 1/16 inch intervals between the 1 and 2 inch mark).

The Lone Star Tick, *Amblyomma americanum* (L.)

16

The lone star tick, *Amblyomma americanum*, is named from the conspicuous spot on the end of the scutum of the female tick. This tick is the vector for *Ehrlichia chaffeensis*, the agent of human monocyctic ehrlichiosis (HME). The tick does not transmit the Lyme disease bacterium, *B. burgdorferi*, but has been linked with a Lyme-like illness with a rash and other symptoms resembling Lyme disease called southern tick-associated rash illness or STARI. Possibly caused by another species of spirochete, attempts to culture the organism from skin biopsies at the rash or obtain serological evidence of Lyme disease from affected patients have not been successful thus far. A new spirochete, *B. lonestari*, has been described from lone star ticks based on a DNA analysis and has recently been cultured from ticks. It has been detected in both a tick and associated rash, but it is yet not clear if it is the agent of the Lyme-like illness.

The lone star tick is widely distributed through the southeastern United States as far west as Texas and north to southern parts of Iowa, Illinois, Indiana, Ohio, and Pennsylvania. Along the Atlantic coast, its northern range extends to New Jersey and Long Island, New York, and it is also abundant on Prudence Island, Rhode Island. Lone star tick populations in Connecticut are sparse, but these ticks are occasionally recovered from residents, mainly in coastal communities in Fairfield and New Haven Counties.



Approximate distribution of *A. americanum* shown in green shaded area.

Lone star ticks are reddish brown in color and about 3 to 4 mm long. The palps of *Amblyomma* ticks are long. Female ticks have a conspicuous spot on the end of the scutum. Male ticks have faint white markings at the edge of the body. Nymphs are more circular in shape than *I. scapularis* nymphs and reddish in tint. Adults are active in the spring, while nymphs are active from April through the mid-summer. Larvae are active in the late summer and early fall.

The lone star tick has a wide host range, feeding on virtually any mammal. All stages will feed on people. On wild hosts, feeding occurs principally in and on the ears and the head. The bite of this tick can be painful because of the long mouthparts and attached ticks can cause great irritation. All stages are active during the summer months. Female ticks can deposit 1,000 to 8,000 eggs with an average of around 3,000 eggs. Deer and other large to medium sized animals are hosts for the adults and nymphs. Heavy infestations of this tick have been known to result in blindness and death of fawns of white-tailed deer. In some localities, this tick may also be known as the “deer” tick. Larvae and nymphs commonly feed on large and medium-sized mammalian hosts. Larval ticks also feed on many species of birds. Rodents do not appear to be important hosts for immature *A. americanum*.

Other Ticks

Ixodes cookei Packard

Ixodes cookei, sometimes referred to as the “woodchuck tick”, is found throughout the eastern half of the United States and Canada. It is a primarily a parasite of medium-sized mammals such as woodchucks, opossums, raccoons, skunks, and foxes. In a New York study, it was the second most abundant tick on medium-sized mammals behind *I. scapularis*. All stages of *I. cookei* will feed on humans, though reports in southern New England and New York are uncommon. It appears to be a more frequent human parasite in northern New England and Ontario, Canada. After the American dog tick, *I. cookei* was the second most common tick removed from humans in Maine from 1989-1990 (*I. scapularis* was third). Lyme disease spirochetes have been detected in this tick, but laboratory studies suggest it is not a good vector for *B. burgdorferi*. However, *I. cookei* is the principal vector for Powassan virus, which can cause severe or fatal human encephalitis.

Brown Dog Tick, *Rhipicephalus sanguineus* (Latreille)

The brown dog tick or kennel tick, *Rhipicephalus sanguineus*, is a three-host tick found almost worldwide and throughout the United States. The tick is more abundant in the southern states. This is the only species of this genus in the U.S. Domestic dogs are the principal host for all three stages of the tick, especially in the United States, although the tick feeds on other hosts in other parts of the world. Adult ticks feed mainly inside the ears, head and neck, and between the toes, while the immature stages feed almost anywhere, including the neck, legs, chest, and belly. People may occasionally be attacked.

This tick is closely associated with yards, homes, kennels and small animal hospitals where dogs are present, particularly in pet bedding areas. In the North, this tick is found almost exclusively indoors. Brown dog ticks may be observed crawling around baseboards, up the walls or other vertical surfaces of infested homes seeking protected areas, such as cracks, crevices, spaces between walls or wallpaper, to molt or lay eggs. A female tick can deposit between 360 to 3,000 eggs. Under favorable conditions, the life cycle can be completed in about two months. This tick is the vector for canine ehrlichiosis (*Ehrlichia canis*) and canine babesiosis (*Babesia canis* or *Babesia gibsoni*). The brown dog tick is a vector for Boutonneuse fever in Europe and Africa.

Winter Tick, *Dermacentor albipictus* (Packard)

The winter tick, *Dermacentor albipictus*, is a one-host tick found commonly on moose (*Alces alces*), elk (*Cervus elaphus*), and deer. Hunters will encounter this tick (as well as *I. scapularis*) on harvested deer, moose, and elk during the hunting season. Heavy tick infestations can cause anemia and other problems and death of the animal. Larval ticks infest animals in the fall and then develop into nymphs and adults without leaving the host. Engorged females will drop off the host animal in the spring. This tick is broadly distributed from Canada to Central America. This tick will occasionally feed on humans.

Western Blacklegged Tick, *Ixodes pacificus* Cooley and Kohls

Although outside the scope of this handbook, readers should note that the western blacklegged tick, *Ixodes pacificus*, is the principal vector for Lyme disease to humans in the western United States. It looks just like the blacklegged tick in the east and only a specialist could tell them apart. It is found along the Pacific Coast in the western half of Washington and Oregon, almost all of California, and in parts of Utah, Arizona, and New Mexico. Infection rates with *B. burgdorferi* are generally low, 5-6% or less, because many of the immature *I. pacificus* ticks feed on the western fence lizard (*Sceloporus occidentalis*), a reservoir incompetent host for *B. burgdorferi* whose blood also contains a borreliacidal factor that destroys spirochetes in *I. pacificus* nymphs. Several rodents (mainly woodrats) and a nest dwelling tick, *I. spinipalpis*, maintain the enzootic cycle of Lyme disease in California and other western states.

Carios (Ornithodoros) kelleyi Cooley and Kohls

This tick feeds on bats and is found in homes, bat colonies, and other areas where bats may be found. It may occasionally bite humans whose dwellings are infested by bats. Distributed throughout the U.S., records from the northeast include Pennsylvania, New York, and Connecticut.

17

Imported ticks

Travelers abroad have found exotic ticks on themselves after returning to the United States. Other ticks may be imported on pets and other animals. Some of these ticks are potential vectors of pathogens of domestic livestock and introduction and establishment of these ticks would have serious consequences for the livestock industry. For humans, there are a number of bacterial and rickettsial pathogens and encephalitis and hemorrhagic fever viruses carried by ticks in Europe, Asia, Africa and Australia. For example, cases of boutonneuse fever, also called Mediterranean spotted fever, have occurred in travelers returning to the U.S. Boutonneuse fever is distributed through Africa, countries around the Mediterranean, southern Europe, and India. Other spotted fever diseases are African tick-bite fever, Siberian tick typhus, and Queensland tick typhus.

Several tick-borne encephalitis viruses, as well as Lyme disease spirochetes, are transmitted by *Ixodes ricinus* ticks in the British Isles, central and Eastern Europe, and Russia and by *Ixodes persulcatus* from central Europe, Russia, parts of China, and Japan. The following ticks have been documented from traveler's returning to the northeast (destination, origin): *Amblyomma cajennense* (CT, Jamaica), *A. hebraeum* (CT, South Africa), *A. variegatum* (NY, Kenya), *Rhipicephalus simus* (CT, Kenya), *Dermacentor auratus* (ME, Nepal), and *Hyaloma marginatum* (CT, Greece). The Connecticut travelers returning from South Africa and Kenya were physician diagnosed with boutonneuse fever. Tick bite prevention measures should be taken by travelers to potentially tick infested areas abroad. Physicians should consider exotic tick-associated diseases in the differential diagnosis for a patient with a travel with a travel history outside the United States.

18

Amblyomma hebraeum, one exotic species that has been imported into the U.S. Found throughout southern Africa, it is a vector for *Rickettsia conori*, the agent of boutonneuse fever. (J. Occi).

Louse Flies of Deer May Be Confused with Ticks

These flies are tick-like, blood-feeding parasitic flies (family Hippoboscidae), which may be confused with true ticks. The adult flies are dorsally flattened like a tick, with short legs. Several species are common parasites of white-tailed deer in the U.S. and are frequently seen by hunters or others in close association with deer. One species, *Lipoptena cervi* is known as the "deer ked" and was imported from Europe. It occasionally will bite humans. Other "deer keds" are native to the U.S. The female fly retains the larvae, nourishing them internally, and then lays mature larvae, which promptly pupate. The hippoboscid flies associated with deer have wings when they emerge, but lose them once they find a host.

Tick-Associated Diseases

There are at least eleven recognized human diseases associated with ticks in the United States, seven or eight of which occur in the mid-Atlantic or northeastern states. Each of the diseases is highlighted in this section of the handbook. The greatest attention is given to Lyme disease, ehrlichiosis, and babesisois. Although each is a zoonotic vector-borne disease, not all are caused by an infectious agent or are exclusively tick transmitted. A toxin causes tick paralysis, tularemia can be transmitted through contaminated animal tissue or other materials, and babesisois and ehrlichiosis can be transmitted perinatally and through blood transfusion. Tick associations with other pathogens like *Bartonella* or *Mycoplasma* are not yet clearly defined. The causative pathogens transmitted to humans by the tick vector are maintained in a reservoir host. *Ixodes* ticks can be infected with more than one agent and co-transmission and infection can occur. Alternatively, multiple infections can occur from multiple tick bites. In a Connecticut and Minnesota study, 20% of Lyme disease patients also had serological evidence of exposure to another tick-borne agent.

Table 2. Tick-associated diseases in the United States.

Disease	Pathogen or causal agent	Tick Vector
Babesiosis	*Babesia microti, Babesia* spp.	*I. scapularis, I. pacificus*
Colorado tick fever	CTF virus (Retoviridae)	*D. andersoni*
Ehrlichiosis, monocytic	*Ehrlichia chaffeensis*	*A. americanum*
Ehrlichiosis, granulocytic	*Anaplasma phagocytophilum*	*I. scapularis, I. pacificus*
Lyme disease	*Borrelia burgdorferi*	*I. scapularis, I. pacificus*
Southern rash illness	*Borrelia lonestari* (?)	*A. americanum*
Powassan encephalitis	Powassan virus	*I. cookei*
Rocky Mountain spotted fever	*Rickettsia rickettsia*	*D. variabilis, D. andersoni*
Tick-borne Relapsing Fever	*Borrelia* species	*Ornithodoros* species ticks
Tularemia	*Franciscella tularensis*	*D. variabilis, A. americanum*, others
Tick paralysis	Toxin	*D. variabilis, D. andersoni*

Lyme disease, monocytic and granulocytic ehrlichiosis, Rocky Mountain spotted fever, and tularemia are nationally reportable diseases. The amount and quality of surveillance data provided to state health departments and then to CDC is quite variable. Most surveillance is passive, dependent upon physician reporting. Most diseases are greatly underreported. Active surveillance or laboratory-based reporting may also exist in some states or areas. Case reports are based on a standardized surveillance case definition, which is not meant to be the basis for diagnosis. An increase in case reports can represent a true increase in disease or increased awareness of the disease and increased reporting. Conversely, a decrease may represent a change in reporting or a lack of reporting, rather than a true decrease in the incidence of disease. Nevertheless, surveillance case reports generally provide valuable long-term tracking of disease trends and may be useful for targeting intervention strategies.

Lyme Disease

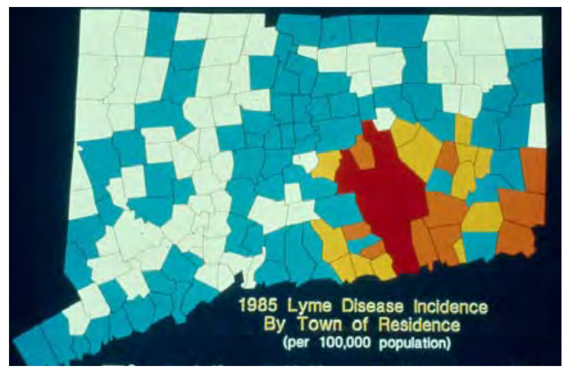
Lyme disease is the leading arthropod-associated disease in the United States and is caused by the spirochete *Borrelia burgdorferi*, a corkscrew-shaped bacterium. It is associated with the bite of certain *Ixodes* ticks, particularly the blacklegged tick, *I. scapularis*, in the northeastern and north-central United States and the western blacklegged tick, *Ixodes pacificus*, on the Pacific Coast. Other *Ixodes* ticks spread the disease in Europe and Asia. The disease has been reported from 49 states, as well as parts of Canada, and across Europe and Asia.

Lyme disease was first recognized as a distinct clinical entity in a group of arthritis patients from the area of Lyme, Connecticut in 1975. In 1981, Dr. Willy Burgdorfer discovered spirochetes in the mid-gut of some *I. scapularis* ticks from Long Island, New York and the bacteria were later named after him. A Lyme disease testing program by the Connecticut Agricultural Experiment Station and Connecticut Department of Public Health found the greatest prevalence in Connecticut in 1984 and 1985 was in towns east of the Connecticut River (map below right). The distribution of the tick and the risk of disease have since expanded dramatically (see map next page). Nationally, 17,739 human cases were reported in 2000, 17,029 cases were reported in 2001 and 23,763 cases were reported in 2002. Twelve states accounted for 95% of reported cases. In order of incidence in 2002 they were Connecticut, Rhode Island, Pennsylvania, New York, Massachusetts, New Jersey, Delaware, New Hampshire, Wisconsin, Minnesota, Maine, and Maryland. Lyme disease is underreported and these numbers may represent only 10-20% of diagnosed cases.

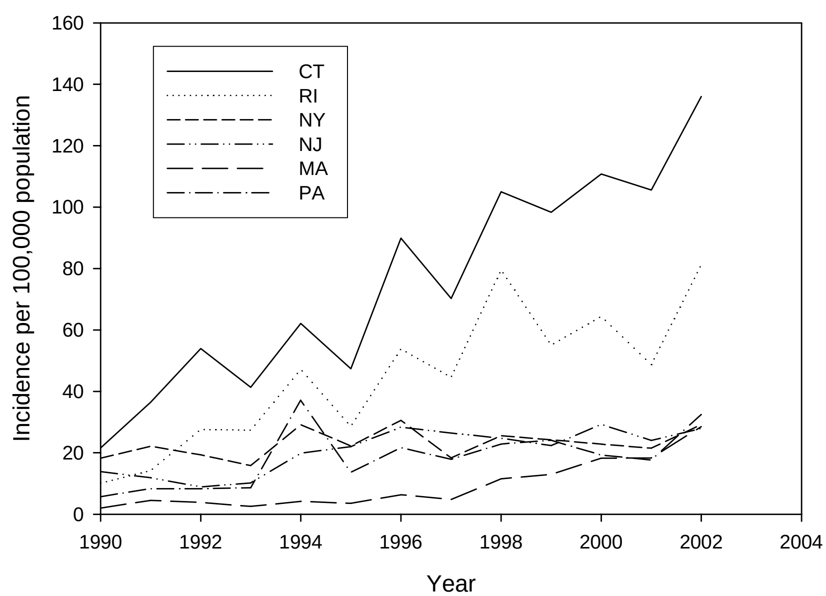

19

The spirochete *Borrelia burgdorferi* (CDC)

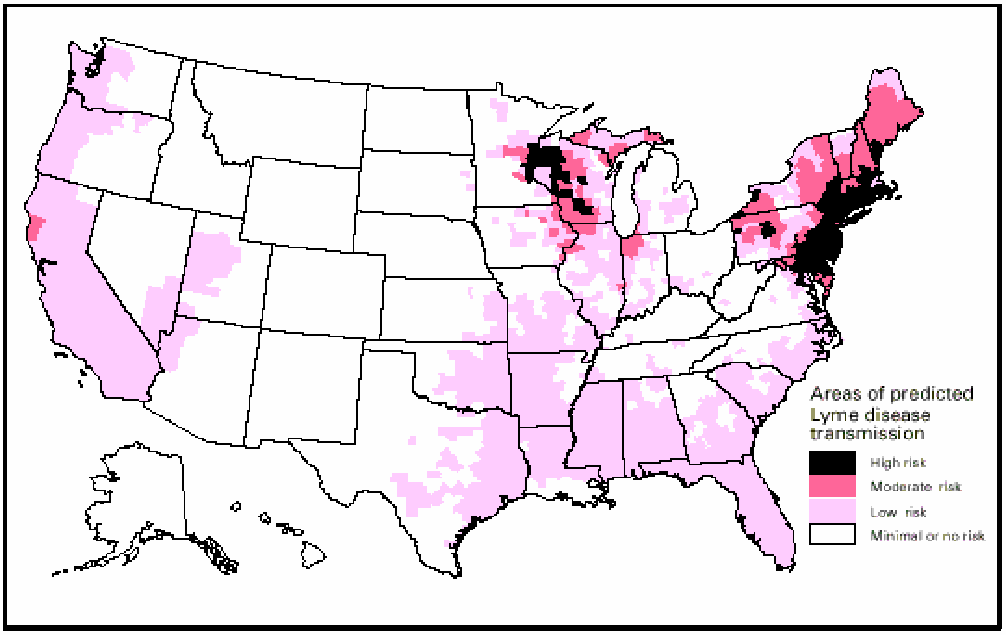
National statistics are available through the CDC website, www.cdc.gov and local statistics may be available through state public health departments or on their websites. Lyme disease affects all age groups, but the greatest incidence of disease has been in children under 14 and adults over 40 years of age. In most cases, Lyme disease symptom onset occurs during the summer months when the nymphal stage of the blacklegged tick is active (see prevention).



Incidence of Lyme disease per 100,000 population by selected northeastern states, 1990-2002. Connecticut and Rhode Island have had the highest incidence of disease, while New York, Connecticut, Pennsylvania, and New Jersey have had the largest number of reported cases.



National Lyme disease risk map with four categories of risk



Note: This map demonstrates an approximate distribution of predicted Lyme disease risk in the United States. The true relative risk in any given county compared with other counties might differ from that shown here and might change from year to year. Risk categories are defined in the accompanying text. Information on risk distribution within states and counties is best obtained from state and local public health authorities.

Clinical signs and symptoms of Lyme disease

Lyme disease is a multisystem disorder with diverse cutaneous, arthritic, neurologic, cardiac, and occasional ocular manifestations. Symptoms that occur within days or weeks following the tick bite reflect localized or early-disseminated infection. Late manifestations become apparent months or years after infection. The major signs and symptoms provided below do not cover all those associated with infection by *B. burgodorferi*. Those who want additional information can consult the literature provided in the bibliography.

Localized infection

20

- Lyme disease is characterized in the majority of patients (70-90%) by an expanding red rash at the site of the tick bite called erythema migrans (or EM). Therefore, the rash serves as a clinical marker for early disease, although the presence of a rash may go unrecognized.
- Erythema migrans may appear within 3 to 30 days (typically 8 or 9 days) after the tick bite. The rash gradually expands over a period of days to a week or more at a rate of ½ to ¾ inch per day and should not be confused with the transient reaction to a tick bite.
- Rashes vary in size and shape, and may occur anywhere on the body, although common sites are the thigh, groin, trunk, and axilla. Many rashes reach about 6 inches in diameter, but some can expand to 8-16 inches or more. The CDC surveillance case definition

specifies that an EM rash must be 2.5 inches or greater in diameter (this definition should not be used as diagnostic criteria).

- An EM may be warm to the touch, but it is usually not painful and is rarely itchy. Swelling, blistering, scabbing or central clearing occur occasionally. The "bull's-eye" appearance usually is noted in less than half the cases and is characteristic of older rashes. The EM will resolve spontaneously without treatment.
- Mild nonspecific systemic symptoms may be associated with the rash in about 80% of cases and include fatigue, muscle and joint pain, headache, fever, chills, and stiff neck. These flu-like symptoms may occasionally occur in the absence of an identified rash and be identified as 'summer flu.' Respiratory or gastrointestinal complaints may occur, but are infrequent.

21

22

Below: Lyme rash (EM) 5 days (left) and 10 days (right) on antibiotic treatment. The rash on the left is the same as above. The rash right is the same EM illustrated on the previous page.

23

24

Early disseminated infection

Lyme disease spirochetes disseminate from the tick bite site through the skin, lymph, or blood to various organ systems, particularly skin, joint, nervous or cardiac tissue. Signs and symptoms may be intermittent, migratory and changing. Nonspecific viral-like symptoms generally mark early-disseminated infection and up to a fourth of patients may develop multiple secondary rashes. Days or weeks after the bite of an infected tick, migratory joint and muscle pain (also brief, intermittent arthritic attacks), debilitating malaise and fatigue, neurologic or cardiac problems may occur. The symptoms appear to be from an inflammatory response to active infection. Multiple EM, headache, fatigue, and joint pain are the most common clinical manifestations noted in early-disseminated disease in children. Multiple components of the nervous system can be affected by *B. burgdorferi*. Early neurologic symptoms develop in about 15% of untreated patients and these can include Bell's palsy (paralysis of facial muscles), meningitis (fever, stiff neck, and severe headache), and radiculoneuropathy (pain in affected nerves and nerve roots, can be sharp and jabbing or deep). Children present less often with facial palsy and more commonly with fever, muscle and joint pain, and arthritis (primarily the knee). Carditis (various degrees of heart block) and rhythm abnormalities may occur in 8% or less of patients. Ocular manifestations may include conjunctivitis and other inflammatory eye problems. Antibodies to *B. burgdorferi* are usually detectable in tests during these manifestations.

25

Late disseminated infection

A year or more after the bite of an infected tick, symptoms of persistent infection in untreated or inadequately treated individuals may include numbness or tingling of the extremities, sensory loss, weakness, diminished reflexes, disturbances in memory, mood or sleep, cognitive function deficits, and an intermittent chronic arthritis (typically swelling and pain of the large joints, especially the knee). Approximately 50-60% of untreated individuals develop arthritis and about 10% of these will progress to chronic arthritis. Attacks of arthritis may last weeks to months with remissions and relapses over a period of several years.

The course and severity of Lyme disease is variable. Mild symptoms may go unrecognized or undiagnosed and some individuals may be asymptomatic (no early illness). The EM rash or subsequent arthritic, cardiac or nervous system problems may be the first or only sign of Lyme disease. Most symptoms eventually disappear, even without treatment, although resolution may take months to over a year. The disease can also be chronic and debilitating with occasional permanent damage to nerves or joints, but is rarely, if ever, fatal. Chronic Lyme disease or post-Lyme disease syndrome is a controversial and unclear constellation of symptoms related to or triggered by infection with *B. burgdorferi*. Disease persistence might be due to a slowly resolving infection, residual tissue damage, inflammation from remains of dead spirochetes, immune-mediated reactions in the absence of the spirochete, co-infection with other tick-borne pathogens, or an alternative disease process that is confused with Lyme disease.

Diagnosis and treatment of Lyme disease

26

A physician should be consulted if Lyme disease is suspected. In the absence of an EM rash, Lyme disease may be difficult to diagnose because its symptoms and signs vary among individuals and can be similar to those of many other diseases. Conversely, other arthritic or neurologic diseases may be misdiagnosed as Lyme disease. Lyme disease is probably both over-diagnosed and under-diagnosed with some patients without Lyme disease convinced they have it and other patients with the disease being told they do not have it. A diagnosis of Lyme disease is based primarily on objective clinical findings. A blood test to detect antibodies to Lyme disease spirochetes (serological testing) can aid or support the diagnosis of the disease. Antibodies to *Borrelia* antigens (parts of the bacteria recognized by the immune system) can usually be detected 3-4 weeks after infection. These tests are not reliable enough to be used as the sole criterion for a diagnosis, however, especially during the early stages of the disease. Tests can give false-negative and false-positive results. Newer tests are more specific, greatly reducing false positive reactions. Reliability of the test improves dramatically in the later stages of the disease as serological reactivity increases, although inaccurate results may still occur. Patients with acute or chronic neurologic or arthritic Lyme disease almost always have elevated antibody levels.

Two stage serological testing for Lyme disease is suggested by many public health organizations:

- Stage One: A relatively sensitive first test by enzyme-linked immunosorbent assay (ELISA) or indirect fluorescent antibody (IFA) test. If negative, no further testing is done. Testing at the time of the Lyme disease rash is unnecessary as many will be negative. Antibiotic treatment early in infection may abrogate the antibody response. An ELISA test provides a quantitative measure antibody levels (measurable color reaction) and for rapid testing of large numbers of samples. An ELISA test measures the reaction to all the antigens in disrupted *Borrelia* or to recombinant antigens, but does not allow identification of which antigens are being bound by antibody and can yield false positives from cross-reactive antibodies. ELISA tests using the C6 peptide of the VslE protein, another protein in *B. burgdorferi* that elicits a strong response by the immune system, may be as sensitive and selective as the two stage testing procedure.
- Stage Two: If the first test is positive or equivocal, a more specific Western immunoblot test is performed to simultaneously demonstrate an antibody response to several *B. burgdorferi* antigens (i.e., proteins recognized by the immune system), which show up as bands on the blot. The Lyme disease spirochete has numerous immunogenic proteins including outer surface proteins (OspA, OspB, and OspC), the 41 kDa antigen on the flagellum, and at least 9 other prominent antigens. The Western blot is labor intensive and requires a subjective interpretation of the results. Although there is an established criterion for a positive blot, there is some disagreement on the number and specific “bands” required for a positive test.

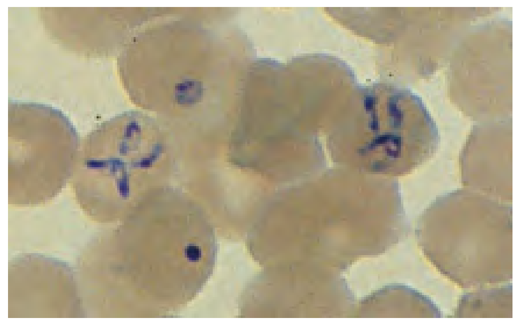
Lyme disease can be treated with one of several antibiotics, including, doxycycline, amoxicillin, cefuroxime axetil, penicillin, ceftriaxone, or cefotaxime. The standard course of treatment is for 14-28 days, depending upon clinical manifestation and drug, though a physician may elect a longer course of treatment. Patients treated in the early stages of the disease usually recover rapidly and completely with no subsequent complications. Oral antibiotics are effective in treating most cases of Lyme disease.

Intravenous antibiotics are indicated for central nervous system involvement and for recurrent arthritis. Full recovery is likely for patients treated in the later stages of the disease but resolution of some symptoms may take weeks even with appropriate treatment. Persistence of some symptoms and inability to determine if the bacteria are eliminated can make decisions on the length of treatment difficult. Courses of antibiotics may have health consequences due to the disruption of the normal intestinal bacteria, allergic reactions, increased sun sensitivity (with doxycycline), gall bladder problems (with ceftriaxone), and infection risks with catheters (extended intravenous antibiotics). Treatment failure may result from incorrect treatment, long delay before treatment, misdiagnosis (not Lyme disease), poor treatment compliance by the patient (did not finish the full course of antibiotics), and infection or co-infection with other tick-borne agents (i.e., *Babesia* or *Anaplasma*). Concurrent babesiosis or ehrlichiosis should be considered in patients with a flu-like illness, particularly fever, chills, and headache, that fails to respond to antibiotic therapy for *Borrelia*. Immunity is insufficient to prevent new infections of Lyme disease with subsequent tick bites that require another course of treatment. Antibody levels generally will decline after treatment, although they may persist for months in some patients after symptoms have resolved.

Southern Tick-Associated Rash Illness (STARI)

A Lyme-like rash has been noted following the bite of the lone star tick, *A. americanum*, in south central and southeastern states and given the name Southern tick-associated rash illness (STARI). The rash is indistinguishable from the rash caused by *B. burgdorferi*. Little is known about this illness. While spirochetes have been observed in about 1-3% of lone star ticks, the bacteria cannot be cultured in the media used for *B. burgdorferi*. A spirochete named *Borrelia lonestari* has been identified in *A. americanum* by DNA analysis and has recently been cultured in tick cell lines.

Human Babesiosis



27

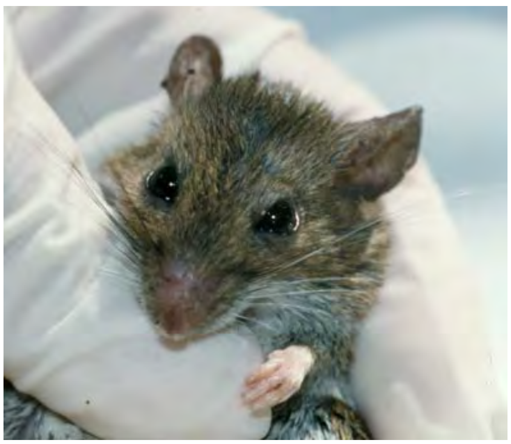
Babesia microti in red blood cells (CDC).

Human babesiosis is a malaria-like illness that is caused by protozoa found in the red blood cells of many wild and domestic animals. Babesiosis is caused by *Babesia microti* in the northeast and upper mid-west United States. *Babesia microti* is a parasite of white-footed mice, as well as voles, shrews, and chipmunks. Other species or variants of *Babesia* are associated with human disease in other parts of the United States (i.e., California and Missouri), Europe, and Asia. Human babesiosis has been recognized since the early 1970's in parts of Massachusetts (particularly Nantucket Island), Block Island, Rhode Island, and the eastern parts of Long Island, New York. Most cases in Rhode Island are reported from the southern coastal regions. The first Connecticut case of human babesiosis was reported from Stonington in 1988 and the majority of cases continue to be reported from the southeastern portion of that state, although recent evidence indicates that the organism has become more widely distributed in the state. The number of confirmed cases has increased in New Jersey in recent years, which may represent increased risk or increased awareness. The disease is reportable in only a few states. The number of reported cases is probably only a small fraction of clinically diagnosed cases with many other subclinical or mild cases going undetected and unreported. Nevertheless, the distribution and number of cases of babesiosis appears to be increasing.

Table 3. Number of reported human cases of babesiosis in select northeastern states, 1997-2001 (compiled from state health department web sites or reports).

State	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
CT	31	45	40	52	56	69				
RI	2	6	18	35	27					
MA	19	66	51	8	18					
NY	26	107	61	72	-					
NJ	3	7	3	15	19					

The white-footed mouse is the primary reservoir for *B. microti*, which is transmitted by *I. scapularis*. While data on the prevalence of infection in *P. leucopus* and particularly in *I. scapularis* is limited to a few studies, babesial parasites have been observed in up to 41% of mice and over 90% can be serologically positive in endemic areas. Infection in mice may be life long. Infections in ticks generally appear to be lower than with *B. burgdorferi*, but in highly endemic areas tick infection by *Babesia* species may be equally prevalent. Maintenance of the parasite seems to require moderate to high tick densities. Most human cases occur during the summer months when nymphs of the blacklegged tick are active. *Babesia* can also be transmitted through blood transfusions from asymptomatic donors.



White-footed mouse with *I. scapularis* ticks.

Both the mouse (or other reservoir competent rodent host such as the meadow vole) and the blacklegged tick are required to complete different aspects of the *Babesia* lifecycle. Larval or nymphal ticks acquire the babesial parasites when feeding on an infected mouse. In the tick gut, male and female gametes unite to form zygotes. Subsequently a stage of the parasite reaches the salivary glands and become dormant until the tick feeds again. The parasite is passed to the next stage of the tick (transstadial transmission). Upon tick attachment, infectious sporozoites are formed and shed in the saliva of the tick. It may require as many as 54 hours of attachment before transmission occurs. Adult *I. scapularis* also can transmit the parasite. During transmission, the sporozoites enter red blood cells, reproduce asexually, and emerge to invade new cells, destroying the infected cells in the process and causing the symptoms associated with babesiosis. Introduction of *B. microti* into another mouse perpetuates the cycle. A female tick does not transmit this parasite to her eggs (transovarial transmission).

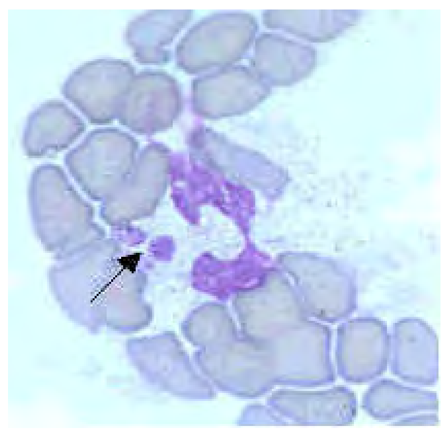
The clinical presentation of human infection ranges from subclinical to mild flu-like illness, to severe life-threatening disease. Infection often is accompanied by no symptoms or only mild flu-like symptoms in healthy children and younger adults. The disease can be severe or fatal in the elderly, the immune suppressed (HIV infection or use of immunosuppressive drugs), and people without spleens. The greatest incidence of severe disease occurs in those older than 40 years of age. Symptoms of babesiosis include fever, fatigue, chills, sweats, headache, and muscle pain beginning 1-6 weeks after the tick bite. Gastrointestinal symptoms (nausea, vomiting, diarrhea, abdominal pain), respiratory symptoms (cough, shortness of breath), weight loss, dark urine, and splenomegaly also may occur. Complications such as acute respiratory failure, congestive heart failure and renal failure have been associated with severe anemia and high levels of infected cells (parasitemia). Up to 80% of red blood cells can be infected in a splenectomized patient, although 1-2% parasitemia is typical in those with intact spleens. Illness may last weeks to months and recovery can take many months. Co-infection with *B. microti* and *B. burgdorferi* can result in overlapping clinical symptoms, a more severe illness, and a longer recovery than either disease alone.

A specific diagnosis of babesiosis can be made by detection of the parasites in Giemsa-stained blood smears and confirmed serologically by an indirect fluorescent antibody (IFA) test. A complete blood count (CBC) is useful in detecting the hemolytic anemia and/or thrombocytopenia (decrease in blood platelets) suggestive of babesiosis. Elevated liver function tests may be present. The parasite can also be detected by polymerase chain reaction (PCR) assay. The drugs of choice in the treatment of babesiosis are oral clindamycin plus quinine sulfate or a combination of oral azithromycin and atovaquone. Adverse effects (i.e., tinnitus, vertigo, lower blood pressure, gastrointestinal upset) are commonly associated with clindamycin and quinine use and some patients cannot tolerate the treatment. The combination of azithromycin and atovaquone is better tolerated. Severely ill patients should be given intravenous clindamycin and quinine and an exchange blood transfusion. Following drug treatment, the parasites usually are eliminated and there is no recurrence of disease. In immunocompromised individuals, parasitemia may persist for months and possibly years following recovery from illness and relapse may occur. Currently, individuals who have ever been diagnosed with babesisois are excluded from donating blood.

Human Ehrlichiosis

The Ehrlichiae are a group of bacteria with several genera and species known to cause disease in dogs, cattle, sheep, goats, horses and humans. These bacteria invade different types of white blood cells (leucocytes) and the disease is often named from the primary type of infected blood cell, including granulocytes or monocytes. Veterinarians have known about canine ehrlichiosis, caused by *E. canis* and transmitted by the Brown dog tick since 1935. Two principal forms of ehrlichiosis in humans currently are recognized in the United States. Human monocytic ehrlichiosis (HME) is caused by *Ehrlichia chaffeensis*. Human granulocytic ehrlichiosis (HGE) is caused by *Anaplasma phagocytophilum* (some cases by *Ehrlichia ewingii*) and accounts for about two-thirds of all ehrlichiosis cases in the U.S. Surveillance for ehrlichiosis in most states is sparse. Ehrlichiosis was added to the national list of reportable diseases in 1999. In Connecticut, there were 544 confirmed cases of HGE reported from 1995-2002. Cases were distributed across all eight Connecticut counties. In New York, both HGE and HME have been reported mainly from the lower Hudson River Valley and eastern Long Island.

Human granulocytic ehrlichiosis was first described from patients in Wisconsin and Minnesota in 1994. The blacklegged tick is the principal vector for HGE (or technically Anaplasmosis) in the northeastern and upper mid-western states. Therefore, most cases of HGE have been reported from states where Lyme disease is highly endemic, particularly Connecticut, New York, and parts of Minnesota and Wisconsin. The western blacklegged tick is the vector in northern California. Laboratory studies indicate transmission can occur within 24 hours of tick attachment and possibly within 8 hours. A single tick has been demonstrated to simultaneously transmit both *B. burgdorferi* and *A. phagocytophilum*.

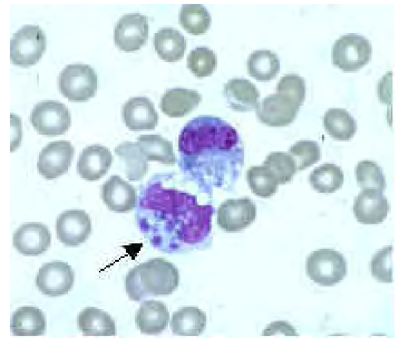


28

Morulae of *A. phagocytophilum* in cytoplasm of neutrophil (CDC).

Human monocytic ehrlichiosis, caused by *E. chaffeensis*, was first recognized in the United States in 1986 in a patient who was bitten by a tick in Arkansas. Lone star ticks are the vector for *E. chaffeensis* in south central and southeastern regions of the country where most cases of HME occur. The DNA of *E. chaffeensis* has been detected in lone star ticks from Connecticut and Rhode Island, so cases of HME may occur in southern New England.

Most cases of ehrlichiosis occur in May, June, or July with 80-90% of cases occurring between April and September. This corresponds to the activity of nymphal *I. scapularis* and adult lone star ticks. Symptoms for both types of ehrlichiosis are non-specific and include fever, headache, muscle pain, nausea, vomiting, and malaise. Initial symptoms appear 5-10 days after the tick bite. Illness may be mild, moderate or severe. Some cases require hospitalization and there have been fatalities. A rash is uncommon in adults, but a rash has been observed in many HME cases in children. Most patients show a decrease in their white blood cell (leukopenia) and blood platelet (thrombocytopenia) counts and an increase in liver enzymes. The number of clinical cases increases with age. The highest rates have been observed for patients 50 years of age or older. Severe cases and fatalities have been reported across all age groups. HME has been confused with Rocky Mountain spotted fever (RMSF). There are no absolute clinical criteria to distinguish Human monocytic ehrlichiosis from RMSF although patients with HME are much less likely to have a rash (10-15 percent) and are more likely to be leukopenic. A diagnosis of ehrlichiosis should be considered for patients with a flu-like febrile illness and possible exposure to *I. scapularis*. Co-infections by the agents of HGE and Lyme disease have been reported and may result in more severe disease. A diagnosis of ehrlichiosis can be confirmed by a serological test, observing the organism in white-blood cells, culturing the organism, or amplification of the DNA of the ehrlichia organism by polymerase chain reaction (PCR). Tests may be negative in the early stages of disease and are more reliable in specimens obtained during the 3 third week of illness. The drug of choice for the treatment of ehrlichiosis is doxycycline (tetracycline may also be used) and should be started upon suspicion or clinical diagnosis of ehrlichiosis. Response to antibiotic therapy is rapid with fever subsiding in 24-72 hours. The use of doxycycline in children under 8 years of age is generally not recommended because it may stain the permanent teeth, but could be used in severe cases. Rifampin has been used successfully when doxycycline cannot be used.

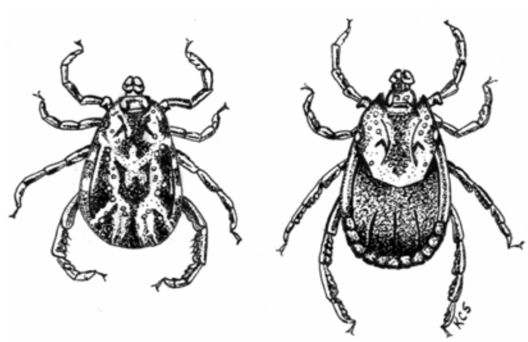


29

Morulae of *E. chaffeensis* in cytoplasm of monocyte (CDC).

Rocky Mountain Spotted Fever

Rocky Mountain spotted fever (RMSF) is caused by *Rickettsia rickettsii*, a type of bacterium that occurs throughout the continental United States, southern Canada, Mexico and Central America and parts of South America. Although the disease was first recognized in 1896 from virulent cases in Idaho and Montana, the name is somewhat misleading as only a small proportion of current cases are reported from the Rocky Mountain region. In the U.S., most cases of RMSF occur in the South Atlantic and West Central states. North Carolina and Oklahoma have the highest rates of RMSF accounting for 35% of the total cases reported to the CDC during 1993-1996. The majority of RMSF cases are associated with the American dog tick. In the western U.S., the vector is the Rocky Mountain wood tick, *D. andersoni*.



RMSF is relatively uncommon in New England. Between 1997 and 2002, based on figures in the CDC's Morbidity and Mortality Weekly Report (MMWR), approximately 3,520 human cases were reported in the United States, of which 28 (less than one percent) were from New England. More cases of RMSF are reported from the mid-Atlantic states, but these still accounted for only 6.7% of the total. Few ticks are infected. Scientists at the Connecticut Agricultural Experiment

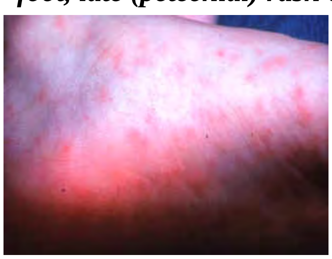
Station found that less than 1% of 3,000 American dog ticks examined in Connecticut had spotted fever-group organisms, and not all spotted fever group rickettsiae are infectious to humans.

Table 4. Number of reported human cases of Rocky Mountain spotted fever in northeastern states, 1997-2002. (Data compiled from MMWR and/or state health department web sites; 2002 numbers provisional. One case was reported from New Hampshire in 2001).

State	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
CT	3	2	0	0	0	0	3			
RI	1	0	4	0	0	4				
MA	1	0	2	2	2	6				
NY	14	13	14	9	4	18				
NJ	9	12	7	12	9	2				
PA	16	13	18	25	20	20				
US total	409	365	579	495	695	961				

Children are particularly at risk for RMSF with two-thirds of the cases in patients under 15 years of age. Like Lyme disease, the highest rate in children is in the 5 to 9 year old age group. Symptoms usually appear within 2 to 9 days after a tick bite. Patients experience a variety of symptoms including sudden fever (90%), severe headache (89%), muscle pain (83%), and rash (78%). The rash may begin as small, pink, non-itchy spots (macules) and then develop into the spotted (petechial) rash characteristic of RMSF. The rash may include the palms (50%) and soles of the feet. The rash may not be present or faint when a physician initially examines a patient. Some patients (10-15%) never develop a rash. The classic spotted rash of RMSF appears after about six days or later. Prompt antibiotic treatment with doxycycline, tetracycline, or chloramphenicol for suspected cases is important because RMSF is fatal in 15-20% of untreated cases. Delays in diagnosis because of the absence of the rash or no knowledge of a tick bite could be dangerous. RMSF is made more severe with inadvertent use of sulfonamides. In recent years, about 1-4% of cases in the U.S. have been fatal. A clinical diagnosis may be confirmed serologically or by PCR, but antibodies may not yet be present when a patient is seen by a physician early in the illness.

Below: Examples of spotted fever rash (CDC). Left to right: early (macular) rash on sole of foot, late (petechial) rash on palm and forearm, and rash on hand of a child.



Tick Paralysis

A toxin produced by certain *Dermacentor* ticks during feeding can cause a progressive, ascending paralysis, which is reversed upon removal of the tick. Recovery is usually complete. Paralysis begins in the extremities of the body with a loss of coordination and inability to walk. It progresses to the face with corresponding slurred speech, and finally shallow, irregular breathing. Failure to remove the tick can result in death by respiratory failure. Cases appear more frequently in young girls with long hair where the tick is more easily overlooked. Most cases of tick paralysis are caused by the Rocky Mountain wood tick (*Dermacentor andersoni*) in northwestern states. The American dog tick has also been known to cause tick paralysis.

Tularemia

The bacterium, *Francisella tularensis*, that causes tularemia (Rabbit Fever or Deer Fly Fever) is transmitted by the bite of several species of ticks or bites from deer flies. Ticks associated with tularemia include the American dog tick, *D. variabilis*; lone star tick, *A. americanum*; and Rocky Mountain wood tick, *D. andersoni*. Most cases occur during the summer (May-August), when arthropod transmission is common. The disease also may be contracted while handling infected dead animals (particularly while skinning rabbits), eating under cooked infected meat, or by an animal bite, drinking contaminated water, inhaling contaminated dust, or having contact with contaminated materials. Natural reservoirs of infection include rabbits, hares, voles, mice, water rats, and squirrels. Tularemia was removed from the list of reportable diseases after 1994, but was reinstated in January 2000 because of its potential as a bioterrorism agent.

Tularemia occurs throughout the United States. There have been fewer than 200 cases reported each year during the first half of the 1990s and again in 2000 and 2001. Most cases have been reported from the central states of Missouri, Arkansas, and Oklahoma. With the exception of outbreaks of pneumonic tularemia on Martha's Vineyard that appear related to gardening, landscaping or mowing activities that may have stirred up contaminated dust, reports of this disease are not common in New England, although sporadic cases and outbreaks may occur. There have been pneumonic cases resulting from accidentally running over a rabbit with a lawnmower.


30

All persons are susceptible to tularemia. The clinical symptoms of tularemia depend upon the route of infection. With infection by a tick, an indolent ulcer often occurs at the site of the bite with occasional swelling of the regional lymph nodes. Fever is the most commonly reported symptom. Diagnosis usually is made clinically and confirmed by an antibody test. Antimicrobials with demonstrable clinical activity against *F. tularensis* include the fluorinated quinolones such as ciprofloxacin as well as streptomycin and gentamicin. While tetracycline or chloramphenicol also may be used, they are less effective and relapses occur more frequently.

Powassan Encephalitis

Powassan virus, a *Flavivirus,* is the sole member of the tick-borne encephalitis (TBE) group present in North America. The disease is named after a town in Ontario, Canada where it was first isolated and described from a fatal case of encephalitis in 1958. Documented cases of Powassan encephalitis (POW) are rare, but the disease may be more common than previously realized. While there were only 27 known cases in North America between 1958-1998 (mainly in Canada and New York state), four additional cases were identified in Maine and Vermont from 1999-2001 as a result of increased testing for West Nile virus. The ages of these recent New England cases ranged from 25 to 70 years. Previously, the latest recognized symptomatic cases occurred in New York in 1978 and Massachusetts in 1994. POW presents as meningitis or meningoencephalitis progressing to encephalitis with fever, convulsions, headache, disorientation, lethargy, with partial coma and paralysis in some patients. The disease has a fatality rate of 10-15% and may result in severe long-term disability in the survivors. The principal tick vector appears to be *Ixodes cookei* with cases occurring from May through October.

Patients generally have a history of tick bite, or a history of exposure to tick habitat or exposure to hosts such as squirrels, skunks, or woodchucks. The blacklegged tick is a competent vector of Powassan virus in the laboratory. A virus very closely related to and apparently a separate subtype of the Powassan virus has been isolated from *I. scapularis*, but the prevalence and public health significance of this virus is unknown.

Tick-borne Relapsing Fever

Soft ticks of the genus *Ornithodoros* transmit relapsing fever, caused by *Borrelia hermsi*, or a group of tick-adapted species of the spirochete. Disease is characterized by cycles of high fever and is treated with antibiotics. Relapsing fever ticks are found in rodent burrows, nests, and caves through the western United States. They can live for many years without feeding. Human cases are often associated with people staying in shelters or cabins infested with these ticks. Relapsing fever may be a risk for northeastern residents vacationing or visiting the western U.S..

Colorado Tick Fever

Colorado tick fever, caused by a virus, occurs in mountainous areas of the western United States and Canada. There are 200-400 cases each year. Scientists believe cases are underreported. The virus is transmitted by female Rocky Mountain wood ticks. Symptoms begin with an acute high fever, often followed by a brief remission, and another bout of fever lasting 2-3 days. Other symptoms included severe headache, chills, fatigue, and muscle pain. Illness may be mild to severe, but is self-limited and is not fatal. Treatment is symptomatic. Recovery occurs over several weeks but occasionally may take months.

Bartonella Infection

The genus *Bartonella* includes at least 16 species of vector-associated, blood-borne bacteria that infect a wide variety of domestic and wild animals, including rodents. Several are known human pathogens. For example, *Bartonella henselae*, the agent of cat scratch disease, is transmitted to cats by fleas and generally to humans by bites or scratches from infected cats. The DNA of various *Bartonella* have been found in ticks, including *I. scapularis* and *I. pacificus*, clearly ingested during feeding, but the ability of ticks to transmit these bacteria in the laboratory or field still needs to be determined.

Lyme Disease in Domestic and Companion Animals

Swollen joints in a dog with Lyme disease (31).

Domestic animals (dogs, cats, horses, cows, and goats) can become infected with Lyme disease bacteria and develop clinical disease. Lameness and swollen joints, fever, lymph node enlargement, reduced appetite, and a reluctance to move are the usual symptoms in these animals. Disease is more common in dogs and relatively less frequent in cats. Most dogs in a Lyme disease endemic area will eventually become infected (based on positive serology) due to their high exposure to ticks and some will develop disease each year. Limb and joint arthritis is the most frequent symptom in canine Lyme disease; cardiac, neurological, ophthalmic, and a unique renal involvement is less common. Lyme nephritis in dogs often results in the death of the animal, even with aggressive treatment. Animals are treated with antibiotics (tetracycline or penicillin-group) and nonsteroidal anti-inflammatory drugs for symptomatic relief. Most dogs respond dramatically to antibiotic treatment within days and will make a complete recovery. Chronic disease appears rare and a lack of response to therapy may suggest another diagnosis. Other disease processes, which should be ruled out, include rheumatoid arthritis, infectious arthritides, and other tick-borne diseases such as Rocky Mountain spotted fever and ehrlichiosis. However, studies have shown infection and antibody titers may persist in dogs after efficacious treatment. It is not clear if a reoccurrence of disease is due to another tick exposure or from the initial infection. Some data suggests that treatment in the absence of clinical disease for seropositive dogs or those with a history of tick bite may be indicated. Prevention of disease in companion animals is covered in the host management section.

Additional sources of information about tick-associated diseases

The Centers for Disease Control and Prevention, National Center for Infectious Diseases, Division of Vector-Borne Infectious Diseases, P.O. Box 2087, Fort Collins, Colorado, 80522 and Division of Viral and Rickettsial Diseases, 1600 Clifton Road, NE, MS G-13, Atlanta, Georgia 30333. The CDC-NCID web site (www.cdc.gov/ncidod/index.htm) provides details on the natural history, epidemiology, signs & symptoms, diagnosis, treatment, prevention & control for several zoonotic diseases.

State health departments can provide information on the incidence of Lyme disease and other tick-borne illnesses in the state. There is usually a division or department that handles Lyme disease and other vector-borne diseases. Statistics are sometimes available on a department's web site.

Lyme disease foundations or groups can provide information or patient support. These include the American Lyme Disease Foundation, Inc. (ALDF), Mill Pond Offices, 293 Route 100, Somers, New York 10589 (telephone 914-277-6970, fax 914-277-6974, e-mail: inquire@aldf.com, web site: www.aldf.com) and the Lyme Disease Foundation (LDF), One Financial Plaza, Hartford, CT 06103 (telephone 860-525-2000, hotline 800-886-LYME, e-mail: Lymefind@aol.com, website: www.Lyme.org).

Personal Protection

Tick Bite Prevention

Personal protection behaviors, including avoidance and reduction of time spent in tick-infested habitats, using protective clothing and tick repellents, checking the entire body for ticks, and promptly removing attached ticks before transmission of *Borrelia* spirochetes can occur, can be very effective in preventing Lyme disease. However, surveys and the continuing incidence of disease suggest that few people practice these measures with sufficient regularity. Preventive measures are often considered inconvenient and, in the summer, uncomfortable. Despite the efficiency of tick repellents, particularly with DEET applied to skin and permethrin applied to clothing, they are under-utilized.

Checking for ticks and prompt removal of attached ticks is probably the most important and effective method of preventing infection!

Important points to consider in tick bite prevention and checking for ticks include:

Tick Behavior

- Most Lyme disease cases are associated with the bite of the nymphal stage of the blacklegged tick, of which 10-36% may be infected with Lyme disease spirochetes.
- Nymphal blacklegged ticks are very small (about the size of a pinhead), difficult to spot, and are active during the late spring and summer months when human outdoor activity is greatest. The majority (about 75%) of Lyme disease cases are associated with activities (play, yard or garden work) around the home.
- Adult blacklegged ticks are active in the fall, warmer days in the winter, and in the spring when outdoor activity and exposure is more limited. They are larger, easier to spot, and therefore associated with fewer cases of Lyme disease (even though infection rates are higher).
- Ticks do not jump, fly or drop from trees, but grasp passing hosts from the leaf litter, tips of grass, etc. Most ticks are probably picked up on the lower legs and then crawl up the body seeking a place to feed. Adult ticks will, however, seek a host (i.e., deer) in the shrub layer several feet above the ground.
- Children 5-13 years of age are particularly at risk for tick bites and Lyme disease as playing outdoors has been identified as a high-risk activity. Take notice of the proximity of woodland edge or mixed grassy and brushy areas from public and private recreational areas and playing fields. While ticks are unlikely to be encountered in open fields, children chasing balls off the field or cutting through woods to school may be entering a high-risk tick area.
- Pets can bring ticks into the home, resulting in a tick bite without the person being outdoors. A veterinarian can suggest methods to protect your pets. Engorged blacklegged ticks dropping off a pet will not survive or lay eggs in the house, as the air is generally too dry.


32


33

Prevention

- Wear light-colored clothing with long pants tucked into socks to make ticks easier to detect and keep them on the outside of the clothes. Unfortunately, surveys show the majority of individuals never tuck their pants into their socks when entering tick-infested areas. It is unclear just how effective this prevention measure is without the addition of a repellent. Larval and nymphal ticks may penetrate a coarse weave sock. Do not wear open-toed shoes or sandals.
- Use a DEET or permethrin-based mosquito and tick repellent, which can substantially increase the level of protection (see section on repellents). This approach may be particularly useful when working in the yard, clearing leaves, and doing other landscaping activity with a high risk of tick exposure. A separate set of work or gardening clothes can be set aside for use with the permethrin-based clothing tick repellents.
- When hiking, keep to the center of trails to minimize contact with adjacent vegetation.
- Unattached ticks brought in on clothing can potentially result in a later tick bite. Blacklegged ticks can survive for many days in the home depending upon the humidity. In the laboratory, nymphal *I. scapularis* can survive for over 6 months at 93-100% relative humidity (RH), but over half will die in less than 4 days at 65% RH (RH in modern homes is generally <65%). On returning home, remove, wash and dry the clothing. Many blacklegged ticks and lone star ticks can survive a warm or hot water wash, but they cannot withstand one hour in a hot dryer.
- Carefully inspect the entire body and remove any attached ticks (see below). Ticks may feed anywhere on the body. Tick bites are usually painless and, consequently, most people will be unaware that they have an attached tick without a careful check. Also, carefully inspect children and pets. A hypersensitivity reaction to tick bite may aid detection in a few individuals, but most people will be unaware a tick is attached and feeding.

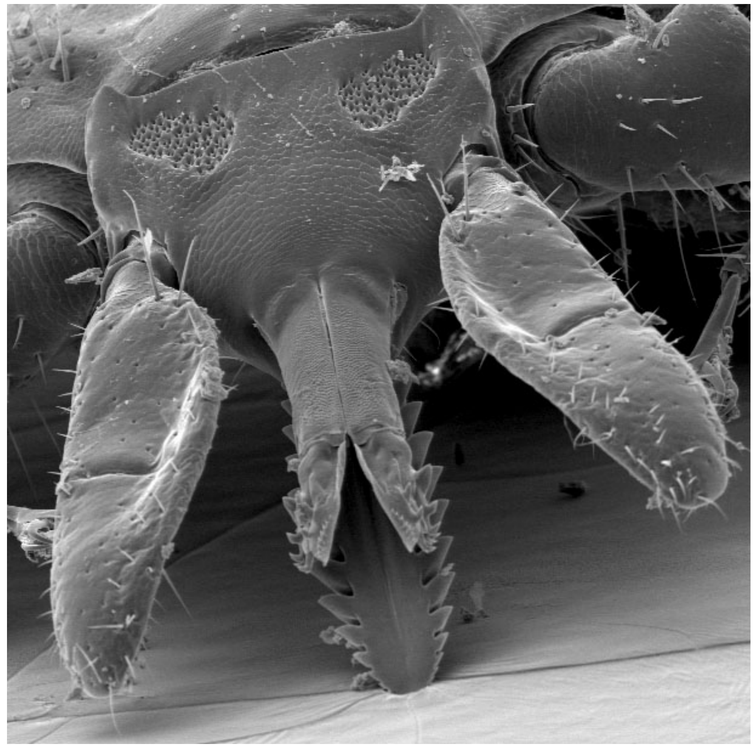
34

Transmission

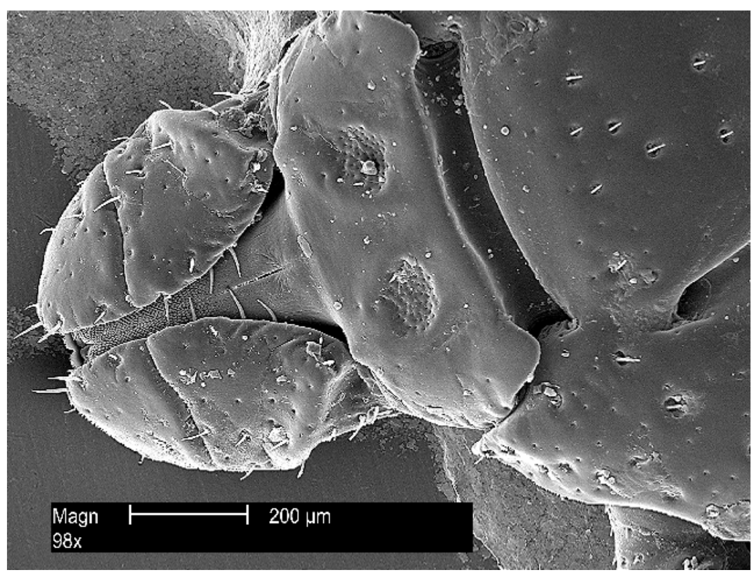
- It takes 36-48 hours or more for transmission of *B. burgdorferi* or *B. microti* to occur from an attached tick and not all ticks are infected. Therefore, a tick bite does not necessarily mean a person will get infected. Prompt removal of an attached tick will reduce the chance of infection. However, transmission of the agent of ehrlichiosis can occur within 24 hours.
- Lyme disease may result from an unrecognized tick rather than the tick that was detected and removed, as the primary Lyme disease rash is sometimes found at a different location than the detected tick. It is not unusual to have more than one tick attached at one time.
- In some areas, tick-testing services for the presence of Lyme spirochetes may be available from a government or commercial laboratory. The detection of spirochetes in a tick does not necessarily indicate transmission and an estimate of risk is difficult without a measure or estimate of length of attachment.

How a Tick Bites and Feeds

The term tick bite may be misleading as ticks do not bite and depart or feed rapidly like a mosquito. Ticks attach and feed gradually over a period of several to many days. Once a tick has found a suitable place to feed, it grasps the skin, tilts the body at a 45-60° angle, and begins to cut into the skin with the paired chelicerae. The palps splay outwards on the skin surface. After the chelicerae and hypostome penetrate the skin, they become encased in "cement" secreted by the tick. The cement serves to hold the mouthparts in place while the tick feeds. Mouthparts on larval and nymphal ticks are small with less penetration and produce a smaller host reaction. Adult *Ixodes* and *Amblyomma* ticks have long mouthparts that can reach the subdermal layer of skin, produce a larger reaction, and make the tick harder to remove. Insertion of the mouthparts often takes around 10-30 minutes, but can take longer (1-2 hours). The reaction to a feeding tick may make the tick appear imbedded, but only the slender mouthparts actually penetrate the skin.



35



36

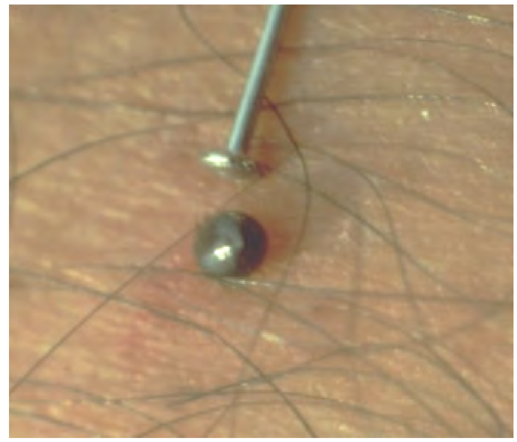
Scanning electron micrographs of the mouthparts of the blacklegged tick (top) and American dog tick (bottom). On the top picture the two palps are spread apart showing the upper two chelicerae and the lower hypostome bracketing the oral cavity.

Physical and enzymatic rupture of tissue creates a lesion or cavity under the skin from which blood is imbibed. A variety of pharmacologically active compounds that aid the feeding process and possibly increase pathogen transmission are introduced in the tick's saliva (e.g., blood platelet aggregation inhibitors, anticoagulants, anti-inflammatory and immunosuppressive agents, enzymes, and vasodilators to increase blood flow). Feeding is not continuous and most of the blood meal is taken up during the last 12-24 hours of feeding. The body weight of a feeding female tick can increase 80-120 times. Male ticks are intermittent feeders, take smaller amounts of blood, and do not change appreciably in size (male *I. scapularis* do not need to feed and are rarely found attached).

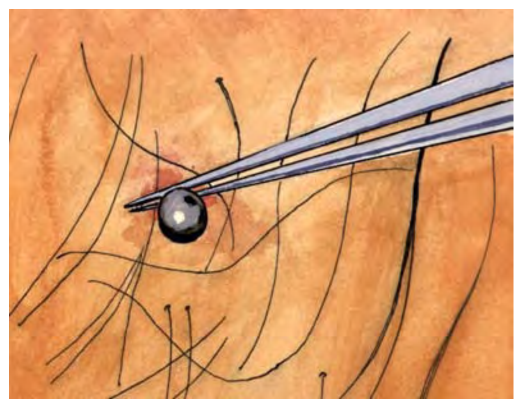
The probability of transmission of Lyme disease spirochetes increases the longer an infected tick is attached (0% at 24 hours, 12% at 48 hours, 79% at 72 hours, and 94% at 96 hours in one recent study). The estimated average time for attachment before detection and removal was 30 hours for nymphs and 10 hours for adult ticks, nymphal ticks were twice as likely as adult ticks to be partially engorged.

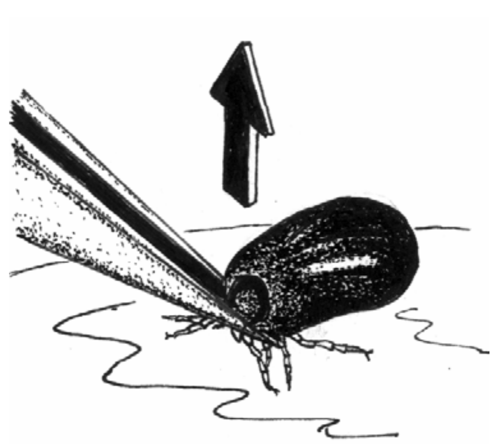
Tick Removal

To remove a tick, use thin-tipped tweezers or forceps to grasp the tick as close to the skin surface as possible. Pull the tick straight upward with steady even pressure. This should remove the tick with the mouthparts intact. Commercial tick removal devices have been shown to vary widely in their efficacy for removing nymphal blacklegged ticks: some worked in every attempt, some failed in every attempt, some were in between. Tick removal devices that have been shown to successfully remove *I. scapularis* nymphs attached for 48 hours in all attempts in a recent study include #4 forceps, Original Tick Kit (Tick Kit, Inc.), Pick-Tick (Encepur, Chiron), Pro-Tick Remedy (SCS, Ltd.), and the Nick Nipper (Josyln Designs, Inc.). Squeezing the tick will not increase the risk of infection.



37





The mouthparts of larval and nymphal ticks will seldom be left in the skin. With proper removal, they usually come out intact. Adult ticks are more difficult to remove intact because of the the longer mouthparts. If the mouthparts break off, it will not change the chance of getting Lyme disease. Spirochetes in the mouthparts or cement plug, and therefore the feeding lesion, means the tick was removed too late and transmission has already occurred. Other methods of tick removal (e.g. petroleum jelly to suffocate the tick, heat from matches to make the tick back out or gasoline or other chemicals) are not effective.

After removing the tick:

- Disinfect the area with alcohol or other skin disinfectant; a topical antibiotic may also be applied.
- Save the tick for reference and in some cases testing (if available). A live tick can be placed in a crush proof container with a blade of grass to keep it alive (a sealable plastic bag will also work). A small plastic vial is best.

Dead ticks are tested by DNA methods and should be held dry in a crush proof container. For long-term storage, ticks are held in 70-80% ethyl alcohol (rubbing alcohol will work). Avoid placing ticks in black film containers or using cellophane tape to mount the tick to paper, a note card or a slide if it needs to be identified or tested. Ticks under cellophane tape are difficult to handle. If the tick is removed by a health professional, ask to keep the tick for future reference or testing.

- Note the site and date of the bite.
- Watch for signs and symptoms of Lyme disease or consider prophylactic treatment if tick is engorged or infected (see below). Watch for evidence of secondary infection.

Localized tick bite reactions develop rapidly and can sometimes resemble a small Lyme disease rash, but these transient reactions generally disappear in 24-48 hours and do not continue to expand like an EM rash. Mouthparts left in the skin may cause irritation as the body attempts to absorb or reject the foreign tick tissue (analogous to a minute splinter that is difficult to remove) with a slight risk of secondary bacterial infection. A foreign body granuloma may persist for weeks, especially if the mouthparts remain. A physician should be consulted if there is evidence of infection.

Tick Bite Prophylaxis

The prophylactic use of antibiotics following a tick bite has not generally been recommended by most medical authorities in the U.S. as the chance of Lyme disease from a known tick bite with *I. scapularis* appears low (< 5%; 0% with flat ticks, 10% with engorged ticks in one study). Only 14-32% of patients diagnosed with Lyme disease remember a feeding tick.

Factors against prophylactic (preventative) treatment:

- The infection status and degree of engorgement of the tick, and therefore the risk of infection, are generally not known. Routine testing of ticks attached <24-36 hours is not necessary.
- Not infrequently, ticks submitted for identification or testing turn out not to be a tick (i.e., a scab, beetle, spider , etc.) or a tick that is not a vector for Lyme disease (better training of physicians or clinic staff to recognize major tick species is important).
- There may be a risk of an adverse reaction to the antibiotic.

Factors in favor of prophylactic (preventative) treatment:

- A single 200 mg dose of doxycycline within 72 hours following a tick bite can prevent Lyme disease. A single dose is less likely to stain teeth in children or produce adverse reactions.
- For a partly or fully engorged blacklegged tick, the risk of infection may be high. It can equal the prevalence of infection in the tick, which can be as high as 36% for a nymphal tick and greater than 60% for an adult tick.
- If a tick is infected (determined by testing at a competent laboratory) and the tick is engorged, infection by Lyme disease spirochetes is highly likely and treatment may be seriously considered. However, results from tick testing may not be available in time for prophylactic treatment or Lyme disease symptoms may already be evident.

Repellents

DEET

The primary active ingredient in most insect/tick repellents today is DEET (N,N-diethyl-3-methylbenzamide, also known as N,N-diethyl-m-toluamide). DEET is the most effective, broad-spectrum repellent ever discovered, effective against mosquitoes, biting flies, chiggers, fleas and ticks. The U.S. Environmental Protection Agency (EPA) estimates that over one-third of the U.S. population will use a DEET-based product. There are approximately 230 products containing DEET registered with the EPA (e.g., *Cutter, Off, Repel, Muskol, Ben's, Sawyer, and others*). Products range in concentration from 5% to 100% DEET and are available as an aerosol can, pump spray bottle, stick, lotion, cream, or towelette for application to skin or clothing. The duration of activity increases with the concentration used.

There are few firm guidelines on the concentration a consumer should use. The effectiveness of DEET on the skin is influenced by the concentration of DEET, absorption through the skin, evaporation, sweating, air temperature, wind, abrasion of the treated surface by rubbing or washing and the arthropod for which protection is desired. A recent study found that a repellent with 23.8% DEET provided an average of 302 minutes of protection against mosquitoes. Higher concentrations generally provide longer protection, but increasing the concentration does not proportionally increase protection time. Several controlled-release or extended-release DEET formulations have been developed which decrease skin absorption and increase protection time. These products may provide longer protection similar to products with a higher concentration of DEET. All active ingredients and their concentrations are listed on the product label.

DEET and ticks

DEET will repel ticks and decrease the chances of tick bite, but depending upon the concentration, it may not provide total protection against the blacklegged tick. Not all products with DEET are labeled for ticks. Little is known about the effectiveness of different concentrations of DEET against *I. scapularis*. Concentrations of DEET that might discourage tick attachment may not deter a tick from walking across the skin to unexposed and untreated areas. Some protection against tick attachment appears to come from the oily or creamy nature of some products. When applied to clothes, 30% and 20% DEET was found to be 92% and 86% effective against *I. scapularis,* respectively, but skin applications were reported to be only 75 to 87% effective against crawling ticks in a second study. For blacklegged ticks, DEET concentrations around 30 to 40% will probably be most effective for general use. A recent evaluation of repellent products by Consumer Reports found a 33% DEET cream-based formulation was effective against nymphal *I. scapularis* for at least 9 hours, while 100% DEET kept ticks off for up to 4 hours. Lower concentrations of DEET were also found repellent. The effectiveness of various concentrations of DEET against *I. scapularis*, especially higher (>50%) and lower (<20%) concentrations, needs to be examined more closely under natural use conditions.

Safe Use of DEET

DEET has been used by many millions of Americans for 40 years and the incidence of adverse reactions is low. The Environmental Protection Agency (EPA) conducted a review of DEET and believes that normal use of DEET does not present a health concern to the general population when used according to label directions (Reregistration Decision document available from the EPA). Some allergic, toxic, and neurological reactions to DEET have been reported in medical literature, but toxic encephalopathic reactions are rare. Reported adverse reactions appear to have involved high concentrations of DEET, over application of product contrary to label directions, or ingestion of product. Repeated applications have occasionally produced tingling, mild irritation or contact dermatitis. Important points in the safe use of DEET include:

- Follow the directions and precautions given on the repellent label.
- Apply DEET sparingly to exposed skin, and spray on clothing when possible.
- Do not use DEET under clothing or over cuts, wounds, or irritated skin.
- Use the lowest concentration necessary for protection and estimated time of needed protection. Minimize the use of higher concentrations on the skin. Lower concentrations, such as 10% DEET, will provide approximately 2 hours of protection against mosquitoes (but may be less effective against ticks), while a concentration of 24% will provide about 5 hours of protection against mosquitoes.
- A concentration of DEET up to 30% for adults and children over 2 years of age is the maximum concentration currently recommended by the American Academy of Pediatrics (AAP).
- The AAP does not recommend the use of DEET on children under 2 months of age. Apply sparingly to small children.
- AAP precautions suggest DEET should not be used in a product that combines the repellent with a sunscreen as sunscreens are often reapplied periodically. DEET is not water-soluble and will last many hours. Reapplications of DEET may increase the possibility of a toxic reaction to DEET.
- Apply the product to a child yourself. Repellent on a child's hands can end up in the eyes or mouth.
- Wash the hands with soap and water after applying DEET.
- People with certain skin conditions should be cautious about the use of DEET.
- Wash off the repellent with soap and water when returning indoors.
- DEET generally won't harm cotton, wool or nylon. DEET can damage some synthetic fabrics (acetate, rayon and spandex), plastics (watch crystals and eyeglass frames), and car and furniture finishes.
- If you suspect a reaction to DEET (or any other repellent), stop using the product, wash the treated skin, and call a poison control center or contact your physician.

Permethrin-based Repellents

Several products contain 0.5% permethrin (e.g., *Duranon Tick Repellent, Repel Permanone, Sawyer's Permethrin Tick Repellent, Sawyer's Clothing Insect Repellent,* and others), which is for use only on clothing or other fabrics such as mosquito netting or tents. A synthetic pyrethroid insecticide rather than a true repellent, permethrin works primarily by killing ticks on contact with the clothes and can provide high levels of protection against ticks (and mosquitoes). Permethrin is available as an aerosol spray or pump, mainly in lawn and garden centers or sports stores. Permethrin has a relatively low mammalian toxicity, is poorly absorbed through the skin and is quickly metabolized and excreted by the body, although the EPA does list it as a potential carcinogen. Permethrin can cause mild skin and eye irritation, but reactions appear uncommon. Important points in the safe use of a permethrin repellent include:

38

- Follow the directions and precautions given on the repellent label.
- Apply to CLOTHING ONLY. Do not apply to skin. Immediately wash with soap and water if you get material on the skin.
- Do not apply to clothing while it is being worn. Apply before you put the clothing on.
- Apply in a well-ventilated area outdoors protected from the wind.
- Lightly moisten the fabric, do not saturate. Allow drying for 2 hours (4 in humid conditions).

- Allow clothing to dry prior to before wearing.
- Do not treat the clothing more than once every two weeks. Launder treated clothing at least once before retreating.

If you suspect a reaction to DEET, permethrin, or any other repellent, stop using the product, wash the treated skin, and call a poison control center or contact your physician.

Botanical and Other Repellents

Botanical products generally provide less protection time against mosquitoes than DEET or permethrin and, though information is limited, are likely to be even less effective against ticks. Many of these products are not labeled for ticks and do not make tick protection claims. Non-DEET products may contain compounds like IR3535 (ethyl butylacetylaminopropionate), or botanical oils such as 0.05% to 15% citronella, 2% soybean oil, or some other plant oil (i.e. eucalyptus, peppermint, lemongrass, geranium or cedar). Consumer Reports found that IR3535 repelled *I. scapularis* nymphs for 3-4 hours, and among plant oils tested, only the soybean oil product offered reasonable protection against mosquitoes (it is not labeled for ticks). Botanical repellents, even if they might reduce tick attachment, probably will not stop a tick from walking across the skin to an unprotected area. Avon's Skin-So-Soft Bath Oil, a widely used folklore mosquito repellent protects against mosquito bites for less than 10 minutes and is unlikely to deter ticks.

Medical and safety information about the active ingredients in an insect repellent is available from:

National Pesticide Information Center by telephone (1-800-858-7378) from 6:30 a.m. to 4:30 p.m. Pacific Standard Time or 9:30 a.m. to 7:30 p.m. Eastern Standard Time, 7 days week, except holidays.

Human Lyme disease vaccine

The Food and Drug Administration (FDA) approved a human Lyme disease vaccine, LYMErix™ (GlaxoSmithKline), which contained recombinant outer-surface protein A (OspA) of *B. burgdorferi*, in December 1998. However, the manufacturer took the vaccine off the market in February 2002 because of declining sales. In clinical trials, vaccine efficacy was 49% after 2 doses for those with definite Lyme disease and 76% after the third dose. Protection in an immunized individual was provided when levels of antibody to OspA in the blood were high enough to neutralize the spirochetes inside a feeding tick before transmission occurred. Protection in vaccinated individuals will wane after a year or two, so protection against Lyme disease in previously vaccinated people will be low to nonexistent. No human Lyme disease vaccine is currently available in the U.S. at this time.

Integrated Tick Management

Integrated pest management (IPM) basically involves the selection and use of several methods to reduce, rather than eliminate, a pest population with expected ecological, economic, and sociological costs and benefits. For ticks, this may involve the use of landscape practices to reduce tick and host animal habitat adjacent to the home, management or treatment of host animals, targeted applications of least-toxic pesticides to high-risk tick habitat – all in conjunction with tick checks and other personal protective measures to either reduce the number of infected ticks and number of tick bites. The ultimate goal, of course, is to reduce the number of human cases of disease as much as possible with the resources available. A decision has to be made on how much one is willing to spend and what ecological impact one is willing to tolerate to reduce the risk of a tick-borne illness. An integrated management approach does not necessarily preclude the use of pesticides, for example, but seeks to use chemicals effectively and responsibly in order to minimize and reduce exposure and use. Research and computer models have shown that pesticides are the most effective way to reduce ticks, particularly when combined with landscaping changes that decrease tick habitat in often-used areas of your yard.

Tick Distribution and Creating a Tick Safe Zone in the Residential Landscape

39

Tick abundance is related to landscape features of the suburban residential environment that provide a suitable environment for the tick and its animal hosts, particularly white-tailed deer and white-footed mice. While there is a lot of variation in tick numbers between homes, larger properties are more likely to harbor ticks because they are more likely to have woodlots. The blacklegged tick is found mainly in densely wooded areas (67% of total sampled) and ecotone (22%), which is unmaintained transitional edge habitat between woodlands and open areas. Fewer ticks are found in ornamental vegetation (9%) and lawn (2%). Within the lawn, most of the ticks (82%) are located within 3 yards of the lawn perimeter particularly along woodlands, stonewalls, or ornamental plantings. Tick abundance in manicured lawns is also influenced by the amount of canopy vegetation and shade. Groundcover vegetation can harbor ticks. Woodland paths also may have a high number of ticks, especially adults, along the adjacent grass and bushes.

The lawn perimeter, brushy areas and groundcover vegetation, and most importantly, the woods, form the high-risk tick zone. The idea for residential tick management is to create a tick managed area around your home that encompasses the portions of the yard that your family uses most frequently. This includes walkways, areas used for recreation, play, eating or entertainment, the mailbox, storage areas and gardens. Tick management strategies are summarized in Table 3 and some actions to consider in an integrated management approach are listed under Table 3.

Table 3. Tick management strategies for the control of *Ixodes scapularis*.

Personal protection	Tick-bite prevention, tick checks and tick removal.
Landscape management	Vegetative modifications to render the environment less suitable for tick survival and for tick hosts.
Management of host abundance	Exclusion of hosts by fencing and host reduction by management of the habitat.
Host-targeted acaricides	Treatment of white-footed mice, chipmunks or deer through passive topical application devices.
Area application acaricides	Spraying chemical insecticides to control ticks.
Biological control	Use of fungal pathogens as biopesticides to control ticks (not yet available at the time this was written, see section on biological control).

- Keep grass mowed.
- Remove leaf litter, brush and weeds at the edge of the lawn.
- Restrict the use of groundcover, such as pachysandra in areas frequented by family and roaming pets.
- Remove brush and leaves around stonewalls and wood piles.
- Discourage rodent activity. Cleanup and seal stonewalls and small openings around the home.
- Move firewood piles and bird feeders away from the house (see section on small mammals and birds).
- Manage pet activity, keep dogs and cats out of the woods to reduce ticks brought back into the home.
- Use plantings that do not attract deer or exclude deer through various types of fencing.
- Move children’s swing sets and sand boxes away from the woodland edge and place them on a wood chip or mulch type foundation.
- Trim tree branches and shrubs around the lawn edge to let in more sunlight.
- Adopt hardscape and xeriscape (dryer or less water demanding) landscaping techniques with gravel pathways and mulches. Create a 3-foot or wider wood chip, mulch, or gravel border between lawn and woods or stonewalls.
- Consider areas with decking, tile, gravel and border or container plantings in areas by the house or frequently traveled.
- Widen woodland trails.
- Consider host products to kill ticks on deer or rodent hosts.
- Consider a pesticide application as a targeted barrier treatment.

Landscape management

Residential landscapes are designed for a variety of aesthetic or environmental reasons and "tickscape" practices can be a part of the landscape in Lyme disease endemic areas. Landscape modifications can create an environment unattractive to primary tick hosts and may decrease the abundance of ticks that are present in parts of the yard. Fewer ticks have been found on well-maintained lawns, except on areas adjacent to woodlands, stonewalls, or heavy groundcover and ornamental vegetation. This section provides some ideas on how to incorporate tick management into the landscape. Clearing leaf litter and woodchip barriers have been documented to help reduce ticks on the lawn. However, landscape practices to create a lower risk tick zone will not directly eliminate many ticks and you may need to consider integrating other tick control practices into the overall program. Landscape work may also be expensive, not acceptable to some residents, and must be done by residents on their own property. In computer simulations of a hypothetical community of 10,000 individuals, a 90% habitat reduction on lawns, 80% habitat reduction in ecotone, and 10% reduction in forested areas by nearly half the residents resulted in the prevention of only a moderate number of Lyme disease cases in comparison to the application of acaricides or treatment or removal of deer. Landscape management alone may not reduce disease incidence, as the undetected bite of only one infected tick is required for transmission of *B. burgdorferi*.

40

Woodland edge and leaf litter are high-risk areas for nymphal blacklegged ticks!

In most cases, alterations will be made to an existing landscape, although landscape architects and designers should also incorporate tick safe landscaping concepts into major renovations or new construction. There are several basic interrelated concepts in modifying the landscape to create an area with fewer ticks and environmentally acceptable management practices.

- Open up to direct solar exposure the part of the landscape used or traveled frequently by family members to reduce tick and small mammal habitat and cover. Bright, sunny areas are less likely to harbor ticks.
- Isolate areas used by the family or public (i.e., lawns, play areas, recreational or ball fields) from tick habitat or tick hot spots (i.e., woods, dense vegetation, groundcover, stonewalls).
- Use hardscape and xeriscape landscaping (i.e., brick, paving, decking, gravel, container plantings, low water requirement plantings) in areas immediately around the house that are frequently used.
- In cases where environmentally acceptable alternatives to large tracts of open lawn or only small lawn areas are desired, consider butterfly gardens, vegetable gardens, formal herb gardens, colonial style gardens, wildflower meadows and hardscapes. Elimination of woodland and all wildlife habitats is not necessary or environmentally desirable. Some evidence suggests a lack of biodiversity and a landscape that specifically favors deer and mice increases tick abundance and transmission of *B. burgdorferi*. The key factor appears to be the presence and abundance of deer.

Reducing tick habitat

Altering the landscape to increase sunlight and lower humidity may render an area less hospitable to ticks. Management of the habitat should focus on the areas frequently used by the family, not necessarily the entire property. To reduce ticks adjacent to homes, prune trees, mow the lawn, remove leaf litter accumulations around the house and lawn perimeter, and cut grass, weeds, and brush along edges of the lawn, stonewalls, and driveways. Plants can be pruned to provide open space between the ground and base of the plant. Individual shade trees, with the exception of fruit trees like crab apple that are attractive to deer, and small ornamental stands in the open lawn will probably not contribute to the tick numbers unless surrounded by groundcover.

A. Yard before landscape intervention.

B. Yard after landscape intervention.

Ticks also may be found in groundcover such as *Pachysandra*. Restrict the use of groundcovers to less frequently used areas of the yard. Clean up the vegetation around or even seal stonewalls near the house. The removal of leaf litter has been shown to reduce the number of *I. scapularis* nymphs on some properties. Mowing and removing cover vegetation around the house also will discourage rodent hosts. Leaf litter and other plant debris can be raked or blown out from under shrubs and bushes (use tick protection measures while handling leaf litter). Composting or removal by appropriate bagging is acceptable method of disposing of leaf litter. Leaves should not be simply moved to another part of the property. Some communities will compost collected leaves and provide the compost to residents for free or a nominal charge.

Move swing sets and playground areas out or away from the woodland edge!

Play activity can be a high-risk activity for tick exposure and children have some of the highest rates of Lyme disease.

The use of hardscapes, mulches, and xericape landscaping techniques can help reduce tick habitat and isolate parts of the yard from tick hot spots. Hardscapes refer to nonliving features of the landscape like patios, decks, and paths. Mulches are used to suppress weeds and help retain soil moisture, but can also help reduce tick movement. In the laboratory, untreated landscape landscape stones and pinebark woodchips have been shown to deter tick movement and around homes, a three-foot wide or broader woodchip barrier may help reduce tick abundance on the lawn, although results have been found to vary widely from home to home and from year to year depending upon other factors (i.e. density of woods, amount of shade, initial tick densities). Mulches are often organic materials like bark chunks or shredded bark, but can also be small stones or gravel. Wood chip and tree bark, gravel, or similar landscaping materials between woods or stonewalls and lawn as a buffer or barrier can help reduce the number of ticks on the lawn and delineate the tick zone. Quality of the landscape material may also influence results as wood chips from chipped trees, especially if it contains leaves, quickly degrade and may soon be no different than leaf litter. Properly maintained each year, the barrier may allow fewer ticks to migrate from the woodlands into the lawn. It also serves as a reminder that people who cross the barrier may be at higher risk of getting ticks. The application of a barrier or buffer will be easiest where there is a sharp delineation between the woods and lawn. A pesticide application can be focused on the landscape barrier or buffer zone to increase the effectiveness of the barrier. Move swing sets and sandboxes away from the woodland edges and place on a covering of smooth bark, mulch or other suitable material.

Xeriscaping is the application of water conserving landscape practices. This approach reduces habitat cover; helps isolate frequently used areas, can provide an attractive focal area in the yard or garden and reduce maintenance and water, fertilizer, and chemical use. Many drought resistant plants are also deer resistant. Landscapes can incorporate formal or informal designs around play, eating, or pool areas. Landscape materials such as laid brick, wood decking, stone paving, raked gravel or pea gravel (set down slightly from bordering bricks, stone, or paved areas), and concrete (exposed aggregate can provide varying attractive colors and textures and edged with brick or tile) can be used to create a patio and paths. Gravel can be laid over a layer of crushed stone covered with black plastic to discourage weed growth. Some plantings can be in raised beds or containers.

Management of Host Animals

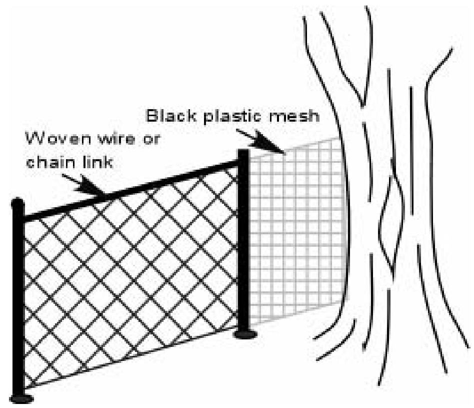
Food and shelter are essential requisites for wildlife. The residential landscape can be particularly attractive to white-tailed deer and conducive to mice, both important hosts in the prevalence of ticks and Lyme disease. One component of a tick management strategy is managing deer and small rodent activity in your yard. Some landscaping practices discussed in the previous section can also help manage key animals in the landscape. Stonewalls, woodpiles, and dense vegetation can harbor rodents.

White-tailed Deer, *Odocoilius virginianus* (Zimmerman)

41

In the northeast from New Jersey to Maine, the deer population is estimated at 1,918,000 animals. In Connecticut, the number of deer has increased from about 12 in 1896 to over 76,000 today. Overabundance of deer is associated with problems such as deer/vehicle collisions, agricultural damage, lack of forest regeneration, detrimental impacts on other wildlife (especially birds), damage to residential landscapes, and the rising incidence of Lyme disease. The fault is not in the animal. Who has not appreciated the thrill of a glimpse of these animals in the meadow or grazing in our landscapes? The problem is in their numbers. There only need be fewer of them. Mature, shaded forests with poor forage and browse support low densities of deer and fewer ticks. A mosaic of light fragmented woodland and woodland edges, clearings and abundant shrubs, berries, grass, and forbs and a lack of predators are ideal for deer. Fencing out deer can allow greater landscape options favorable to other wildlife.

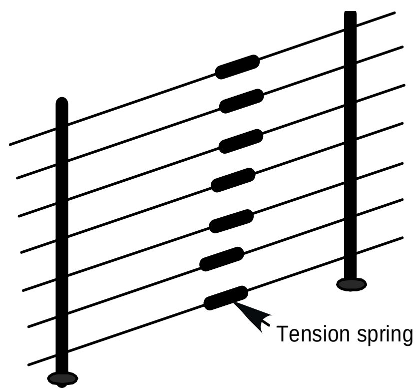
The abundance and distribution of *I. scapularis* has been directly related to the size of the deer population. It has been estimated that over 90% of adult ticks feed on deer. Therefore, deer are key to the reproductive success of the tick. Deer transport blood-engorged female ticks into the property where they can lay thousands of eggs, increasing the number of larval ticks available to feed on small animals. Reservoir incompetent, deer do not infect feeding ticks with Lyme disease bacteria. Larvae of *I. scapularis* pick up the spirochetes when they feed on small animals, especially mice, which are reservoir competent hosts. Island or peninsular communities with extremely high deer densities have superabundant tick populations. Conversely, islands without deer do not appear to support *I. scapularis* or *B. burgdorferi*. Deer management options include deer fencing, repellents, and deer resistant landscape plantings. Dogs also may help deter deer, but to be effective the animal may have to be active both day and night, something a family pet may not do.



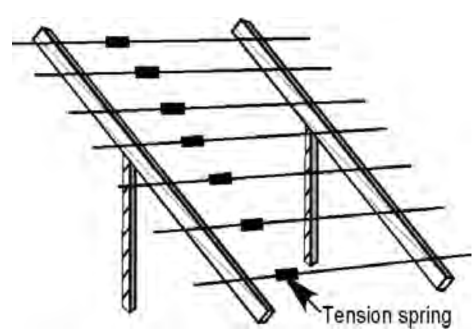
Deer Fencing: Fencing is the most effective method to control access by deer to a property. Fences can keep deer from large garden beds or small to moderate sized home lots. The exclusion of deer from areas of 15 to 18 acres with a slant high-tensile electric fence was shown to reduce the abundance of *I. scapularis* nymphs by as much as 84% and larval ticks by 100% approximately 70 yards or greater inside the fence. Fencing of smaller areas also may be beneficial, but tick management practices within the enclosure and the use of an insecticide at the fence perimeter may also be needed. A deer fence does not stop small animal movement and tick movement. Barrier fencing can be used to protect individual trees, shrubs or other plantings from deer.

There are many types of deer fences and selection will depend upon deer pressure, area to be protected, and site characteristics. The most common choice in a fence is a plastic or wire mesh vertical fence. An electric fence is another option. A number of companies specialize in providing deer fencing and can provide the fencing materials or install the fence. However, many communities have local restrictions or ordinances on the type and height of fencing allowed – check with your local authorities.

42



Non-electric fence – The fence may be vertical or three-dimensional. A vertical fence requires the least space and a wide variety of fence materials and designs are available. Increasingly, a black polypropylene plastic fence-like mesh or steel mesh is being used instead of a chain-link for vertical fences because of reduced cost, low maintenance, long life, and near invisibility, an attractive feature in the residential landscape. The plastic material comes in rolls of various lengths and 7.5 feet wide and can be fastened to existing trees or several different types of posts. White flags should be attached at around 4 feet to signal the presence of the fence. While deer can jump a vertical fence of eight feet from a standing position, they rarely do so and are more likely to try and push under fencing. Proper anchoring or staking of the fence along the ground is important. Single or multiple electric strands also can be placed along the top of a vertical wire or mesh fence. Another option is a slant deer fence set at an angle of 45 degrees for use in areas with moderate to high deer densities, but it requires more space (about 6 feet of horizontal space). Deer cannot clear both the height and width of the fence and often find themselves under the top outer wire. Solid 5- to 6-foot fences are also effective. Access gates, driveway gates (can be remotely controlled in more expensive systems), or in ground driveway deer grates (similar to cattle guards) will be needed to completely enclose the area and still allow owner and vehicle access.



Electric fence – An electric fence requires maintenance, proper grounding, and may not be appropriate in many residential settings. A vertical or slant seven-strand, high-tensile electric fence is very effective for larger areas where deer densities are high.

Deer Repellents: The use of deer repellents may reduce damage to plants and help defer the animals elsewhere, but by itself will not impact tick abundance unless deer consistently avoid the property entirely. Repellent performance is highly variable depending upon the product (most are either odor or taste-based), rain, frequency of application, and the availability of other food sources for deer. Nevertheless, some repellents are fairly effective with low to moderate deer densities.

Deer Resistant Plantings: Substituting less palatable landscape plants may discourage browsing around the home, reduce damage to ornamental plants and may help make the yard less attractive to deer, though deer will also readily graze on lawns. The use of deer resistant plantings may have no impact on ticks unless deer consistently avoid the property and the use of these plants specifically as part of tick management has not been examined. It simply seems to make sense to make your yard and plantings less attractive to deer.

No plant is completely browse resistant and susceptibility depends upon deer density, food availability, and food preferences, which can vary regionally. Plant selection will depend partly upon the type of terrain you have: a sunny, moist yard, a dry, sunny garden, a dry shady garden, or a wet, shady yard, proximity to streams or ponds and effect desired (e.g., fragrance, foliage color, seasonal color, showy borders, etc.). Use of native shrubs and trees is encouraged and the use of invasive plantings is discouraged. Non-native invasive plants, some of which are very resistant to deer browse damage, can crowd out natives. Examples include Japanese barberry, multiflora rose, Asiatic bittersweet, and several non-native honeysuckles. Lists of invasive species and alternative plantings are usually available from state agencies, universities, or environmental groups in each state.

A rating of deer browse damage to many plants was compiled at the Connecticut Agricultural Experiment Station (CAES) from a survey of Connecticut gardeners. A comprehensive list of the survey results with plants ranging from very susceptible to highly resistant to browse damage is available in CAES Station Bulletin 968 (online at www.caes.state.ct.us). Information is also available on deer resistant plantings and deer proofing from a variety of books and handouts. Many nurseries and garden centers can provide a suggested list of deer resistant plantings.

Groundcovers like pachysandra and myrtle, while browse resistant, have been found to harbor ticks and may not be the most appropriate choice near heavily used areas around the house, porch, or mailbox. In general, ornamental grasses and ferns are browse resistant and may be good choices in sunny and moist shady areas, respectively. A number of medicinal herb varieties, ornamental herbs, and butterfly garden plants are resistant to deer browse. The most browse resistant plantings should be placed at the edges and entrances of the property and the most browse susceptible plants closer to the house or areas frequented by people and pets. Susceptible plants can be surrounded by less palatable species. Clean up fruits and other produce from under trees or crop plants. While eliminating cover like mixed tall grass and brush may help discourage deer from bedding near the home, deer will bed wherever they consider it safe – even open lawn. In a study of tick egg-laying, female ticks from deer were found to survive in field bedding areas and lay eggs from which larvae successfully hatched. However, larval survival in the field was shorter than in the woods and they are less likely to be picked up by a mouse host.

Deer Reduction and Management

Some communities have explored the reduction of deer through regulated hunting or controlled hunts to reduce problems associated with deer overabundance. The incremental removal and virtual elimination of deer has been shown to substantially reduce tick abundance, but observational studies and computer models suggest deer densities must be reduced to very low levels (possibly as low as 8 deer per square mile or less) to interrupt the transmission of Lyme disease. In comparison, typical suburban deer densities along coastal Connecticut have been around 30-60 deer per square mile. With the exception of some islands or peninsulas, the need for such a drastic reduction in deer population to achieve satisfactory control levels may render this strategy unrealistic in many areas. Conversely, unregulated deer populations may lead to steadily increasing tick populations. It is not clear if *I. scapularis* can be maintained on medium-sized animal hosts in the absence of deer. Adult ticks also feed on opossums, raccoons, skunks, foxes, dogs and other animals. However, tick densities may be low enough to interrupt the enzootic cycle and transmission of *B. burgdorferi* to humans.

Lethal management options for deer are effective, though controversial, while the use of anti-fertility agents is experimental and labor intensive. A community that wishes to implement a deer management program, especially in densely populated urban and suburban areas must deal with hunting restrictions, real or perceived safety or liability concerns, and conflicting attitudes on managing wildlife. Since most land in the northeast is privately held, homeowner views and hunter access are important to deer management. Any deer population control program would require an initial reduction phase to lower high densities of deer and a maintenance phase to keep the deer population at the desired targeted level. Deer capacity for reproduction is high and deer herds can potentially double in size in one year. Management would be an ongoing process.

Host-Targeted Chemical Tick Control for White-tailed deer

43

The U.S. Department of Agriculture has developed a new experimental approach for the application of topical acaricides to white-tailed deer to kill ticks feeding on the deer. It consists of a feeding station with four paint rollers that hold the pesticide. Deer self treat as they brush against the rollers when they feed. These 4-posters were evaluated in the northeastern United States for the control of the blacklegged tick, having performed well in a trial against lone star ticks on deer in Texas. Computer models indicated that 95% control of *I. scapularis* on 90% of a local deer population could dramatically reduce the tick population in a treated area over a period of several years. While usage of the devices is generally high (> 90%), utilization of the devices by deer was extremely low when alternative food sources were available (i.e., acorns). The treatment of deer with 2% amitraz reduced tick abundance in the treated communities by around 64-69% by the fifth and sixth year in comparison with untreated areas. The use of 10% permethrin resulted in a 91-100% reduction of larval, nymphal, and adult questing ticks in sampled plots. According to computer simulations, this approach, in principal, could provide the greatest reduction in Lyme disease with the least direct community involvement (i.e. number of direct participating households).

The American Lyme Disease Foundation (Somers, NY) holds the license to the product's patent and works with Dandux Outdoors (Ellicott City, MD) for manufacturing the device. The U.S. Environmental Protection Agency has registered 10% permethrin as a restricted use, ready to use tickicide (Y-TEX® 4-Poster™ Tickicide, Y-TEX Corporation, Cody, WY) for application to deer via the 4-poster device to control *I. scapularis* and *A. americanum*. The 4-posters are to be placed as far as possible, but in no case less than 100 yards from any home, apartment, playground, or other place children might be present without adult supervision. States may have more restrictive requirements than the federal label. At the time of this writing, state pesticide registrations have been obtained in 33 states including Connecticut, Massachusetts, Rhode Island, New Jersey, Maine, New Hampshire, Vermont, Maryland, Delaware, Michigan, and Minnesota. Approvals or regulations for use by state wildlife officials are pending or under review. The use of the 4-poster will probably make the most sense as part of a neighborhood or community coordinated program to reduce ticks and the risk of Lyme disease, managed under state use regulations, combined with some form of a deer management program.

Small Mammals and Birds

Rodents and birds can infect ticks with *B. burgdorferi* and transport ticks onto your property. The importance of these animals in the dynamics of Lyme disease depends on the abundance of the animal host, number of ticks feeding on the host, and the host’s ability to infect feeding ticks with the Lyme disease spirochete (i.e., the reservoir potential). In other words, what animals are contributing infected ticks to your property? Some animals may have a lot of ticks, but not be able to infect them with spirochetes.

Rodents

While different rodent and bird species may predominate in certain years and locations, white-footed mice, *Peromyscus leucopus*, are generally the most abundant and efficient animal reservoir for the Lyme disease bacteria. They contribute more infected ticks than eastern chipmunks or meadow voles. White-footed mice also are a reservoir for the causal agents of ehrlichiosis and babesisois. Over 90% of white-footed mice will be infected with *B. burgdorferi* in many areas and up to half have been found to carry all three pathogens in some areas. In one study, a single mouse was estimated to infect as many ticks as 12 chipmunks or 221 voles. Meadow voles, *Microtus pennsylvanicus*, are most abundant in fields, pastures, orchards, which harbor few *I. scapularis*. Although they harbor fewer ticks, short-tailed shrews, *Blarina brevicauda*, with their high reservoir potential, may contribute to the maintenance of both *B. burgdorferi* and *B. microti* in some areas, especially when mouse numbers are low. By contrast, squirrels have a lower Lyme disease reservoir potential. One study indicated that squirrels might reduce or dilute the number of infected ticks in the landscape.

Note in the second picture of the white-footed mouse the engorged larval ticks feeding on the ears and around the eyes of the animal. Larval ticks become infected with B. burgdorferi and other pathogens while feeding on an infected mouse or chipmunk.

White-footed Mouse
Peromyscus leucopus (Rafinesque)

44

The white-footed mouse is the principal animal carrying the pathogens that cause Lyme disease, human anaplasmosis (i.e., ehrlichiosis) and human babesisois. White-footed mice are found throughout most eastern and Midwestern United States, except in Florida and northern Maine. This mouse is difficult to distinguish from the deer mouse, *P. maniculatus*.

White-footed mice have a home range of generally 0.1 to 0.5 acre, sometimes larger. This woodland and brushy area dwelling animal nests in stonewalls, tree cavities, abandoned bird or squirrel nests, under stumps, logs, and may readily enter and nest in buildings, especially during the winter months. Mice may line the nest with fur, feathers or shredded cloth. These nocturnal animals are omnivorous and feed on acorns, seeds (including newly planted gardens), fruits, insects, snails, tender young plants, and carrion.

Mouse densities usually are around 1-10 per acre but can be higher (15 per acre) and may go relatively unnoticed until they enter homes that are not rodent proof. Breeding spring through fall, a female mouse typically has 3-4 young after a gestation period of 22-25 days. The mice reach sexual maturity in 6-7 weeks. There are no ticks on the mice during the winter and, inside buildings, they do not pose a risk for the transmission of Lyme disease. Folded hardware cloth (1/4-inch mesh) may be used to exclude mice from buildings, flowerbeds, and garden plots. Cleaning up small black droppings and urine-contaminated areas in confined areas can pose a risk for hantavirus disease.

Reduction of small mammal abundance should focus mainly on reducing mouse habitat near homes and encouraging predators like foxes, snakes, hawks, and owls, and weasels, to name a few. However, predators require large territories of several square miles. Although not quantified, this author has noticed mouse populations drop dramatically (based on trapping success) with resultant drops in the tick population at sample sites where a fox family or snakes have taken up residence in or near the stone walls. Mice have relatively small home ranges. Dense vegetation and ground cover plants like pachysandra adjacent to homes provide cover for rodents as they forage for food. Shaded stonewalls overgrown with grass and brush can harbor many mice and chipmunks.

Eastern Chipmunk
Tamias striatus L.

Eastern chipmunks are found in most states east of the Mississippi River, except along the southeastern coastal region. They are often the second most important rodent in the maintenance of Lyme disease and can be the principal reservoir in some areas. Solitary by habit and active during the day, chipmunks feed on seeds, grains, fruits, nuts, bulbs, mushrooms, insects, carrion and may prey on young birds and eggs. They can climb trees to gather seeds, fruit and nuts and store food throughout the year. They hibernate during the winter, but may become active for brief periods on sunny warm days. Requiring ample vegetative cover, chipmunks are found in deciduous woodlands with undergrowth, old logs, stonewalls, and in brushlands. Their home range is small, typically less than 100 yards in diameter and females defend a 50-yard radius around the home. A small (2 inch), inconspicuous entrance leads to a complex burrow system. There are typically 2 to 4 chipmunks per acre, but densities may be higher with adequate food and cover. There are 1 or 2 litters each year. Hardware cloth (1/4-inch mesh) may be used to exclude chipmunks from buildings and flowerbeds.

A fitted stonewall is unlikely to harbor rodents and ticks like the old stonewall with leaf litter and other vegetative cover.

Birds

Birds are frequent hosts for immature stages of the blacklegged tick. At a woodland residence, 26% of birds were infested with ticks and 94% were *I. scapularis*. While some bird species can infect feeding ticks with *B. burgdorferi* (i.e., American robin, veery, grackle, common yellowthroat, Carolina wren, house wren), other species (i.e., gray catbird, woodthrush) do not. Due to variability in bird species composition, population, habitat preferences, reservoir competence and feeder activity, it is unclear how many ticks (much less those infected with spirochetes) most birds actually contribute to a typical residential landscape. One early study found that American robins, a reservoir competent bird, were likely contributors to the nymphal tick population found in some suburban residential landscapes. Unlike mice, however, reservoir competency in robins declines after 2 months. A recent study suggested most birds probably contribute few infected ticks and may actually dilute pathogen transmission, at least in comparison to mice. Bird feeders in landscaped areas like mowed lawns were not found to be a risk factor for Lyme disease, probably because the habitat does not favor tick survival and seed feeding birds that frequent feeders in the summer do not deposit many ticks. However, higher tick abundance has been noted where feeders were installed at or beyond the lawn edge in wooded habitat suitable for tick survival and rodent activity (Gary Maupin, CDC retired, personal observation). Adult ticks, which are active in the fall, winter and spring months, do not feed on birds.

It is unknown what impact summer or winter fruit bearing trees and shrubs for birds has on the prevalence of ticks as related to mouse and chipmunk activity, as seeds and fruits can also serve as a food source for these animals.

Many berry plants, however, are important to fall migrants and the berries are quickly consumed. Deer resistant bird favorites include bayberry (*Myrica pensylvanica*) and Virginia creeper (*Parthenocissus*) and highbush blueberry (*Vaccinium corymbosum* – produces summer berries); cedars and certain holly cultivars, however, are subject to heavy deer browsing. Common winterberry (*Ilex verticillata*) is also fairly susceptible to heavy deer browse damage. It requires both female and male plants to produce winterberries for birds. Native viburnums will suffer only occasional to minimal damage

45

Note the ticks feeding around the eyes of this veery (J. Occi).

from deer and are good bird plants. Japanese barberry (*Berberis thunbergii*) is considered invasive.

Possible small animal and bird management strategies include:

- Keep potential mouse nesting sites in stonewalls and woodpiles near the residence free of brush, high grass, weeds, and leaf litter.
- Seal or rework stonewalls near or under the home to reduce harborage.
- Move firewood away from the house.
- Place the birdhouses and feeders away from the house, but it is unknown if this will decrease risk of exposure to ticks. Clean up spilled feed (spilled bird feed can also attract mice).
- Set up bird feeders in late fall and winter when natural foods are scarce (and the immature stages of *I. scapularis* are not present on birds).
- Seal foundations. For example a garden shed on cement blocks can harbor raccoons, skunks, or woodchucks. This can be avoided through a proper foundation or use of hardware cloth buried at least two feet beneath the ground. A poorly sealed building or old garden shed can harbor mice.

Host-Targeted Chemical Tick Control for Rodents

The first rodent-targeted product was a cardboard tube of cottonballs treated with the insecticide permethrin (Damminix®). The product is aimed at larvae and nymphs of *I. scapularis* feeding on white-footed mice. The effectiveness of this product is dependent upon the mice collecting the cotton as nesting material from cardboard tubes distributed throughout the mouse habitat. Studies in Connecticut and New York state failed to show any reduction in the number of infected, host-seeking *I. scapularis* nymphs when this product was used for a three year period in woodland and residential areas of about 4 acres or less. Lack of control may be due to failure by the mice in some areas to collect the cotton or the presence of alternative tick hosts, such as chipmunks, an important secondary tick host and spirochete reservoir. Reductions in tick numbers were reported in a Massachusetts study with the treatment of one 18-acre tract.

Another approach, using bait boxes for the topical treatment of rodents with fipronil, was first evaluated for the control of *I. scapularis* on wild white-footed mice on an island community in Connecticut and then subsequently at residential locations in Connecticut, New Jersey, New York and Massachusetts. Fipronil is the active ingredient in topical or spray flea and tick control products (Frontline®). In the laboratory, a single topical application to a mouse can kill all ticks on the animal for up to 7 weeks. In the island community trial, the prevalence of infection of *B. burgdorferi* in the mice dropped dramatically after one year and nymphal tick populations were substantially reduced after only two years of use. A commercial version called the Maxforce® Tick Management System (Bayer Environmental Science, Montvale, NJ) received EPA registration July 2003 and is available through licensed pesticide applicators. The rodent bait box is one alternative to area applied sprays or efforts to reduce the small mammal population. The device consists of a sealed, ready to use, child resistant box containing nontoxic food blocks and an applicator wick impregrated with 0.70% fipronil. This device treats both white-footed mice and Eastern chipmunks as they pass through the box to forage on the food attractant. While high levels of immature tick control may be obtained by treating single, isolated properties, a number of adjacent homeowners may have to use this approach for optimum impact. The impact of the boxes on the tick population accumulates over time. There is no affect on the existing host-seeking tick population the first year the boxes are placed, so a pesticide application may be a consideration in the initial year if the Maxforce Tick Management System is used.

46

A. **B.**

The pictures show an open rodent box used in the initial experimental trials in Connecticut with two non-toxic bait blocks and a yarn wick treated with fipronil (A) and the Maxforce® TMS rodent bait box (B).

Prevention of Tick-Associated Disease in Companion Animals

The prevention of Lyme disease and other tick-associated disease in dogs relies on avoiding tick habitat, reducing ticks on the animal, daily tick checks, and use of one of the canine Lyme disease vaccines available (whole-cell killed bacterin or recombinant outer surface protein A of *B. burgdorferi* - OspA). Electronic fencing systems can help confine a pet in an area where the animal is less likely to pick up ticks or where other tick control measures have been implemented. If the pet is not allowed to freely roam into the wooded areas, it is less likely to pick up ticks. Animals can carry ticks into the home. However, studies to determine whether pet owners may be at increased risk of Lyme disease have been inconclusive. Ticks, once attached or fed, will not seek another host. Dogs and cats should be checked daily for ticks, but the immature stages may be virtually impossible to detect on longhair or dark-hair animals. Outdoor activities with animals also may increase the exposure of pet owners to ticks and their habitat.

47

Engorged female *I. scapularis* on a domestic cat.

48

A veterinarian should be consulted about the prevention and treatment of Lyme disease in your animals. A variety of products can repel and/or kill ticks on the animal. Some are available over the counter (OTC) and others only through your veterinarian. Chemical products to protect dogs from ticks are available as spot-ons, sprays, collars, powders, and dips. Ingredients include several insecticides such as pyrethrin, permethrin, amitraz, or fipronil (see section on chemical control). Some products are combined with an insect growth regulator to help control flea eggs. Follow label directions to minimize the chances for an adverse reaction to the product in your pet and do not combine products without the advice of your veterinarian. Different products can contain the same or similar ingredients, which could result in an overdose of the animal.

Although the risk of clinical disease is low, the canine Lyme vaccines can provide high levels of protection for dogs living in or traveling to Lyme disease endemic areas with a likely exposure to ticks. Depending upon the vaccine, an initial dose can be given as early as 9 or 12 weeks of age with a second required dose several weeks later. An annual booster is recommended.

Backyard Wildlife Programs and Environmentally Friendly Lawns

With increased environmental awareness, the focus for some residents has been to provide a more natural or organic landscape, with reduced inputs of energy, water, pesticides, fertilizer and labor, and provide increased wildlife habitat. Some shrubs and other plants are selected for their wildlife value due to the berries, fruit and cover they provide for birds and small mammals. Many resources are available to help create backyard wildlife habitats. How can the desire to have a more natural, environmentally friendly habitat be balanced with the need to reduce contact with animals carrying ticks and the creation of a tick safe zone? The presence of deer and rodents will result in the presence of ticks. Little information is available on how to integrate these two different objectives. Open lawns harbor fewer ticks and wildlife that carry potentially infected ticks. There is some evidence that increased animal diversity can actually reduce the rate of transmission of tick-associated disease, resulting in fewer infected ticks, although ticks are still present. The fragmented woodland and ecotone environment of suburbia favors the deer, mice, and chipmunks most involved in the maintenance and transmission of ticks and tick-associated diseases. Mixed ecotone with uncut grass, wildflower and shrubby vegetation, especially adjacent to woodlands is good deer, mouse and tick habitat.

Little is known about relative tick densities in various alternative landscapes to turf like wildflower meadows, gardens, and butterfly gardens. It is not known what specific plants or plant groupings may be associated with more or fewer ticks or if it makes that much of a difference. Some plants used in butterfly gardens are attractive to deer, while most herbs are highly resistant to deer browsing. Fencing against deer will allow greater landscape flexibility. While data is limited, meadows appear to harbor few blacklegged ticks except along the edge with woodlands, dense vegetation and stonewall. If a property is large enough, a separate wildlife and tick-managed zone could possibly be maintained. The objective of a tick management program is to discourage activity of several key tick hosts and create a physical and/or chemical barrier between woodland habitat and areas the family uses most frequently.

Area-Wide Chemical Control of Ticks

Insecticides, or as termed for ticks, acaricides, are the most effective way to reduce ticks, particularly when combined with the landscaping changes to decrease tick habitat reviewed earlier in this handbook. They provide consistent control, are relatively easy to apply, and are relatively inexpensive. Only small amounts of an acaricide applied at the right time of year are necessary. Chemical intervention should focus on early control of nymphal *I. scapularis* ticks, the stage most likely to transmit Lyme disease, by spraying once in May or early June. A fall application in October may be used to control adult blacklegged ticks (or in the spring if no fall application was made). Targeting lawn and woodland edges and perimeter areas near tick "hot-spots" or along the "tick zone" can minimize exposure. Some general points to consider if you spray for ticks:

- Applications can be made by the homeowner or by a commercial applicator.
- Spray once in the late spring or early summer for control of *I. scapularis* nymphs. For American dog ticks, an application can be made anytime after the adults emerge in the spring.
- A single application of most ornamental-turf insecticides will provide 85-90% or better control with some residual activity so multiple applications are rarely necessary. Some organic pesticide products are less effective, breakdown rapidly, and multiple applications may be required.
- Treat tick habitat only.
  Spray areas where the lawn meets the woods, stonewalls, or ornamental plantings. Spray several yards into bordering woodlands, area of greatest tick density. Spray groundcover vegetation like *Pachysandra* near the home or walkways. Spray perimeter of areas of the yard often used by people (play areas, gardens, outside storage areas, walkways or paths to neighbors or mailboxes). Avoid herb, vegetable, and butterfly gardens.
- In parks and school athletic fields, restrict any applications to high-risk tick habitat. Spraying of open fields and lawns is not necessary.
- Use a product specifically labeled for controlling ticks. Some products are packaged as fertilizer-pesticide mixtures or mixtures of different pesticides (e.g., herbicide and insecticide).

Acaricides Used for Tick Control

There are several factors that will influence the selection of a specific chemical product. All pesticides sold must be registered with the U.S. Environmental Protection Agency (EPA) and the appropriate state pesticide agency for use within that state.

- The product must be labeled for area-wide tick control (see Table 3). Some products are General Use Pesticides and others are classified as Restricted Use Pesticides for commercial use only, available only to licensed applicators. Some products are labeled for brown dog ticks only or for ticks on surfaces, indoors, as a building foundation or perimeter treatment and are not labeled for use on ornamentals or turf. Check the label and ask for assistance. A licensed commercial applicator often will have a preferred acaricide that is used most frequently.
- The toxicity and environmental impact of the chemical. Chemicals differ in their toxicity to humans, wildlife, aquatic organisms and beneficial insects. While some general information is provided in this handbook, more detailed information can be obtained from sources listed at the end of chemical control section.
- The type of formulation and method of application. Both liquid and granular formulations have been reported effective against *I. scapularis* with somewhat better control usually obtained with liquid formulations. Sufficient spray volume and pressure should be used for thorough coverage and penetration of the vegetation and leaf litter. A small hand pump sprayer is unlikely to provide the coverage needed for good tick control and, at a minimum, some type of garden hose sprayer is suggested. A homeowner who wishes to apply a granular material with a fertilizer spreader for tick control may not be able to treat woodland margins effectively and the product may be labeled for lawn use only.
- Effectiveness in controlling ticks. Blacklegged ticks and American dog ticks are readily killed by almost all ornamental and turf insecticides labeled for tick control. With the withdrawal of the organophosphate insecticides chlorpyrifos and diazinon from residential use (the U.S. Environmental Protection Agency has cancelled registration of these compounds for residential area-wide use), the synthetic pyrethroid insecticides are the most commonly used tick control agents. Pyrethroids are particularly effective at rates 6-45 times less than the now cancelled organophosphate insecticides and the carbamate insecticide carbaryl. In the laboratory, nymphal *I. scapularis* crawling on landscape stones treated with pyrethrin-based desiccants and insecticidal soaps suffered high (> 88%) mortality. However, natural pyrethrin with the synergist piperonyl butoxide provided limited tick control in the residential landscape in several trials. By contrast, synergized pyrethrin was more effective when combined with insecticidal soap or as part of a silicon dioxide (from diatomaceous earth) product. Silicon dioxide acts as a desiccant. Thorough coverage appears particularly important with pyrethrin and insecticidal soap products. With the exception of a desiccant, there is little residual activity. At least two applications may be required.

Table 4. Acaricides with products labeled for the control of ticks in the residential landscape.

Chemical	Some brand or common names*	Chemical type and usage
Bifenthrin	Talstar® Ortho® product	Pyrethroid insecticide. Available as liquid and granular formulations. Products available for homeowner use and commercial applicators.
Carbaryl	Sevin®	Carbamate insecticide. A common garden insecticide for homeowner use, some products are for commercial use only.
Cyfluthrin	Tempo® Powerforce™	Pyrethroid insecticide. Available for commercial and homeowner use with concentrates and ready to spray (RTS) products.
Deltramethrin	Suspend® DeltaGard® G	A pyrethroid insecticide for commercial applicators.
lambda-cyhalothrin	Scimitar® Demand®	A pyrethroid insecticide for commercial applicators.
Permethrin	Astro® Ortho® products Bonide® products Tengard® SFR Others	Pyrethroid insecticide. There are concentrates and ready to spray (RTS) products. Most are for homeowner use, a few are for commercial use only.
Pyrethrin	Pyrenone® Kicker® Organic Solutions All Crop Commercial & Agricultural Multipurpose Insecticide®	Natural pyrethrins with the synergist piperonyl butoxide (PBO) or insecticidal soap provide limited tick control. A combination of pyrethrin and PBO with either insecticidal soap or silicon dioxide (from diatomaceous earth) was found effective against ticks in one trial.

*Active ingredients and brand names frequently change as new products are registered and others discontinued. New formulations for homeowner use may become available. Mention of a product is for information purposes only and does not constitute an endorsement by the Connecticut Agricultural Experiment Station.

Homeowner Application of Acaricides

One option is for the homeowner to make the pesticide application. Anyone applying pesticides to their own property should be familiar with how to read a pesticide label, how to correctly mix the pesticide, and follow the listed precautions in handling and applying the material. The pesticide label provides information on the active chemical ingredients, formulation, pests and sites for which it can be legally used, directions for use, precautions, hazards to humans, wildlife and the environment, and first aid instructions. Always read and follow pesticide label directions and precautions. It is a violation of federal law to use a pesticide in a manner inconsistent with the label. The label will provide an indication of how hazardous a pesticide is by the signal word on the label. Signal words are based on the EPA toxicity class and must be included on pesticide labels.

- Danger-Poison means highly toxic or poisonous through oral or dermal exposure
- Danger means highly toxic, but may include severe skin or eye irritants

- Warning means moderately toxic or hazardous
- Caution means slightly toxic or hazardous
- No signal word means practically nontoxic

Not all brands of a particular pesticide chemical will be labeled for area tick control. Some products may be for application in or on building and their immediate surroundings. Check the label. Homeowner products come in three forms.

- Ready-to-use (RTU) is premixed and applied directly from the existing container. They are used for spot treatments, treatments of individual plants, or treatment of small areas. Some RTU products, for example, are used to control dog ticks indoors or around a dog's bedding. Ready-to-spray (RTS) products are used for treating larger areas. The container attaches directly to a garden hose for automatic mixing of the water with the concentrate. For example, a ready spray of 2.5% permethrin or 0.75% cyfluthrin is available as a hose end sprayer for the control of *I. scapularis* and will cover about 5,000 square feet.
- Concentrates require mixing the product with water and using your own sprayer (pump-up style, hose-end style, or other type sprayer). Homeowner products may contain carbaryl, cyfluthrin, or permethrin.
- Granules are designed for lawn applications with a hand held or broadcast spreader. The chemical is usually released with addition of water, so granules generally must be watered in. Granules for tick control on the lawn may contain bifenthrin or carbaryl.

Appropriate protective gear as directed on the label should be used when applying pesticides. Surveys have shown many individuals fail to take precautions while applying pesticides. Store pesticides in a cool, dry, secure place. Keep them out of the reach of children. An EPA survey found 85% of households had at least one pesticide on the property and 47% with young children (under age 6) stored them within reach of the child. Keep a pesticide in its original container; do not store diluted spray. Either use up the product or properly depose of leftover product through a community household hazardous waste program. Pesticides should never be poured down the sink or toilet. Empty containers should be triple rinsed and placed in the trash. For more information on handling, applying, storing and deposing of pesticides, readers may refer to the EPA's Citizen's Guide to Pest Control and Pesticide Safety (available at www.epa.gov).

Commercial Application of Acaricides

Another option is to have a licensed commercial pesticide applicator apply the acaricide. Most companies offering tick control services are lawn care, landscape, or tree care companies, but may include some pest control operators (PCOs) in some states, depending upon what licenses the operator has obtained. A survey of commercial applicators in Connecticut in the mid-1990s found that about 16% offered tick control services. The application of pesticides for tick control comprised less than 5% of their business for most companies. Nevertheless, most companies reported that tick control business had increased and a few companies have specialized solely in providing tick control. A follow-up survey by the author in 1999 indicated that 53% were now offering tick control services. A number of companies provide organically oriented pest management services.

A company offering commercial application of pesticides must be registered with the state or states in which they conduct business. A pesticide license is required for the commercial application of pesticides or the application of restricted use materials in the area. There must be at least one commercial supervisory pesticide applicator certified in the type of application being made. In Connecticut, for example, a license for ornamental and turf application from the Department of Environmental Protection is required for applying pesticides for tick control in the landscape. Some tree service companies (arborists) also treat for ticks. Although arborists are tested and licensed by the state specifically for arboriculture services, they must also possess an ornamental and turf license to spray for ticks. Consumers should employ individuals who are licensed to spray for ticks and may request to see the license or license number or check with the agency responsible for the state pesticide program to see if the firms are properly registered and licensed. A commercial company should provide a consumer the name of the pesticide product to be used, the active ingredient in the product, the reentry period (the time before family members can safely reenter the treated area), and the form of the pesticide and type of equipment to be used. In most states, companies are required to provide copies of the label and material safety data sheets (MSDS). With this information, additional information can be obtained over the Internet, from local Cooperative Extension offices, state agencies and pesticide alternative groups. Tips on hiring an applicator are available from EPA's Citizen's Guide to Pest Control and Pesticide Safety (available at www.epa.gov). Some general guidelines about a pesticide application that homeowners and commercial applicators should be aware of include:

- Many states (including all New England states, New York, New Jersey, Pennsylvania) have notification laws that require customers or adjacent residents receive written notice prior to an urban pesticide application. Usually this notification is provided only to those who request it through a registry.
- Pesticides should not be applied on windy days (greater than 10 mph) to avoid drift to non-target areas.
- Before the spraying, the windows and doors of the home should be closed.
- Pesticides should be kept away from plants and play areas that you do not want treated. Most tick control pesticides are for ornamental and turf use only and are not labeled for use on plants meant for human consumption. Most of these chemicals are toxic to bees and should not be applied to areas with foraging bees.
- Pesticides should not be applied near (within 25 feet) wetlands (i.e. lakes, reservoirs, rivers, streams, marshes, ponds, estuaries, and commercial fish farm ponds) or near (within 100 feet) coastal marshes or streams. Even organic pesticides are toxic to fish and aquatic invertebrates.
- Family members and pets, especially cats, should be kept off the treated area for 12-24 hours or other specified reentry interval following the treatment (generally until a spray thoroughly dries).
- Do not water the lawn after the application of a pesticide to avoid run off (there are a few exceptions with some granular products which must be watered in). Do not apply within 24 hours of rain to avoid run-off. Once the pesticide has dried, however, some materials bind tightly to the soil or vegetation and do not readily move or wash off. They will breakdown with exposure to sunlight and soil microbes.
- Avoid pesticide applications near a wellhead. The shaft of the well should be tightly sealed and the well water source should be isolated from surface water source. Most acaricides used for tick control are water insoluble and pose little risk to wells by leaching through the soil, but direct exposure should be avoided.
- Many states (including all New England states, New York, New Jersey, Pennsylvania) have laws that require signs to be posted after an urban treatment is made.

An Acaricide Primer

The purpose of this section is to serve as a reference for some basic, general material on the major classes of chemicals used in tick control. More detailed information is available from the EPA, the Cooperative Extension Service, state pesticide agencies, and independent groups, particularly over the Internet. Some sources of information are listed at the end of this section. Acaricides belong to a variety of chemical classes, which differ in their chemistry, mode of action, toxicology, and environmental impacts. They also contain "inert ingredients," chemicals that carry or enhance the application or effectiveness of the active ingredient (i.e., the actual acaricide). A variety of pesticides are also used in products to control ectoparasites on pets. Some pet care products are available over the counter and others through a veterinarian.

- **Organophosphates.** There were two organophosphate insecticides commonly used for area-wide tick control, chlorpyrifos (i.e., Dursban) and diazinon. The EPA has cancelled the residential use and some agricultural uses of chlorpyrifos and has cancelled the registration of diazinon for lawn, garden, and other residential outdoor use. Residential applications accounted for nearly 75% of the use of diazinon. Products with these chemicals are no longer used for tick control.
- **Carbamates.** Carbaryl (Sevin®) is the carbamate used in the control of ticks. Carbaryl is a broad-spectrum compound used for a wide variety of pests on the lawn, on pets, and in the home. Carbaryl in animals is readily broken down and excreted. It does not appear to cause reproductive, birth, mutagenic, or carcinogenic effects under normal circumstances, but it is a suspected endocrine disrupter. Carbaryl is extremely toxic to bees and beneficial insects, is moderately toxic to fish, but is relatively nontoxic to birds.
- **Pyrethrins.** Pyrethrum is a natural insecticide extracted from certain chrysanthemum plants. Natural pyrethrins are a group of six compounds that form the insecticidal constituents of the natural pyrethrum, which is highly unstable in light and air. Natural pyrethrins are considered knockdown agents because they rapidly paralyze insects, but many insects can detoxify the compound and recover. Therefore, pyrethrins are sometimes combined with a synergist. A synergist is a compound that enhances the toxicity of an insecticide, but is not an insecticide itself. The most common synergist used with pyrethrin is piperonyl butoxide, which inhibits the enzymes that breakdown pyrethrin. Pyrethrins also may be combined with insecticidal soaps, spreader sticker agents, silicon dioxide (desiccant) and other agents to enhance the effectiveness of the product. Pyrethrins have little residual effect, being quickly broken down by exposure to light, moisture, and air.
- **Pyrethroids.** Synthetic pyrethroids are derivatives of the natural compounds, chemically modified to increase toxicity and stability. Most of the chemicals used for area-wide tick control are pyrethroids. The pyrethroids are less volatile than the natural compounds and photostable, which provides some residual activity and greater insecticidal activity. Both pyrethrins and pyrethroids are highly toxic to fish and other aquatic organisms, but generally are much less toxic to mammals, birds and other wildlife. Pyrethroids can be skin and eye irritants. Many concentrated pyrethroid formulations are restricted to commercial use by licensed applicators because of their potential impact on aquatic organisms. However, low concentration, ready-to-use products are available for homeowner use.
- **Inert ingredients**. They may be solvents, propellants, spreaders, stickers, wetting agents, or carriers for the active pesticide chemical. Because these compounds are not the active chemical, they are labeled "inert ingredients" or sometimes "other ingredients". These compounds often make up the major part of a pesticide formulation. In some cases, the

inert ingredients may be more toxic than the active ingredient. A few examples of inerts include napththalene, petroleum distillates, and the organic solvents xylene and toluene.

- **Acaricides for control of ticks on pets**. Carbaryl and the pyrethroid permethrin are used in several flea and tick control products for dogs. Studies have indicated that use of permethrin products (i.e., K9 Advantix™, Kiltix®) can prevent the transmission of *B. burgdorferi* and *A. phagocytophilum*. Both are topical products applied to spots along or on the back of the animal. They are not for use on cats, as cats are particularly susceptible to pyrethrin poisoning. Fipronil, a phenypyrazole, is the only commercial insecticide of this chemical type. Formulated pet products are available as a spray or topical spot application (Frontline®, Frontline® Top Spot™, Frontline® Plus) for long-term control of fleas and ticks on dogs and cats. It is the material used in the Maxforce® TMS rodent bait box. Fipronil dissolves in the oils on the skin, spreads over the body, and collects in sebaceous glands and hair follicles for long-term reapplication. It is not affected by bathing or water immersion. Skin irritation may occur. Fleas are killed from 1-3 months, while ticks are killed for about a month. Trizapentadiene or formanidene compounds include one currently used material, amitraz. In livestock, it is used to control ticks, mites, and lice. It is not a skin irritant, is not readily absorbed into tissue, and degrades rapidly in the environment. Amitraz is used in a tick prevention collar for dogs (Preventic®), and one study indicated it could prevent transmission of *B. burgdorferi*. An amitraz product was one of the compounds initially evaluated for the topical treatment of deer to control *I. scapularis*.

Additional sources of information about pesticides

Environmental Protection Agency (EPA) Public Information Center (telephone 202-260-2080), National Center for Environmental Publications and Information (telephone 513-489-8190), EPA booklets or the EPA web site (www.epa.gov).

National Pesticide Information Center (NPIC) (formerly the National Pesticide Telecommunications Network) is a cooperative effort of Oregon State University and the U.S. Environmental Protection Agency (EPA). The toll-free service is staffed 6:30 am – 4:30 pm Pacific time (9:30 a.m. – 7:30 p.m. Eastern time) 7 days week, except holidays (telephone 1-800-858-7378). Information provided by the NPIC includes pesticide information, information of recognizing and managing pesticide poisonings, safety information, health and environmental effects, referrals for investigation of pesticide incidents and emergency treatment information, and cleanup and disposal procedures. Pesticide related fact sheets and other information are available at the web site (http://npic.orst.edu/). Their address is NPIC, Oregon State University, 33 Weniger Hall, Corvallis, Oregon 97331-6502.

Extension Toxicology Network (EXTOXNET) is a cooperative effort of University of California-Davis, Oregon State University, Michigan State University, Cornell University, and the University of Idaho. Primary files are maintained and archived at Oregon State University. Pesticide Information Profiles (PIPs) and Toxicology Information Briefs (TIBs) provide information on pesticide trade names, regulatory status, acute and chronic toxicological effects, signs and symptoms of poisoning, ecological effects and environmental fate, physical properties, manufacturer, and references (http://ace.orst.edu/info/extoxnet/).

State pesticide regulatory agencies can provide information on the laws and regulations governing the application of insecticides, certification of pesticide applicators, and which products are registered for use in the state. Depending upon the state the agency may be associated with the state Department of Agriculture, Consumer Protection, or Environmental Protection.

Organic Landcare Practices

Standards for organic land care practices for design and maintenance of ecological landscapes have been developed and published by the Connecticut and Massachusetts chapters of the Northeast Organic Farming Association (NOFA). Tick IPM practices are covered under pest and wildlife management guidelines. Practices that are preferred to manage ticks would include personal protection measures, making the environment unsuitable for the pest (i.e., landscape modifications), deer resistant plantings (natives recommended), fencing against deer, and herbal-based deer repellents. The use of arthropod pathogens like entomopathogenic fungi (fungi that kill insects), diatomaceous earth, insecticidal soaps and botanical insecticides are allowed under the standards. However, botanicals cannot be formulated with aromatic petroleum distillates. Ammonia or hot sauce based deer repellents are allowed. Prohibited under the organic standards are all synthetic insecticides and piperonyl butoxide as an insecticide synergist, rodenticides containing warfarin, predator urine (due to collection practices), and products containing sewage sludge (e.g., Milorganite).

Biological Control of Ticks

Ticks have relatively few natural enemies, but the use of predators, parasites, and pathogens has been examined for tick control. Tick predation is difficult to document and observations are sporadic. Most arthropod predators are non-specific, opportunistic feeders and probably have little impact on ticks. Anecdotal reports suggested that guinea-fowl or chickens may consume ticks and impact local tick abundance. However, there is no good evidence to support this and turkey foraging was not found to reduce the local density of adult ticks. A minute parasitic wasp, *Ixodiphagus hookeri*, parasitizes blacklegged ticks in a few areas of New England with superabundant deer and tick populations. However, studies indicate that the usefulness of this wasp to control *I. scapularis* is very limited. Insect parasitic nematodes have been studied as possible biological control agents. Engorged female *I. scapularis* are susceptible to certain types of nematodes, but these nematodes are too sensitive to the colder autumn temperatures when the ticks are present. The application of entomopathogenic fungi, however, is a promising approach for controlling ticks. Several fungi have been shown pathogenic to *I. scapularis*. A perimeter treatment of existing commercial formulations of the fungus *Beauveria bassiana* and with *Metarhizium anisopliae* at residential sites has been shown to control *I. scapularis* in small experimental trials. The EPA has approved *M. anisopliae* for residential outdoor grub and tick control (Tick-Ex™, an oil formulation, and Taenure™, a granular formulation; Earth BioSciences, Glastonbury, CT). At the time of this writing, additional trials and commercial development are in progress. Entomopathogenic fungi, applied like a traditional pesticide, may be an option in tick management programs, and an oil-free formulation could meet organic standards.

Lyme disease can be a preventable disease!

Surveys have consistently shown most residents in Lyme disease endemic areas consider the disease an important or very important issue that poses a high risk to members of their family. A few precautions and the management of infected ticks in the residential or recreational landscape can substantially reduce the risk of Lyme disease and other tick-associated illnesses. Prompt recognition of infection and treatment can prevent more serious manifestations of disease. While education is important to preventing or mitigating disease, landscape and host management practices combined with the judicious use of acaricides can provide excellent tick control with minimal risk or impact to the environment.

Selected Bibliography and References

Ticks and Tick Ecology

Anderson, J. F., and L. A. Magnarelli. 1999. Enzootiology of *Borrelia burgdorferi* in the northeastern and northcentral United States, pp. 385-389. *In* G. R. Needham, R. Mitchell, D. J. Horn and W. C. Welborne [eds.], Acarology IX: Volume 2, Symposia. Ohio Biological Survey, Columbus.

Anderson, J. F. 1988. Mammalian and avian reservoirs for *Borrelia burgdorferi* [Review]. Ann. N.Y. Acad. Sci. 539: 180-191.

Balashov, Y. S. 1972. Bloodsucking ticks (Ixodoidea): Vectors of diseases of man and animals. Misc. Pub. Entomol Soc. Am. 8: 159-376.

Battaly, G. R., and D. Fish. 1993. Relative importance of bird species as hosts for immature *Ixodes dammini* (Acari: Ixodidae) in a suburban residential landscape of southern New York state. J. Med. Entomol. 30: 740-747.

Durden, Lance A. and James E. Keirans. 1996. Nymphs of the Genus *Ixodes* (Acari: Ixodidae) of the United States: Taxonomy, Identification Key, Distribution, Hosts, and Medical/Veterinary Importance. Entomological Society of America, Lanham, MD. 95 pp.

Donahue, J. G., J. Piesman, and A. Spielman. 1987. Reservoir competence of white-footed mice for Lyme disease spirochetes. Am. J. Trop. Med. Hyg. 36: 92-96.

Drummond, Roger. 1998. Ticks and What You Can Do About Them, 2nd ed. Wilderness Press. 74 pp.

Ginsberg, Howard S. 1993. Ecology and Environmental Management of Lyme Disease. Rutgers University Press. 224 pp.

IJdo, J. W., C. Wu, L. A. Magnarelli, K. C. S. III, J. F. Anderson, and E. Fikrig. 2000. Detection of *Ehrlichia chaffeensis* DNA in *Amblyomma americanum* ticks in Connecticut and Rhode Island. J. Clin. Microbiol. 38: 4655-4656.

IJdo, J. W., J. I. Meek, M. L. Cartter, L. A. Magnarelli, C. Wu, S. W. Tenuta, E. Fikrig, and R. W. Ryder. 2000. The emergence of another tickborne infection in the 12-town area around Lyme, Connecticut. J. Infect. Dis. 181: 1388-1893.

Keirans, J. E., and L. Durden. 2001. Invasion: Exotic ticks (Acari: Ixodidae) imported into the United States. A review and new records. J. Med. Entomol. 38: 850-861.

Keirans, James E. and Taina R. Litwak. 1989. Pictorial Key to the Adults of Hard Ticks, Family Ixodidae (Ixodida: Ixodoidea), East of the Mississippi. Journal of Medical Entomology. 16(5): pp 435-448.

Keirans, James E. and Lance E. Durden. 1998. Illustrated Key to Nymphs of the Tick Genus *Amblyomma* (Acari: Ixodidae) Found in the United States. Journal of Medical Entomology. 35(4): pp. 489-495.

Lane, R. S., J. Piesman, and W. Burgdorfer. 1991. Lyme borreliosis: Relation of its causative agent to its vectors and host in North America and Europe. Ann. Rev. Entomol. 36: 587-609.

LoGiudice, K., R. S. Ostfeld, K. A. Schmidt, and F. Keesing. 2003. The ecology of infectious disease: Effects of host diversity and community composition on Lyme disease risk. Proc. Nat. Acad. Sci (USA).

Mather, T. N., M. L. Wilson, S. I. Moore, J. M. C. Ribeiro, and A. Spielman. 1989. Comparing the relative potential of rodents as reservoirs of the Lyme disease spirochete (*Borrelia burgdorferi*). Am. J. Epidemiol. 130: 143-150.

Mather, T. N., S. R. Telford III, A. B. MacLachlan, and A. Spielman. 1989. Incompetence of catbirds as reservoirs for the Lyme disease spirochete (*Borrelia burgdorferi*). J. Parasitol. 75: 66-69.

McDaniel, Burruss. 1979. How to Know the Mites and Ticks. Wm. C. Brown Company Publishers. Dubuque, Iowa. 335 pp. (Out-of-Print)

Oliver Jr., J. H., M. R. Owsley, H. J. Hutcheson, A. M. James, C. Chen, W. S. Irby, E. M. Dotson, and D. K. McLain. 1993. Conspecficity of the ticks *Ixodes scapularis* and *I. dammini* (Acari: Ixodidae). J. Med. Entomol. 30: 54-63.

Sonenshine, Daniel E. 1991. Biology of Ticks, Volume 1. Oxford University Press. Oxford. 447 pp.

Sonenshine, Daniel E. 1993. Biology of Ticks, Volume 2. Oxford University Press. Oxford. 465 pp.

Smith, Carroll N., Moses M. Cole, and Harry K Gouck. Biology and Control of the American Dog Tick. USDA Technical Bull. No. 905, January 1946.

Smith, R. P., Jr., E. H. Lacombe, R. W. Rand, and R. Dearborn. 1992. Diversity of tick species biting humans in an emerging area for Lyme disease. Am. J. Public Hlth. 82: 66-69.

Stafford III, K. C., R. F. Massung, L. A. Magnarelli, J. W. IJdo, and J. F. Anderson. 1999. Infection with agents of human granulocytic ehrlichiosis, Lyme disease, and babesiosis in wild white-footed mice (*Peromyscus leucopus*) in Connecticut. J. Clin. Microbiol. 37: 2887-2892.

StaffordIII, K. C., V. C. Bladen, and L. A. Magnarelli. 1995. Ticks (Acari: Ixodidae) infesting wild birds (Aves) and white-footed mice in Lyme, CT. J. Med. Entomol. 32: 453-466.

Stafford III, K. C. 1994. Survival of immature *Ixodes scapularis* (Acari: Ixodidae) at different relative humidities. J. Med. Entomol. 31: 310-314.

Stafford III, K. C. 1993. The epizootiology of Lyme disease. Northeast Wildlife 50: 181-189.

Strickland, R.K., R.R. Gerrish, J.L. Hourrigan, and G.O. Schubert. 1976. Ticks of Veterinary Importance. USDA, HPHIS, Agric. Handb. No. 485.

Telford III, S. R., T. N. Mather, G. H. Adler, and A. Spielman. 1990. Short-tailed shrews as reservoirs of the agents of Lyme disease and human babesiosis. J. Parasitol. 76: 681-683.

Telford III, S. R., T. N. Mather, S. I. Moore, M. L. Wilson, and A. Spielman. 1988. Incompetence of deer as reserviors of the Lyme disease spirochete. Am. J. Trop. Med. Hyg. 39: 105–109.

Yuval, B., and A. Spielman. 1990. Duration and regulation of the developmental cycle of *Ixodes dammini* (Acari: Ixodidae). J. Med. Entomol. 27: 196-201.

Tick-Associated Diseases

Anderson, J. F., and L. A. Magnarelli. 1994. Lyme disease: A tick-associated disease originally described in Europe, but named after a town in Connecticut. Am. Entomol. 40: 217-227.

Bakken, J. S., J. S. Dumler, S. Chen, M. R. Eckman, L. L. V. Etta, and D. H. Walker. 1994. Human granulocytic ehrlichiosis in the upper midwest United States: A new species emerging? J. Am. Med. Assoc. 272: 212-218.

Benach, Jorge L. and Edward M. Bosler, eds. 1988. Lyme Disease and Related Disorders. Annals of the New York Academy of Sciences. Volume 539.

Barbour, Alan G. 1996. Lyme Disease: The Cause, the Cure, the Controversy. The John Hopkins University Press. 258 pp.

Barbour, A. G., and D. Fish. 1993. The biological and social phenomenon of Lyme disease. Science (Washington, D.C.) 260: 1610-1616.

Breitschwerdt, E. B., and D. L. Kordick. 2000. Bartonella infection in animals: Carriership, reservoir potential, pathogenicity, and zoonotic potential for human infection. Clin. Microbiol. Rev. 13: 428-438.

Dumler, J. S., and J. S. Bakken. 1995. Ehrlichial disease of humans: emerging tick-borne infections. Clin. Infect. Dis. 20: 1102-1110.

Edlow, J. A. 2003. Bull's Eye: Unraveling the medical mystery of Lyme disease. Yale University Press, New Haven.

Eskow, E., R. V. Rao, and E. Mordechai. 2001. Concurrent infection of the central nervous system by *Borrelia burgdorferi* and *Bartonella henselae*: evidence for a novel tick-borne disease complex. Arch. Neurol. 58: 1357-1367.

Centers for Disease Control and Prevention. 2004. Lyme disease – United States, 2001-2002. MMWR 53:365-369

Centers for Disease Control and Prevention. 2002. Lyme disease - United States, 2000. MMWR 51: 29-31.

Centers for Disease Control and Prevention. 2001. Outbreak of powassan encephalitis - Maine and Vermont, 1999-2001. MMWR 50: 761-764.

Centers for Disease Control and Prevention. 2002. Tularemia - United States, 1990-2000. MMWR 51: 181-184.

Centers for Disease Control and Prevention. 1995. Recommendations for test performance and interpretation form the second national conference on serologic diagnosis of Lyme disease. MMWR 44: 590-591.

Chang, Y. F., M. J. Appel, R. H. Jacobson, S. J. Shin, P. Harpending, R. Straubinger, L. A. Patrican, H. Mohammed, and B. A. Summers. 1995. Recombinant OspA protects dogs against infection and disease caused by *Borrelia burgdorferi*. Infect. Immun. 63: 3543-3549.

Dennis, D. T., and E. B. Hayes. 2002. Epidemiology of Lyme Borreliosis, pp. 251-280. *In* J. S. Gray, O. Kahl, R. S. Lane and G. Stanek [eds.], Lyme Borreliosis: Biology, Epidemiology and Control. CABI Publishing, Wallingford, Oxon, UK.

Ebel, G. D., A. Spielman, and S. R. Telford III. 2001. Phylogeny of North American Powassan virus. J. Gen. Virol. 82: 1657-1665.

Gerber, M. A., E. D. Shapiro, G. S. Burke, V. J. Parcells, and G. L. Bell. 1996. Lyme disease in children in southeastern Connecticut. New Eng. J. Med. 335: 1270-1274.

Gholam, B. I., S. Puksa, and J. P. Provias. 1999. Powassan encephalitis: a case report with neuropathology and literature review. Can. Med. Assoc. J. 161: 1419-1422.

Gray, Jeremy, Olaf Kahl, Robert S. Lane, and Gerold Stanek. 2002. Lyme Borreliosis: Biology, Epidemiology, and Control. CABI Publishing, Oxon, UK. 347 pp.

Herwaldt, B. L., P. C. McGovern, M. P. Gerwel, R. M. Easton, and R. R. MacGregor. 2003. Endemic babesiosis in another eastern state: New Jersey. Emerg. Infect. Dis. 9: 184-188.

Hu, R., and K. E. Hyland. 1997. Human babesiosis in the United States: a review with emphasis on its tick vector. Syst. Appl. Acarol. 2: 3-16.

Kjemtrup, A. M., and P. A. Conrad. 2000. Human babesiosis: an emerging tick-borne disease. Int. J. Parasitol. 30: 1323-1337.

Klempner, M. S., L. T. Hu, J. Evans, C. H. Schmid, G. M. Johnson, R. P. Trevino, D. Norton, L. Levy, D. Wall, J. McCall, M. Kosinski, and A. Weinstein. 2001. Two controlled trials of antibiotic treatment in patients with persistent symptoms and a history of Lyme disease. N. Engl. J. Med. 345: 85-92.

Krause, P. J. 2002. Babesiosis. Med. Clin. North Am. 86: 361-373.

Krause, P. and H. M. Feder, Jr. 1994. Lyme disease and babesiosis. Adv. Pediatric Infect. Dis. 9: 183-209.

Krause, P. J., K. McKay, C. A. Thompson, V. K. Sikand, R. Lentz, T. Lepore, L. Closter, D. Christianson, S. R. Telford III, D. A. Persing, J. D. Radolf, and A. Spielman. 2002. Disease-specific diagnosis of coinfecting tickborne zoonoses: babesiosis, human granulocytic ehrlichiosis, and Lyme disease. Clin. Infect. Dis. 34: 1184-1191.

Krause, P. J., T. Lepore, V. K. Sikand, J. Gadbaw, G. Burke, S. R. Telford III, P. Brassard, D. Pearl, J. Azlanzadeh, D. Christianson, D. McGrath, and A. Spielman. 2000. Atovaquone and azithromycin for the treatment of babesiosis. N. Engl. J. Med. 343: 1454-1458.

Krause, P. J., S. R. Telford III, A. Spielman, V. Sikand, R. Ryan, D. Christianson, G. Burke, P. Brassard, R. Pollack, J. Peck, and D. H. Persing. 1996. Concurrent Lyme disease and babesiosis: Evidence for increased severity and duration of illness. J. Am. Med. Assoc. 275: 1657-1660.

Levy, S. A., S. W. Barthold, D. M. Dombach, and T. L. Wasmoen. 1993. Canine Lyme borreliosis. Comendium (Small Animal) 15: 833-846.

Magnarelli, L. A., J. W. IJdo, J. F. Anderson, S. J. Padula, R. A. Flavell, and E. Fikrig. 1998. Human exposure to a granulocytic Ehrlichia and other tick-borne agents in Connecticut. J. Clin. Microbiol. 36: 2823-2827.

Magnarelli, L. A., J. S. Dumler, J. F. Anderson, R. C. Johnson, and E. Fikrig. 1995. Coexistence of antibodies to tick-borne pathogens of babesiosis, ehrlichiosis, and Lyme disease in human sera. J. Clin. Microbiol. 33: 3054-3057.

Meek, J. I., C. L. Roberts, J. E. V. Smith, and M. L. Cartter. 1996. Underreporting of Lyme disease by Connecticut physicians, 1992. J. Pub. Hlth. Man. 2: 61-65.

Murray, Polly. 1996. The Widening Circle: A Lyme Disease Pioneer Tells Her Story. St. Martin's Press. 321 pp.

Piesman, J., and A. Spielman. 1980. Human babesiosis on Nantucket Island prevalence of *Babesia microti* in ticks. Am. Soc. Trop. Med. Hyg. 29: 742-746.

Rahn, D. W., and M. W. Felz. 1998. Lyme disease update. Current approach to early, disseminated, and late disease. Postgrad. Med. 103: 51-54, 57-59, 63-64.

Rahn, Daniel W. and Janine Evans, eds. 1998. Lyme Disease. American College of Physicians. Philadelphia, PA. 245 pp. + color plates.

Schoen, R. T. 1989. Treatment of Lyme disease. Connecticut Medicine 53: 335-337.

Scoles, G. A., M. Papero, L. Beati, and D. Fish. 2001. A relapsing fever group spirochete transmitted by *Ixodes scapularis* ticks. Vector Borne Zoonotic Dis. 1: 21-34.

Sigal, L. H. [ed.] 1995. A symposium: National clinical conference on Lyme disease. Am. J. Med. 98 (suppl 4A): 1S-90S.

Sonenshine, Daniel E. and Thomas N. Mather. Eds. 1994. Ecological Dynamics of Tick-Borne Zoonoses. Oxford University Press. Oxford. 447 pp.

Stafford, K. C., III, M. L. Cartter, L. A. Magnarelli, S. Ertel, and P. A. Mshar. 1998. Temporal correlations between tick abundance and prevalence of ticks infested with *Borrelia burgdorferi* and increasing incidence of Lyme disease. J. Clin. Microbiol. 36: 1240-1244.

Steere, A. C. 2003. Duration of antibiotic therapy for Lyme disease [editorial]. Ann. Intern. Med. 138: 761-762.

Steere, A. C. 2001. Lyme disease. N. Engl. J. Med. 345: 115-125.

Steere, A. C., S. E. Malawista, D. R. Snydman, R. E. Shope, W. A. Andiman, M. R. Ross, and F. M. Steele. 1977. Lyme arthritis: an epidemic of oligoarticular arthritis in children and adults in three Connecticut communities. Arth. and Rheum. 20: 7-17.

Straubinger, R. K., B. A. Summers, Y. F. Chang, and M. J. Appel. 1997. Persistence of *Borrelia burgdorferi* in experimentally infected dogs after antibiotic treatment. J. Clin. Microbiol. 35: 111-116.

Telford, S. R., P. M. Armstrong, P. Katavolos, I. Foppa, G. A. S., M. L. Wilson, and A. Spielman. 1997. A new tick-borne encephalitis-like virus infecting New England deer ticks, *Ixodes dammini*. Emerging Infect. Dis. 3: 165-170.

Treadwell, T. A., R. C. Holman, M. J. Clarke, J. W. Krebs, C. D. Paddock, and J. E. Childs. 2001. Rocky mountain spotted fever in the United States, 1993-1996. Am. J. Trop. Med. Hyg. 63: 21-26.

Trock, D. H., J. E. Craft, and D. W. Rahn. 1989. Clinical manifestations of Lyme disease in the United States. Connecticut Medicine 53: 327-330.

Vanderhoof-Forschner, Karen. 1997. Everything You Need to Know About Lyme Disease and Other Tick-Borne Disorders. John Wiley & Sons, Inc. New York. 237 pp.

Varela, A. S., M. P. Luttrell, E. W. Howerth, V. A. Moore, W. R. Davidson, D. E. Stallknecht, S. E. Little. 2004. First culture isolation of *Borrelia lonestari*, putative agent of southern tick-associated rash illness. J. Clin. Microbiol. 42:1163-1169.

Walker, D. H., and J. S. Dumler. 1996. Emergence of ehrlichioses as human health problems. Emerging Infect. Dis. 2: 18-29.

Wormser, G. P., R. Ramanathan, J. Nowakowski, D. McKenna, D. Holmgren, P. Visintainer, R. Dornbush, B. Singh, and R. B. Nadelman. 2003. Duration of antibiotic therapy for early Lyme disease: A randomized, double-blind, placebo-controlled trial. Ann. Intern. Med. 138: 697-704.

Wormser, G. P., R. B. Nadelman, R. J. Dattwyler, D. T. Dennis, E. D. Shapiro, A. C. Steere, T. J. Rush, D. W. Rahn, P. K. Coyle, D. A. Persing, D. Fish, and B. J. Luft. 2000. Practice guidelines for the treatment of Lyme disease. Clin. Infect. Dis. 31: S1-S14.

Personal Protection, Repellents, Risk and Transmission

Cartter, M. L., T. A. Farley, H. A. Ardito, and J. L. Hadler. 1989. Lyme disease prevention - knowledge, beliefs, and behaviors among high school students in an endemic area. Connecticut Medicine 53: 354-356.

Consumers Union. 2000. Buzz Off! Consumer Reports June: 14-17.

Costello, C. M., A. C. Steere, R. E. Pinkerton, and J. H. M. Feder. 1989. A prospective study of tick bites in an endemic area for Lyme disease. J. Infect. Dis. 159: 136-139.

Couch, P., and C. E. Johnson. 1992. Prevention of Lyme disease. Am. J. Hosp. Pharm. 49: 1164-1173.

des Vignes, F., J. Piesman, R. Heffernan, T. L. Schulze, K. C. Stafford III, and D. Fish. 2001. Effect of tick removal on transmission of *Borrelia burgdorferi* and *Ehrlichia phagocytophila* by *Ixodes scapularis* nymphs. J. Infect. Dis. 183: 773-778.

Falco, R. C. 1996. Duration of tick bites in a Lyme disease-endemic area. Am. J. Epidemiol. 143: 187-192.

Falco, R. C., and D. Fish. 1989. Potential for exposure to tick bites in recreational parks in a Lyme disease endemic area. Amer. J. Public Health. 79: 12-15.

Fradin, M. S., and J. F. Day. 2002. Comparative efficacy of insect repellents against mosquito bites. JAMA 347: 13-18.

Levin, M. L., and D. Fish. 2000. Acquistion of coinfection and simultaneous transmission of *Borrelia burgdorferi* and *Ehrlichia phagocytophila* by *Ixodes scapularis*. Infect. Immun. 68: 2183-2186.

Medical Letter Advisory Board. 1985. Insect repellents. Med. Lett. Drugs-Ther. 27: 62-64.

Nadelman, R. B., J. Nowakowski, D. Fish, R. C. Falco, K. Freeman, D. McKenna, P. Welch, R. Marcus, M. E. Aguero-Rosenfeld, D. T. Dennis, and G. P. Wormser. 2001. Prophylaxis with single-dose doxycycline for the prevention of Lyme disease after an *Ixodes scapularis* tick bite. N. Engl. J. Med. 345: 79-84.

Osimitz, T. G., and R. H. Grothaus. 1995. The present safety assessment of deet. J. Am. Mosquito Cont. Assoc. 11: 274-278.

Piesman, J., and E. B. Hayes. 2003. How can we prevent Lyme disease? N. Engl. J. Med. 348: 2424-2430.

Piesman, J. 2002. Ecology of Borrelia burgdorferi sensu lato in North America, pp. 223-250. *In* J. S. Gray, O. Kahl, R. S. Lane and G. Stanek [eds.], Lyme Borreliosis: Biology, Epidemiology and Control. CABI Publishing, Wallingford, Oxon, UK.

Piesman, J., and M. C. Dolan. 2002. Protection against Lyme disease spirochete transmission provided by prompt removal of nymphal *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 39: 509-512.

Piesman, J., B. S. Schneider, and N. S. Zeidner. 2001. Use of quantitative PCR to measure density of *Borrelia burgdorferi* in the midgut and salivary glands of feeding tick vectors. J. Clin. Microbiol. 39: 4145-4148.

Piesman, J., T. N. Mather, R. J. Sinsky, and A. Spielman. 1987. Duration of tick attachment and *Borrelia burgdorferi* transmission. J. Clin. Microbiol. 25: 557-558.

Schreck, C. E., D. Fish, and T. P. McGovern. 1995. Activity of repellents applied to skin for protection against *Amblyomma americanum* and *Ixodes scapularis* ticks (Acari: Ixodidae). J. Am. Mosq. Cont. Assoc. 11: 136-140.

Schreck, C. E., E. L. Snoddy, and A. Spielman. 1986. Pressurized sprays of permethrin or deet on military clothing for personal protection against *Ixodes dammini* (Acari:Ixodidae). J. Med. Entomol. 23: 396–399.

Shadick, N. A., L. H. Daltroy, C. B. Phillips, U. S. Lang, and M. H. Lang. 1997. Determinants of tick-avoidance behaviors in an endemic area for Lyme disease. Am. J. Prev. Med. 13: 265-270.

Shapiro, E. D., M. A. Gerber, N. B. Holabird, A. T. Berg, H. M. Feder, G. L. Bell, P. N. Rys, and D. H. Persing. 1992. A controlled trial of antimicrobial prophylaxis for Lyme disease after deer-tick bites. N. Engl. J. Med. 327: 1769-1773.

Sood, S. K., M. B. Salzman, B. J. Johnson, C. M. Happ, K. Feig, L. Carmondy, L. G. Rubin, E. Hilton, and J. Piesman. 1997. Duration of tick attachment as a predictor of the risk of Lyme disease in an area in which Lyme disease is endemic. J. Infect. Dis. 175: 996-999.

Warshafsky, S., J. Nowakowski, R. B. Nadelman, R. S. Kamer, S. J. Peterson, and G. P. Wormser. 1996. Efficacy of antibiotic prophylaxis for prevention of Lyme disease: a meta-analysis. J. Gen. Intern. Med. 11: 329-333.

Tick Distribution, Landscape and Host Management

Adler Jr., Bill. 1999. Outwitting Deer. The Lyons Press, New York, New York. 177 pp.

Anderson, J. F., R. C. Johnson, L. A. Magnarelli, F. W. Hyde, and J. E. Myers. 1987. Prevalence of *Borrelia burgdorferi* and *Babesia microti* in mice on islands inhabited by whitetailed deer. Appl. Environ. Microbiol. 53: 892-894.

Borman, F. H., D. Balmori, and G. T. Geballe. 2001. Redesigning the American Lawn: A Search for Environmental Harmony. 2nd edition. Yale University Press. 178 pp.

Carroll, M. C., H. S. Ginsberg, K. E. Hyland, and R. Hu. 1992. Distribution of *Ixodes dammini* (Acari: Ixodidae) in residential lawns on Prudence Island, Rhode Island. J. Med. Entomol. 29: 1052-1055.

Daniels, T. J., D. Fish, and I. Schwartz. 1993. Reduced abundance of *Ixodes scapularis* (Acari: Ixodidae) and Lyme disease risk by deer exclusion. J. Med. Entomol. 30: 1043-1049.

Deblinger, R. D., M. L. Wilson, D. W. Rimmer, and A. Spielman. 1993. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following incremental removal of deer. J. Med. Entomol. 30: 144-150.

DeNicola, Anthony J., Kurt C. VerCauteren, Paul D. Curtis, and Scott E. Hygnstrom. 2000. Managing White-tailed Deer in Suburban Environments: A Technical Guide. Cornell Cooperative Extension, the Wildlife Society, and Northeast Wildlife Damage Research and Outreach Cooperative. 52 pp.

Ellingwood, Mark R. and Suzanne L Caturano. 1988. An Evaluation of Deer Management Options. Publication No. DR-11. CT Department of Environmental Protection. 16 pp. (revised and reformatted, NH Fish & Game Dept., 1996).

Falco, R. C., and D. Fish. 1988. Prevalence of *Ixodes dammini* near the homes of Lyme disease patients in Westchester County, New York. Am. J. Epidemiol. 127: 826-830.

Hart, Rhonda Massingham. 1997. Deer Proofing Your Yard & Garden. Storey Books. Pownal, Vermont. 155 pp.

Hygnstrom, Scott E., Robert M. Timm, and Gary E. Larson, eds. 1994. Prevention and Control of Wildlife Damage. University of Nebraska Cooperative Extension, USDA-APHIS-Wildlife Services, and Great Plains Agricultural Council Wildlife Committee.

Levy, S. A., B. A. Lissman, and C. M. Ficke. 1993. Performance of a *Borrelia burgdorferi* bacterin in borreliosis-endemic areas. J. Am. Vet. Med. Assoc. 202: 1834-1838.

Lewis, A. 1997. Butterfly Gardens: Luring Nature's Lovelist Pollinators to Your Yard. Brooklyn Botanic Garden, Inc., Brooklyn, NY.

Maupin, G. O., D. Fish, J. Zultowsky, E. G. Campos, and J. Piesman. 1991. Landscape ecology of Lyme disease in a residential area of Westchester County, New York. Am. J. Epidemiol. 133: 1105-1113.

McDonald Jr., John E., Mark R. Ellingwood, and Gary M. Vecellio. 1998. Case Studies in Controlled Deer Hunting. Northeast Deer Technical Committee. 16 p. Available from your state wildlife management agency.

Solberg, V. B., J. A. Miller, T. Hadfield, R. Burge, J. M. Schech, and J. M. Pound. 2003. Control of *Ixodes scapularis* (Acari: Ixodidae) with topical self-application of permethrin by white-tailed deer inhabiting NASA, Beltsville, Maryland. J. Vector. Ecol. 28: 117-134.

Stafford III, K. C. 2001. An increasing deer population is linked to the rising incidence of Lyme disease. Frontiers Plant Sci. 53: 3-4.

Stafford III, K. C. 1993. Reduced abundance of *Ixodes scapularis* (Acari: Ixodidae) with exclusion of deer by electric fencing. J. Med. Entomol. 30: 986-996.

Stafford, K. C., III, and L. A. Magnarelli. 1993. Spatial and temporal patterns of *Ixodes scapularis* (Acari: Ixodidae) in southcentral Connecticut. J. Med. Entomol. 30: 762-771.

Tekulski, M. 1985. The Butterfly Garden. The Harvard Common Press, Harvard, MA.

Ward, J.S. Limiting Deer Browse Damage to Landscape Plants. Connecticut Agricultural Experiment Station Bulletin 968, November 2000.

Wilson, M. L., S. R. Telford III, J. Piesman, and A. Spielman. 1988. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following elimination of deer. J. Med. Entomol. 25: 224-228.

Wilson, M. L. 1986. Reduced abundance of adult *Ixodes dammini* (Acari: Ixodidae) following destruction of vegetation. J. Econ. Entomol. 79: 693-696.

Tick IPM and Chemical Control

Addiss, S. S., N. O. Alderman, D. R. Brown, and J. Wargo. 1999. A survey of private drinking water wells for lawn and tree care pesticides in a Connecticut town. Environmental & Human Health, Inc., North Haven, CT.

Allan, S. A., and L. A. Patrican. 1995. Reduction of immature *Ixodes scapularis* (Acari: Ixodidae) in woods by application of desiccant and insecticidal soap formulations. J. Med. Entomol. 32: 16-20.

Curran, K. L., D. Fish, and J. Piesman. 1993. Reduction of nymphal *Ixodes dammini* (Acari: Ixodidae) in a residential suburban landscape by area application of insecticides. J. Med. Entomol. 30: 107-113.

Deblinger, R. D., M. L. Wilson, D. W. Rimmer, and A. Spielman. 1993. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following incremental removal of deer. J. Med. Entomol. 30: 144-150.

Dolan, M.C., G. O. Maupin, B. S. Schneider, C. Denatale, N. Hamon, C. Cole, N. S. Zeidner, and K. C. Stafford III. 2004. Control of immature *Ixodes scapularis* (Acari: Ixodidae) on rodent reservoirs of *Borrelia burgdorferi* in a residential community of southeastern Connecticut. J. Med. Entomol. In Press.

Elfassy, O. J., F. W. Goodman, S. A. Levy, and L. L. Carter. 2001. Efficacy of an amitraz-impregnated collar in preventing transmission of *Borrelia burgdorferi* by adult *Ixodes scapularis* to dogs. J. Amer. Vet. Med. Assoc. 219: 185-189.

Fish, D. 1995. Environmental risk and prevention of Lyme disease. Am. J. Med. 98 (suppl 4A): 2S-9S.

Hansen, Michael. 1992. Pest Control for Home and Garden: The Safest and Most Effective Methods for You and the Environment. Consumer Reports Books. Yonkers, New York. 304 pp. (out-of-print)

Hayes, E. B., G. O. Maupin, G. A. Mount, and J. Piesman. 1999. Assessing the prevention effectiveness of local Lyme disease control. J. Public Health Mgt. Practice 5: 84-92.

Kamrin, Michael A. Editor. 1997. Pesticide Profiles: Toxicity, Environmental Impact, and Fate. CRC Press. 676 pp.

Mount, G. A., D. G. Haile, and E. Daniels. 1997. Simulation of management strategies for the blacklegged tick (Acari: Ixodidae) and the Lyme disease spirochete, *Borrelia burgdorferi*. J. Med. Entomol. 34: 672-683.

Olkowski, William, Shelia Daar, Helga Olkowski. 1991. Common Sense Pest Control. The Taunton Press. 715 pp.

Ostfeld, R. S., and D. N. Lewis. 1999. Experimental studies of interactions between wild turkeys and black-legged ticks. J. Vector. Ecol. 24: 182-186.

Patrican, L. A., and S. A. Allan. 1995. Laboratory evaluation of desiccants and insecticidal soap applied to various substrates to control the deer tick *Ixodes scapularis*. Med. Vet. Entomol. 9: 293-299.

Patrican, L. A., and S. A. Allan. 1995. Application of desiccant and insecticidal soap treatments to control *Ixodes scapularis* (Acari: Ixodidae) nymphs and adults in a hyperendemic woodland site. J. Med. Entomol. 32: 859-863.

Pound, J. M., J. A. Miller, and J. E. George. 2000. Efficacy of amitraz applied to white-tailed deer by the '4-poster' topical treatment device in controlling free-living lone star ticks (Acari: Ixodidae). J. Med. Entomol. 37: 878-884.

Pound, J. M., J. A. Miller, J. E. George, and C. A. LeMeilleur. 2000. The '4-Poster' passive tropical treatment device to apply acaricide for controlling ticks (Acari: Ixodidae) feeding on white-tailed deer. J. Med. Entomol. 37: 588-594.

Schulze, T. L., R. A. Jordan, R. W. Hung, R. C. Taylor, D. Markowski, and M. S. Chomsky. 2001. Efficacy of granular deltamethrin against *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) nymphs. J. Med. Entomol. 38: 344-346.

Schulze, T. L., R. A. Jordan, and R. W. Hung. 1995. Suppression of subadult *Ixodes scapularis* (Acari: Ixodidae) following removal of leaf litter. J. Med. Entomol. 32: 730-733.

Solberg, V. B., K. Neidhardt, M. R. Sardelis, F. J. Hoffman, R. Stevenson, L. R. Boobar, and H. J. Harlan. 1992. Field evaluation of two formulations of cyfluthrin for control of *Ixodes dammini* and *Amblyomma americanum* (Acari: Ixodidae). J. Med. Entomol. 29: 634-638.

Stafford, K. C., III, A. J. DeNicola, and H. J. Kilpatrick. 2003. Reduced abundance of *Ixodes scapularis* (Acari: Ixodidae) and the tick parasitoid *Ixodiphagus hookeri* (Hymenoptera: Encyrtidae) with reduction of white-tailed deer. J. Med. Entomol. In press.

Stafford III, K. C. 2002. Environmental management for Lyme borreliosis, pp. 368. In J. Gray [ed.], Lyme Borreliosis: Biology and Control. CABI Publishing, Oxon, UK.

Stafford III, K. C. 1997. Pesticide use by licensed applicators for the control of *Ixodes scapularis* (Acari: Ixodidae) in Connecticut. J. Med. Entomol. 34: 552-558.

Stafford III, K. C. 1991. Effectiveness of carbaryl applications for the control of *Ixodes dammini* (Acari: Ixodidae) nymphs in an endemic residential area. J. Med. Entomol. 28: 32-36.

Stafford III, K. C.. 1989. Lyme disease prevention: Personal protection and prospects for tick control. Conn. Med. 53: 347-351.

Wargo, J., N. O. Alderman, and L. Wargo. 2003. Risks from lawn-care pesticides including inadequate packaging and labeling, pp. 96. Environmental and Human Health, Inc., North Haven, CT.

Wilson, M. L., and R. D. Deblinger. 1993. Vector management to reduce the risk of Lyme disease, pp. 126-156. *In* H. S. Ginsberg [ed.], Ecology and Environmental Management of Lyme Disease. Rutgers University Press, New Brunswick, N.J.

Zhioua, E., M. Browning, P. W. Johnson, H. S. Ginsberg, and R. A. LeBrun. 1997. Pathogenicity of the entomopathogenic fungus *Metarhizum anisopliae* (Deuteromycetes) to *Ixodes scapularis* (Acari: Ixodidae). J. Parasitol. 83: 815-818.

About the Author

Dr. Kirby Stafford is a medical-veterinary entomologist whose research focuses on the ecology and control of the blacklegged tick. He received his B.S. in entomology and M.S. in veterinary entomology from Colorado State University and Kansas State University, respectively, and his Ph.D. in medical/veterinary entomology from Texas A&M University in 1985. After working at Penn State on a poultry pest management project, he joined the Connecticut Agricultural Experiment Station in 1987. Dr. Stafford became Chief Scientist and Head of the Department of Forestry and Horticulture in 1997.

The Nation's First State Agricultural Experiment Station

The Connecticut Agricultural Experiment Station is a state-supported scientific research institution dedicated to improving the food, health, environment and well-being of Connecticut's citizens since 1875. The Connecticut Agricultural Experiment Station investigates the growth of plants and studies their pests, insects, ticks, soil and water quality, and food safety, and performs analyses for state agencies. Station staff registers and inspect nurseries, certify honeybee colonies, and inspect thousands of individual plants or other regulated material being shipped into or from Connecticut.

The Experiment Station first opened its doors in a laboratory in Wesleyan University in Middletown in October 1875. It was moved to Yale University in 1877 and to its current location in New Haven in 1882. Today, the Experiment Station is composed of one administrative and six scientific departments with around 100 scientists, technicians, and support staff. The Experiment Station also operates a 75-acre research farm in Hamden and a farm at its Valley Laboratory in Windsor, Connecticut.

Among many information sheets and publications, The Experiment Station's web page (www.caes.state.ct.us) features this handbook and an extensive electronic Plant Pest Handbook, which covers diseases, insects, cultural and nematode problems of Connecticut. plants.

The Connecticut Agricultural Experiment Station

Putting Science to Work for Society

Founded 1875

This handbook is available in electronic format at www.caes.state.ct.us

---

The Connecticut Agricultural Experiment Station prohibits discrimination on the basis of race, color, ancestry, national origin, sex, religious creed, age, political beliefs, sexual orientation, criminal conviction record, genetic information, learning disability, present or past history of mental disorder, mental retardation or physical disability including but not limited to blindness, or marital or family status. To file a complaint of discrimination, write Director, The Connecticut Agricultural Experiment Station, P.O. Box 1106, New Haven, CT 06504 or call (203) 974-8440. CAES is an equal opportunity provider and employer. Persons with disabilities who require alternate means of communication of program information should contact the Station at (203) 974-8446 (voice); (203) 974-8502 (FAX).

Printed by Printing Plus, Portland, Connecticut

The ecology of tick-borne disease

Article *in* International journal for parasitology · August 2013

DOI: 10.1016/j.ijpara.2013.06.009 · Source: PubMed

4 authors:

Miriam Pfäffle
Karlsruhe Institute of Technology

Nina Littwin
Karlsruhe Institute of Technology

Senta Verena Muders
Karlsruhe Institute of Technology

Trevor Neil Petney
Karlsruhe Institute of Technology

International Journal for Parasitology xxx (2013) xxx–xxx

LogID 6459

Contents lists available at ScienceDirect

International Journal for Parasitology

journal homepage: www.elsevier.com/locate/ijpara

Invited Review

The ecology of tick-borne diseases

Miriam Pfäffle *, Nina Littwin, Senta V. Muders, Trevor N. Petney

Zoological Institute, Department of Ecology and Parasitology, Karlsruhe Institute of Technology, Kornblumenstrasse 13, 76131 Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 24 April 2013
Received in revised form 26 June 2013
Accepted 27 June 2013
Available online xxxx

Keywords:
Tick-borne disease
Global change
Tick
Host
Environment
Anthropogenic influence

ABSTRACT

Zoonotic diseases are major causes of infection related morbidity and mortality worldwide. Of the various arthropods capable of transmitting pathogens that cause such diseases to humans, ticks, which are vectors of more kinds of pathogens than any other group of invertebrate, have become an increasing focus of attention. This is particularly the case in the temperate northern hemisphere where they are a significant vector of human disease. Here, we provide an overview of the complex ecological systems defining the various epidemiological cycles of tick-borne diseases. We highlight the abiotic and biotic factors influencing the establishment and persistence of tick populations and their associated pathogens. Furthermore, we emphasize the dynamic nature of such systems, especially when they are under the influence of both small and large-scale anthropogenic changes to the environment. Although a great deal of work has been done on ticks and the diseases which they transmit, the very dynamism of the system means that new factors are continually arising which shift the epidemiological pattern within specific areas. We therefore consider that more detailed, long-term (i.e. at least 10 years), multidisciplinary studies need to be carried out to define why and how these pattern shifts take place and to determine their public health significance.

1. Introduction

1.1. Zoonotic diseases and ticks

Ticks transmit more pathogen species than any other group of blood-feeding arthropods worldwide (Durden, 2006), affecting humans, livestock and companion animals. Probably all tick-borne diseases (TBDs) are zoonotic while anthropogenic diseases including mosquito-transmitted diseases such as malaria, caused by *Plasmodium falciparum* and *Plasmodium vivax*, do not appear to have evolved into zoonoses. There is one possible exception in the relapsing fever pathogen, *Borrelia duttoni*, which was long considered to be anthropogenic. Recent evidence, however, has shown that this species can infect domestic pigs and chickens and that it is probably also zoonotic (McCall et al., 2007).

Tick-borne zoonoses have been known since the second half of the 19th century (Hoogstraal, 1967; Hoogstraal, 1977. Tick-borne diseases of humans – a history of environmental and epidemiological changes. Medical Entomology Centenary. Symposium Proceedings, pp. 48–55.) and represent some of the world's most rapidly expanding arthropod-borne diseases (Committee on Lyme Disease and Other Tick-Borne Diseases: The State of the Science; Institute of Medicine, 2011). Diseases such as tick-borne encephalitis (TBE) and Rocky Mountain spotted fever, although known for many years, were either locally confined and/or showed a low prevalence of infection (e.g. Wolbach, 1919; Chumakov and Seitlenok, 1940). The major impact of TBDs on the general public in Europe and North America first became evident with the detection of *Borrelia burgdorferi* as the causative agent of Lyme disease (LD)) in the 1980s (Burgdorfer et al., 1982; Granström, 1997) and the recognition of its medical significance, wide distribution and high prevalence (O'Connell et al., 1998; Sood, 2002). Since then the number of recognized, medically important TBDs has increased dramatically, undoubtedly due to the stimulus generated by the impact of LD. For instance, more than 10 new *Rickettsia* spp. pathogenic to humans have been described since 1984, and the notifiable TBDs in the United States of America (USA) increased from two in 1990 to five in 1998 (Paddock and Telford, 2011). Not only is the number of newly recognized TBDs increasing, but also the number of case reports. For instance, the reported numbers of LD in the USA increased by 101% in a 14 year period between 1992 and 2006 (Bacon et al., 2008). In Germany, TBE is notifiable country-wide and cases of borreliosis have become notifiable in nine federal states over the last few years (Robert Koch Institute, http://www.rki.de/DE/Content/Infekt/EpidBull/Merkblaetter/Ratgeber_LymeBorreliose.html#doc2398672bodyText13, accessed 22 July 2013). During the last two decades, new endemic foci of TBE and an increase in the number of cases have been reported throughout Europe. Even in Austria, where the coverage of vaccination is high and incidence has decreased by 90%, the risk of an unvaccinated person

* Corresponding author. Tel.: +49 721 608 42701; fax: +49 721 608 47655.
E-mail address: miripfaeffle@web.de (M. Pfäffle).

0020-7519/$36.00 © 2013 Australian Society for Parasitology Inc. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

contracting TBE is likely to be higher now than 30 years ago (Lindquist and Vapalahti, 2008).

In this review our aim is to provide a broad overview of the abiotic and biotic factors which influence the distribution and abundance of predominantly ixodid ticks, to consider how these factors influence the transmission dynamics of tick-borne pathogens (TBPs), and finally to consider how the anthropogenic changes to the environment, both at small and at large scales, influence these dynamics. We will also highlight certain controversial aspects of the complex, dynamic host-tick-pathogen system and point out the need for strong interdisciplinary cooperation in order to elucidate the reasons for current changes in tick distribution and abundance.

Although the number of publications on tick ecology and tick-borne disease in increasing rapidly, most of these are short-term studies, only considering a single aspect within the complex host-tick-pathogen system, and are often based on limited data sets. For a full understanding of the epidemiology of these diseases, it is essential to understand the complex interaction between ticks, their hosts, their environment and the pathogens which they transmit over a long enough period to be able to determine annual variation (Ostfeld et al., 2006). This cannot be done by ecologists alone because geological, geoecological and climatic factors, including global climate change, are important, as are changes in landscape, land use and human behaviour leading to increased (or decreased) contact times with infected ticks.

1.2. Ticks as vectors

To date, almost 900 tick species have been described. These are divided into three families: the Argasidae or soft ticks (191 species), the Ixodidae or hard ticks (701 species) and the Nuttalliellidae consisting of only one species, *Nuttalliella namaqua* (Guglielmone et al., 2010). The generic taxonomy of argasid ticks is currently highly controversial with different authorities listing between four and 10 valid genera (Guglielmone et al., 2010). The genera *Argas*, *Ornithodoros* and *Carios*, if recognized, are all of medical importance for humans. *Argas monolakensis*, for example, transmits Mono Lake virus, while various relapsing fever *Borrelia* spp. are transmitted by a variety of *Ornithodoros* spp. (Estrada-Peña and Jongejan, 1999; Jongejan and Uilenberg, 2004). The Ixodidae consist of 13 current genera of which the most important for humans are *Amblyomma*, *Dermacentor*, *Haemaphysalis*, *Hyalomma*, *Ixodes* and *Rhipicephalus* (Estrada-Peña and Jongejan, 1999; Guglielmone et al., 2010).

Each ecological, physiological and behavioral characteristic of a tick determines the likelihood and route of contact with its host, as well as its ability to survive and transmit a pathogen, therefore directly affecting its performance as a vector (Randolph, 1998). Ticks differ from other arthropod vectors in various ways and they open up habitats for pathogens in areas where, for example, mosquitoes are not able to transmit diseases due to constraining abiotic factors (L'vov and Gostinshchikova, 1970). Their low mobility forces them into a way of life which makes them more vulnerable to a wide range of changing climatic conditions (questing on vegetation) or to specialized protective host responses (living in or near nests or the burrows of their hosts) (Randolph, 1998). They usually invest less energy in finding a host than flying vectors but can use their energy reserves to survive for relatively long periods, in some cases for many years (Oliver, 1989). They also use, compared with other arthropod vectors, more energy in the uptake of a usually large blood meal, which enhances the tick's potential as a vector (Randolph, 2004a). Unlike other blood-feeding arthropods, with some exceptions, every life history stage of a tick feeds only once before moulting or oviposition (female argasids feed several times and lay eggs after each blood meal), but feeding occurs over a prolonged period, in some ixodid species up to 14 days (Kröber and Guerin, 2007). While insect vectors approach many different host individuals per generation, members of the Argasidae feed on very few hosts and members of the Ixodidae on a maximum of three individual hosts per lifetime (Oliver, 1989).

In order to use a tick as a vector, a pathogen must survive transstadially (from one life history stage to the next) or, more rarely, trans-ovarially from female to egg. Thus the pathogen has to maintain itself through the tick's developmental phases, which can last several months to years depending on the species and environmental conditions, and then through transmission to a new host. This means that a pathogen depends heavily on the development, survival and reproductive rate of its tick vector and the tick's developmental, stage-specific host relationships (Randolph, 1998). A tick's way of life usually precludes the pathogen's use of alternative transmission routes and therefore limits the distribution of TBDs to areas where its tick vector and its hosts are able to survive and establish stable populations.

2. Factors influencing tick distribution and abundance

Tick-borne diseases such as LD occur in environments where the presence of vector-competent ticks, the aetiological agent and reservoir hosts overlap (Barbour and Fish, 1993). Human exposure to tick-borne pathogens, in turn, can only occur within these geographic locations (Gage et al., 2008; Jaenson et al., 2012). Therefore, a habitat suitable for the presence and propagation of tick-borne pathogens has to primarily meet the basic requirements of the ticks and their hosts.

2.1. Microclimate and climate

The microclimate is composed of the suite of micro-scale climatic conditions measured in defined areas, for example, near the ground surface (Geiger, 1965; Chen et al., 1999), including temperature, wind speed, degree of exposure, saturation deficit (SD) and soil moisture. Variations in microclimate can increase or decrease the survival chances and the developmental rate of a tick, induce changes in population growth, behavior, susceptibility to pathogens, incubation period of pathogens, seasonality of activity and pathogen transmission (Norval, 1977; Campbell and Glines, 1979; Koch and Dunn, 1980; Fujimoto, 1989; Peavey and Lane, 1996; Hunter, 2003; Süss, 2003; Brownstein et al., 2005; Dantas-Torres and Otranto, 2011).

This applies not only to hard ticks but also to soft ticks, both of which show very narrowly defined temperature and SD tolerance ranges for development, activity and survival (Vial, 2009). The measure of water content and therefore the drying power of the air, which is a measure of the likelihood/length of tick survival, are best expressed as SD. Many studies also use relative humidity (RH), which, when it reaches a certain threshold, is an indication of the tick's ability to rehydrate. For example, *Ixodes ricinus*, *Dermacentor variabilis* and *Amblyomma cajennense* only survive when the RH in their microhabitat is not lower than 80% for extended periods of time (Kahl and Knülle, 1988). The longevity of these species is drastically shortened when the equilibrium humidity drops below 80% (Knülle, 1966).

The overall tolerance to temperature extremes and desiccation, however, varies with species, developmental stage, sex, age and physiological condition (Needham and Teel, 1991). Unfed larvae of *Rhipicepalus sanguineus* sensu lato (Kolonin, 2009; Dantas-Torres, 2010; Guglielmone et al., in press) show a higher heat stress resistance and tolerate 1 h of exposure to temperatures up to 50 °C at a RH of 97% while*Ixodes scapularis*, a tick which is associated with high humidity and mild winter temperatures, displays

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

high mortality rates at temperatures of only 30 °C (Yoder et al., 2006). Madder et al. (2005) compared the survival of adults of two African ticks in relation to different temperature and RH conditions. The survival rate of *Rhipicephalus zambesiensis*, a tick adapted to hot and dry conditions, was higher under extreme conditions with higher temperatures and lower RH than that of *Rhipicephalus appendiculatus*, which is found in cooler and wetter areas.

Interstadial development, such as pre-oviposition, pre-eclosion and premoult periods, depends on the ambient temperature, with very low and very high temperatures and high SDs potentially preventing successful hatching and development by increasing mortality (Ogden et al., 2004, 2008a; Petney et al., 2011). For *I. ricinus*, climate plays an important role at the northern limit of its distribution (Dautel and Knülle, 1997). The damaging effects of very cold temperatures are cumulative and increase the winter mortality rate, especially in diapausing engorged larvae and nymphs (Gray, 1981; Dautel and Knülle, 1997). Additionally, the moulting stages of this tick are very vulnerable to cold temperatures, meaning that if summer temperatures do not favour complete development before the onset of winter, they are unlikely to survive moderate frosts (Gray et al., 2009). The southern limit of the distribution of this species is determined by high temperatures and SDs leading to unsuitable environmental conditions (Estrada-Peña, 2001b).

For *I. scapularis*, the colder the environment, the longer the interstadial developmental periods, the total generation time and the greater the proportion of ticks that die before reproduction (Ogden et al., 2006b). Additionally, in an 8 year study on *I. scapularis* populations in a LD focus in Illinois, USA, Jones and Kitron (2000) related extreme weather events such as drought in 1 year with decreasing larval density on both the vegetation and the tick's most important host, the white-footed mouse (*Peromyscus leucopus*). In contrast cumulative rainfall was positively correlated with larval density.

Questing ticks are exposed to variable climatic conditions, which often do not correspond to their equilibrium humidity and thus lead to water loss (Knülle and Rudolph, 1982). To prevent desiccation, ticks leave their questing spot occasionally and return to the leaf litter, where the RH is higher, in order to rehydrate. The questing duration is negatively correlated with the SD in the case of *I. ricinus* (Perret et al., 2004), which means that the hotter and drier the environment, the less time ticks spend questing on the vegetation.

The preferred questing conditions vary between the nymphs of two tick species which can be found in similar habitats in the USA. *Amblyomma americanum* and *I. scapularis* differ in the time of day and microclimatic conditions at which they prefer to quest. *Ixodes scapularis* is predominantly found early and late when temperatures and SD are lower (higher humidity), while *A. americanum* is more often found in the late morning and early afternoon, when temperatures and SD are higher (Schulze et al., 2001; Schulze and Jordan, 2003). *Ixodes scapularis* is substantially less tolerant to higher SDs than *A. americanum*. Its activity period thus occurs at a time when the danger of desiccation is lowest, which at the same time is correlated with the main activity period of one of its main hosts, the white tailed deer, *Odocoileus virginiana*. The reasons for the daytime questing of *A. americanum* are much less clear. Although much more tolerant to high temperatures and SDs, it also attaches predominantly to nocturnal and crepuscular hosts. Schulze and Jordan (2003) suggested that this tick may actively seek out its hosts when they are resting during the daylight hours.

Both species transmit zoonotic disease to humans but the spectrum of these diseases differs. *Amblyomma americanum* is a vector of *Ehrlichia chaffeensis*, the causative agent of human monocytic ehrlichiosis, *Ehrlichia ewingii* (human and canine granulocytic ehrlichiosis), *Borrelia lonestari*, which has been associated with a rash, *Francisella tularensis* (tularemia) as well as various *Rickettsia* spp. (Goddard and Varela-Stokes, 2009). *Ixodes scapularis* is the most important vector of *B. burgdorferi* (LD) in North America and also transmits *Anaplasma phagocytophilum* (human anaplasmosis) and *Babesia microti* (human babesiosis) (De la Fuente et al., 2008). Thus, the pattern of human activity, whether mornings, evenings or at midday, will determine the likelihood of which diseases can be contracted.

Most ticks show seasonal variation in activity, differing between species and developmental stages. Nymphs of *Ixodes pacificus* show different seasonal activity patterns, depending on the type of habitat and the related climatic factors. Under dryer and warmer conditions, nymphs begin to quest earlier and have an overall shorter activity peak than under colder and more moisture-rich conditions (Eisen et al., 2002). A similar pattern exists for *I. ricinus* in Europe. In central Europe, northern England and Scotland, nymphs and adults (sometimes larvae) show a bimodal pattern, with activity peaks in spring and autumn, while *I. ricinus* from Ireland and southern England have only one peak in spring or early summer (Kurtenbach et al., 2006). This is related to a milder climate in Ireland and southern England provided by the Gulf Stream. Burri et al. (2011) point out in a study on *I. ricinus* in Switzerland that milder temperatures allow activity earlier in the year, whereas questing behavior is delayed in areas with lower average temperatures (e.g. in higher altitudes) due to delayed development caused by colder climatic conditions (Jouda et al., 2004). Such changes in development lead to changes in the patterns of seasonal activity making tick cohorts available to different diapause windows (Gray et al., 2009). Randolph (2002) quantitatively analyzed the population dynamics of *I. ricinus* in England, providing a model for such work in other areas within the distributional range of *I. ricinus* where climatic and habitat conditions vary substantially from those found in the UK.

2.2. Habitat characteristics

Ixodid ticks spend up to 99% of their lives off the host, except for one- and two-host ticks which normally live in arid, harsh environments where off-host survival is difficult (Oliver, 1989). The microclimatic characteristics discussed above are directly dependent on the characteristics of the habitat in which the tick and their hosts live (Norval, 1977; Chilton and Bull, 1994; Adeyeye and Phillips, 1996; Chilton et al., 2000; Gage et al., 2008). The canopies of woody plants, for example, modify the microclimate beneath and around them by intercepting precipitation and by shading, which influences the soil moisture (Breshears et al., 1998). In contrast to intercanopy patches, canopy patches normally have lower soil temperatures during warmer and higher soil temperatures during colder days as a result of shading and leaf litter accumulation (insulation effect). They additionally receive less rainfall due to foliar interception (Pierson and Wight, 1991; Breshears et al., 1997, 1998). The soil temperature itself has an influence on soil evaporation, with increasing temperatures leading to an increase in evaporation rates (Hillel, 1980). Therefore, more shielded habitats with a permanent leaf litter layer providing a more constant microclimate benefit the development of ticks and the establishment of tick populations. It is this specific microclimate that must be considered when discussing tick survival (Daniel and Dusabek, 1994). SD and RH also depend on the soil water content and soil pore size, which can influence the ticks' ability to hide from direct sunlight, for example in desert environments (Fielden and Rechav, 1996; Schwarz et al., 2009).

For *I. ricinus*, undergrowth and shrub cover provide an intermediate temperature but a high humidity, and more ticks are found in deciduous than in coniferous forests (Schwarz et al., 2009; Williams and Ward, 2010). Lindström and Jaenson (2003) investigated

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

the influence of different vegetation types on the abundance of *I. ricinus* in Sweden. The abundance of nymphs was significantly higher in forest areas compared with open fields, while the highest abundance was found in beech forests (40 nymphs/100 m^2). In warmer Mediterranean climates, *I. ricinus* is more abundant in habitats with secondary plant growth such as river canopies, heterogeneous pine forests or deciduous heterogeneous forests, as Estrada-Peña (2001a) revealed in a study from Spain. This was attributed to the shrub cover and litter depth in forest habitats creating more favorable microclimatic conditions than open fields.

A study on *I. scapularis* in Wisconsin, USA showed that the presence and abundance of this tick varied in different habitats, although the host populations were adequate (estimated by small mammal trapping) (Guerra et al., 2002). Here too, tick presence correlated positively with deciduous forests and negatively with grasslands. This applies for a number of other tick species (see e.g. Semtner et al., 1971; Kolonin et al., 1981; Fourie et al., 1996).

Altering suitable habitats by either mechanical and/or chemical treatment can change the microclimate in a way that negatively affects tick populations and their development (Hoch et al., 1971). This was nicely demonstrated by Meyer et al. (1982) who investigated the potential for habitat modification, which changed both microclimatic temperature and humidity conditions, together with animal control and standard spraying as control methods against *A. americanum*. Of these, only habitat modification was successful in reducing both free-living nymphs and tick burdens on cattle.

The "Normalized Difference Vegetation Index" (NDVI), which gives a measure of photosynthetic activity on the ground, derived from a combination of the red and near-infra-red channels of satellite data, has been shown to be a good predictor of tick (and TBD) abundance and can explain more than 50% of the variation in tick abundance in an area (Estrada-Peña, 2001b). Kitron and Kazmierczak (1997) used the NDVI to identify vegetation and differentiate between agricultural land and wooded areas in Wisconsin. They found that high NDVI values in spring and fall were strongly correlated with both *I. scapularis* distribution and human disease incidence. Using the NDVI to predict the future distribution of *I. scapularis* in Canada, Ogden et al. (2006a) suggested that tick populations would be able to establish in more northern woodland areas, in contrast to Carolinian forests where most populations now occur. Nevertheless, it is not possible to use the NDVI as a universal index to predict tick distribution. *Rhipicephalus appendiculatus* distributions correlated with NDVI values in Kenya, while in the neighboring Ethiopia this tick does not occur (Kolonin, 2009), despite suitable vegetation (NDVI) and climatic values (CLIMEX) (Perry et al., 1991). Although the CLIMEX model is outdated – it cannot capture fine-scale suitable habitats and is not able to simulate local specific population dynamics – other statistical analyses and more recent models also detected the habitat suitability of the Ethiopian Highlands for *R. appendiculatus* (see Randolph, 1999; Leta et al., 2013). The most likely cause for the absence of this species in the Ethiopian Highlands, despite suitable habitat and host populations, is that this tick is has not been introduced from eastern African countries, where it is endemic, due to natural, physical barriers between these countries which are unsuitable for tick survival (Leta et al., 2013).

2.3. Hosts

2.3.1. Host suitability and tick dispersal

Access to potential hosts species and their population densities are critical for the development and survival of ticks (Kirstein et al., 1997; Gray et al., 1999; Estrada-Peña, 2001b; Wood and Lafferty, 2012). For some tick species, such as the generalist *I. ricinus*, which occurs on hundreds of different hosts including reptiles, birds and mammals, the presence of a potential host is likely in most habitats, whereas other species may only be found on one or a few host species, e.g. *Ixodes lividus* which is specific for sand martins, *Riparia riparia* (Ulmanen et al., 1977; Petney et al., 2011). The persistence of specialist ticks therefore relies on the presence of these host species and can be severely threatened if their hosts are endangered, probably leading to co-extinction if their host should die out (Durden and Keirans, 1996; Miller et al., 2007; Mihalca et al., 2011).

The behaviour of hosts is an important factor in the distribution and dispersal of ticks (Estrada-Peña, 2001b; McCoy et al., 2001), which have only limited independent movement (McCoy et al., 1999; Miller et al., 2007; Petney et al., 2011). The movement of hosts through the landscape facilitates dispersion, including invasion into new regions (Léger et al., 2013). The chance of being picked up by a suitable host is increased by high population densities and diverse communities of hosts, which might be a reason for the predominant association of many species of hard tick larvae and nymphs with small mammals (Krasnov et al., 2002; Kiffner et al., 2011b). Such mammals, in particular, offer the immature stages of ixodid ticks the advantage of reaching suitable feeding sites (Schwarz et al., 2009; Kiffner et al., 2011b), wheareas big game animals offer large blood meals, serving as key hosts for adult ticks and more strongly influencing tick distribution (Wilson et al., 1984; Duffy et al., 1994; Estrada-Peña, 2001b; Léger et al., 2013).

Red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) are common and well-studied species in Europe (De la Fuente et al., 2004; Kiffner et al., 2010) which are frequently parasitized by *I. ricinus*, *Dermacentor marginatus* and *Hyalomma marginatum* (Pichon et al., 1999; Ruiz-Fons et al., 2006; Kiffner et al., 2010). Roe deer is the most synanthropic and widespread deer species in Europe and plays an outstanding role as a host for ticks (Rizzoli et al., 2009; Vor et al., 2010; Kiffner et al., 2011a). Tick abundance is positively correlated with deer abundance and hence zones with a high density of cervids are considered areas with a higher disease risk (Pichon et al., 1999). The most important cervid species in North America is the white-tailed deer (*Odocoleus virginianus*) which is a suitable host for the tick species *I. scapularis* (Smith et al., 1990; Fish and Childs, 2009). Deer numbers have increased significantly over the last century throughout Europe (Fuller and Gill, 2001) and North America (Nelson et al., 2000).

Besides the high population densities of these hosts, ticks may also profit from their social activities: adult roe deer are territorial in spring and summer, which involves the dominant male chasing away subadult or subdominant individuals, providing the chance for ticks to be distributed quickly and effectively over long distances. Roe deer are known to migrate more than 100 km, although distances up to a few kilometres are usual (Mysterud, 1999; Vor et al., 2010). White-tailed deer have been documentend to travel 23–45 km in 31–356 h (minimum 2.1–18.6 km/day) over two to four periods of travel (Nelson et al., 2004), increasing the range and distribution of associated ticks such as *I. scapularis*.

Since birds are highly mobile and can travel great distances in a relatively short time, they are also likely to play a major role as dispersers of ticks and TBD agents (Olsen et al., 1995; Bjöersdorff et al., 2001; Gern, 2008). Ogden et al. (2008b) estimate that migratory birds disperse 50–175 million *I. scapularis* ticks across Canada each spring, implicating migratory birds as significant in tick range expansion.

Once introduced into a new and appropriate ecosytem, ticks may infest suitable local animals or even evolve associations with new hosts. In New Caledonia, for example, the cattle tick *Rhipicephalus* (*Boophilus*)*australis* (previously recognized as *R.* (*B.*) *microplus*; *R. australis* was reinstated for Australia and New Caladonia by Estrada-Peña et al. (2012a,b) has evolved in contact with two sympatric host species into two differentiated genetic pools: on cattle, its original host and on rusa deer (*Rusa timorensis*), a new host for the tick (De Meeus et al., 2010). This genetic isolation, while in

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

sympatry, has occurred over a relative short period of time, within fewer than 244 tick generations (De Meeus et al., 2010).

2.3.2. Acquired resistance against ticks

Tick infestation and the development of pathogens in both ticks and their vertebrate hosts are mediated by species-specific molecular mechanisms (Rubaire-Akiiki, 1990; De la Fuente et al., 2008), but are also modified by the host individual's age, sex and immune status (Kazmierczak and Burgess, 1989; Szep and Moller, 1999).

The immune system of the host is stimulated by both the infestation of the tick and infection with TBPs (Brossard and Wikel, 2004). The immune system of the host activates innate and acquired host defenses against infestation, the latter involving humoral and cellular immunoregulatory and effector pathways (Wikel and Bergman, 1997). Tick feeding induces a complex array of host immune regulatory and effector responses involving antigen-presenting cells, cytokines, immunoglobulins, complement and T-lymphocytes (Wikel et al., 1997). The development of acquired resistance can lead to an influx of cells into the dermis and the epidermis surrounding the tick's mouthparts (Wikel and Bergman, 1997). Basophils together with eosinophils are recruited to the site of tick attachment and induce tick rejection by local basophil degranulation (Brown et al., 1982). Basophil infiltrates also increase the vascular permeability at tick feeding sites, causing enhanced oedema formation, providing only a protein-low serum (Ribeiro, 1989). Histamine produced by the host inhibits tick salivation and engorgement (Wikel, 1996). Langerhans cells trap salivary antigens and migrate to the lymph nodes where they act as antigen-presenting cells for specialized lymphocytes. Antibodies against tick-specific antigens are produced and contribute, together with the complement, to acquired resistance (Allen et al. 1979; Nithiuthai and Allen, 1985).

Although ticks have evolved countermeasures to suppress host immune reactions and to facilitate blood ingestion, the balance between host defense and tick induced modulation of host defense is quite an important factor for tick survival and pathogen transmission (Brossard and Wikel, 2004). The bank vole (*Myodes glareolus*) is a natural host for *I. ricinus* but develops acquired resistance to these ticks, which can be generally expressed by reduced attachment success, engorgement size and weight, and tick survival (Wikel and Bergman, 1997; Hughes and Randolph, 2001b). This is also the case for infestations of *M. glareolus* with *Ixodes trianguliceps* (Randolph, 1994). However, acquired resistance to *I. ricinus* or *I. trianguliceps* does not develop in the yellow-necked mouse, *Apodemus flavicollis*, which is another natural host for these species (Randolph, 1994; Dizij and Kurtenbach, 1995).

Acquired resistance has also been shown in other host-tick systems, e.g. the resistance of European (*Bos taurus*) and zebu cattle (*Bos indicus*) to *R.* (*B.*) *australis* (= *microplus*) (Riek, 1962) or of rabbits to *R. appendiculatus* (Dobbelaere et al., 1987; Fivaz et al., 1991). Nevertheless, acquired resistance and the intensity of reaction depend on host species and the rate of exposure to tick infestation (Randolph, 2001). As an additional complicating factor, host hormone status may also influence the development of immunity. Hughes and Randolph (2001b) showed that testosterone affects the acquired resistance to *I. ricinus* in *M. glareolus*. High testosterone levels lead to reduced innate and acquired resistance against the ticks and their associated pathogens in the hosts.

3. Factors influencing transmission dynamics

In order for an infection to become established or a pathogen to be transmitted at least two ticks have to feed on the same individual host, not necessarily at the same time, one infecting the host (this infection has to become established in the host) and one becoming infected via the host. This pattern may be modified by tick-to-tick transmission (co-feeding). One characteristic of ticks or parasites in general, is their tendency to occur in an aggregated or overdispersed pattern, both in a host population as well as on an individual host (e.g. Andrews et al., 1982; Petney and Fourie, 1990; Petney et al., 1990). This facilitates the co-feeding process in which the host does not become infected but an uninfected tick ingests the pathogen when an infected tick introduces the pathogen to the host via its saliva and an uninfected tick feeding alongside the infected tick ingests the pathogen (Labuda et al., 1993a,b). Thus even if the host itself does not become infected, it is required for disease transmission between the different tick life history stages. For example, in contrast to *B. burgdorferi* sensu lato (s.l.), where patent infections can persist in a susceptible host over weeks and months, the viraemia caused by infections with TBE virus (TBEV) is less persistent, making it less likely that the pathogen is transmitted through an infected host but through ticks in which an infection can persist throughout their life (Nosek et al., 1967). Transmission of TBEV normally occurs via co-feeding, with infected nymphs feeding on the same host at the same time as uninfected larvae (Labuda et al., 1993a,b). Therefore, the maintenance of TBE foci depends on large numbers of uninfected larvae feeding next to infected nymphs on a rodent host.

3.1. Abiotic conditions

3.1.1. Climate

The close relationship between pathogens and their tick vectors makes the pathogens susceptible to the abiotic factors affecting ticks. For instance, the likelihood of *R. sanguineus*, a vector of *Rickettsia conorii* (the causative agent of Mediterranean spotted fever) and *Rickettsia rickettsii* (Rocky Mountain spotted fever), attaching to hosts other than dogs, including humans, increases with warmer summer temperatures. This is related to a warming-mediated increase in the host-seeking behaviour of *R. sanguineus* leading to a higher risk of infection with *Rickettsia* spp. (Parola et al., 2008; Socolovschi et al., 2009).

Bioclimatic threshold temperatures affect the transmission of TBDs (Lindgren et al., 2000). The occurrence of LD in the northeast of the USA is correlated with monthly precipitation, drought events and temperature, with late spring and early summer precipitation being the most significant climatic factors related to the disease incidence (Jones and Kitron, 2000; Estrada-Peña, 2002; McCabe and Bunnell, 2004).

If the activity of *I. ricinus* begins earlier in the year or indeed continues throughout winter there will be an increase in the duration over which transmission can occur (Burri et al., 2011). However, climatic conditions and thus transmission likelihood are also dependent on altitude. Thus the prevalence of *B. burgdorferi* s.l. infections in nymphs was negatively correlated with altitude in a Swiss study, reducing the likelihood of transmission in higher areas (Jouda et al., 2004). Locally, focal warm and dry climatic conditions reduce the questing density of *I. ricinus*, the proportion of hosts with co-feeding larval and nymphal ticks and, therefore, the transmission efficiency of enzoonotic TBEV (Burri et al., 2011).

From the standpoint of the pathogen, infection with *B. burgdorferi* spirochetes in nymphs kept at temperatures of 27 °C or less for 6 months was persistent, while only 10% of nymphs kept at 30 °C and 0% of nymphs kept at 37 °C maintained their infections (Shih et al., 1995). Nymphs were already unable to infect rodent hosts after being incubated at temperatures higher than 27 °C for 2 weeks (Shih et al., 1995).

Estrada-Peña et al. (2012a,b) discussed the limited literature currently available on the direct role of temperature on disease transmission and suggested that tick stress response (TSR), questing behavior and pathogen transmission are interconnected. TSR

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

can be initiated by temperature changes and works against the negative effects of heat shock and pathogen infection on the questing behavior as well as the longevity of ticks.

3.1.2. Habitat characteristics

Ticks find their hosts either passively by questing on vegetation, waiting in a host's nest or burrow or actively by moving toward more distant stimuli. Micro- and macroclimatic factors influence this behavior (Knap et al., 2009) and are therefore likely to decrease or increase the human risk of becoming infected with a TBP (Rizzoli et al., 2009).

As ticks are passive dispersers, not every habitat that is basically suitable for the establishment of tick populations actually harbours ticks and thus TBP transmission is not possible in these areas. A variety of other landscape parameters, such as habitat connectivity, also contribute to the potential establishment of a stable vector population and, therefore, habitat suitability for the occurrence of TBPs (Estrada-Peña, 2003).

The requirements of *I. ricinus* for specific temperature and SD conditions are consistent with the factors stated by Montomoli (2009, A new seroepidemiological survey in Italy. Lecture, ISW Vienna, http://www.isw-tbe.info, accessed 24 April 2013), providing optimal habitat and microclimatic conditions for TBEV infection of ticks, namely an average annual temperature of approximately 8 °C, a high RH and earth moisture $\geqslant$92%. Infected ticks are frequently found in areas where different types of vegetation are located in close proximity (Montomoli, 2009. A new seroepidemiological survey in Italy. Lecture, ISW Vienna, http://www.isw-tbe.info, accessed 24 April 2013), such as around the edges of forests with neighbouring vegetation such as grassland, forest clearings, river meadows and marshlands, forest plantations with thick undergrowth and shrubs, and in transient areas between deciduous and coniferous forests (Süss, 2003).

Lindström and Jaenson (2003) stated that reforestation in Sweden was likely to increase *I. ricinus* abundance and, in addition, the risk of TBP transmission because forest ecosystems act as a buffer and prevent climatic extremes and excessive microclimatic variability. A study carried out in the State of New York, USA, showed that the composition of fine scale structures such as understory vegetation may steer vector density and allow prediction of the prevalence of infection in small mammals, with an increasing understory density of herbaceous foliage and underbrush shrubs leading to increasing prevalences of *B. burgdorferi* in small mammal hosts (Prusinski et al., 2006).

The distinction between the wide range of vegetated land cover types included in such habitats in Europe and North America, especially between arable and abandoned fields, confirms the negative impact of agricultural land on TBE incidence (Vanwambeke et al., 2010). An examination of land cover variables such as landscape composition revealed that a greater area, larger patch size of forest, and known habitat for vectors and hosts were related to higher disease incidence (Vanwambeke et al., 2010). Conversely, TBE incidence was lower not only where there were relatively large areas of unfavorable land cover, such as arable land, but also where forests were surrounded by more agricultural land (Vanwambeke et al., 2010).

3.2. Hosts

Although both the host and the tick can serve as reservoirs for a wide range of viral, bacterial and protozoan pathogens (Socolovschi et al., 2012), vector potential is severely constrained by the contact rates between hosts and ticks per blood meal (Randolph, 2004a). In addition, host competence is determined by complement sensitivity or resistance. This is both host as well as pathogen-specific and is one of the crucial factors governing host-pathogen relationships, as complement-mediated killing determines the reservoir competence of a host species (Bhide et al., 2005). Thus, the species-specific pattern of viability and/or lysis of pathogens determine the reservoir competence of hosts and, hence, play a key role in the tick infection rate (Kurtenbach et al., 1998; Gern, 2008). In the case of specific host-pathogen relationships this might result from an adaptation to complement-mediated killing, so that certain pathogen species exploit the molecules of their host which protect them from an alternative pathway of complement killing (Richter et al., 2004; Richter and Matuschka, 2010). Conversely, pathogens which are not adapted to the host are exposed to complement-mediated lysis soon after attachment of the tick (Kurtenbach et al., 1998).

3.2.1. Reservoir hosts

Tick infection rate strongly depends on the population density and susceptibility of the most important tick hosts, their infection rate, duration of infection and the immune status of the individual host (Wilson et al., 2002; De la Fuente et al., 2004; Speck et al., 2013). Therefore, the reservoir status of the main tick hosts harboring pathogens, as well as the intensity of infection, is extremely important for the persistence of a pathogen in an area (Wilson et al., 1984, 2002; Humair and Gern, 1998; Bjöersdorff et al., 2001; Ostfeld and LoGiudice, 2003; Perkins et al., 2003; Pfäffle et al., 2011).

In the case of LD, a few dozen vertebrate hosts have been identified as reservoirs for the *B. burgdorferi* s.l. complex (Kirstein et al., 1997; Gern and Humair, 2002; Rauter and Hartung, 2005). The endemic areas of this disease are maintained through complex interactions among different tick species, a variety of *Borrelia* strains and the large number of vertebrate hosts upon which ticks feed, with specific associations between hosts, ticks and *Borrelia* genospecies (Richter et al., 2004; Gern, 2008). Such specific associations have been confirmed between rodents and *B. afzelii* and *B. burgdorferi* sensu stricto (s.s.), as well as between birds and *B. garinii* and *B. valaisiana* (Kirstein et al., 1997; Gray et al., 1999; Gern, 2008). Several studies in Europe have confirmed that particularly small rodents (e.g. wild mice and voles) are key hosts in the epidemiological cycle of LD, not only due to the high susceptibility of this group (Ogden et al., 1997; Humair and Gern, 1998; Humair et al., 1999; Hughes and Randolph, 2001a; Hanincova et al., 2003; Randolph, 2004a; Tonteri et al., 2011), but also due to the preference of some tick species, such as *I. ricinus* and *D. marginatus*, during their immature stages (Kiffner et al., 2011b).

Once a susceptible host is present, it can also act as a factor in the dispersal of pathogens. The St. Louis encephalitis virus, for example, was probably introduced during the past few centuries into South America from Africa by migrating birds, and gradually dispersed to North America using the same transport pathway (Gould et al., 2006). Ogden et al. (2008b) investigated the role of northward-migrating birds and the northward range expansion of LD and human granulocytic anaplasmosis. Ticks on these birds harboured different *Borrelia* genospecies, including those species which are known to cause LD in humans and alleles that are rare in the northeastern USA. Olsen et al. (1995) examined the prevalence of *Borrelia* spp. in ticks of migrating birds in Scandinavia and observed five different species of ticks harbouring various strains of *B. burgdorferi* s.l. *Borrelia garinii* was most prevalent in ticks from birds arriving from the south or southeast in the spring, whereas the distribution of *Borrelia* spp. was more heterogeneous in ticks from birds migrating from the southwest. Thus, birds may partly be responsible for the heterogeneous distribution of LD in Europe and North America.

3.2.2. Epidemiological sub-cycles

Another area about which we know relatively little is epidemiological sub-cycles. For example, *I. ricinus* is a generalist species

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

using a large number of mammalian, avian and reptilian hosts. Some of these host species are susceptible to TBDs and have their own, more specialist, tick fauna which can also transmit TBPs. Thus the European hedgehog (*Erinaceus europaeus*) serves as a host for*I. ricinus* and *Ixodes hexagonus* and is known to harbor a variety of different pathogens (Gern et al., 1997; Skuballa et al., 2007, 2010, 2012). Although *I. hexagonus* is a nest-dwelling species, and moreover largely a specialist associated primarily with hedgehogs (Pfäffle et al., 2011), the species could serve as a vector within hedgehog populations, thus leading to high infection rates (Skuballa et al., 2010; Speck et al., 2013). This increases the probability of *I. ricinus* becoming infected by feeding and/or co-feeding on the same host, and consequently the transmission of pathogens crossing the species barrier to include humans (Wikel and Bergman, 1997; Estrada-Peña and Jongejan, 1999; Mahy and Brown, 2000; Taylor et al., 2001; Skuballa et al., 2010).

Such sub-cycles have also been suggested for*I. trianguliceps* in the UK, which has an endemic cycle involving field voles, *Microtus agrestis* (Bown et al., 2006). These common hosts are often infested with both *I. trianguliceps* and*I. ricinus* nymphs and larvae. Both ticks have been found infected with *A. phagocytophilum* (Bown et al., 2006).

3.2.3. Dilution hosts

Disease risk is reduced by the presence of hosts with a low capacity to infect feeding vectors (incompetent reservoirs) which dilute the effect of competent reservoir hosts (Schmidt and Ostfeld, 2001; LoGiudice et al., 2003). Domestic ruminants seem to be dilution hosts for some TBPs, especially *B. burgdorferi* s.l. Sheep for example are not susceptible to *B. burgdorferi* s.l., although transmission of pathogens is considered to occur via tick co-feeding (Ogden et al., 1997). Richter and Matuschka (2010) also indicated the zooprophylactic characteristics of ruminants. Engorged ticks from cattle and goats showed no infection with LD spirochetes, although approximately 25% of those ticks found on vegetation were infected with *B. burgdorferi*. Therefore it seems that the more immature ticks that are diverted from reservoir hosts such as rodents to zooprophylactic ruminants, the lower is the risk of LD (Richter and Matuschka, 2010). This does not account for other *Borrelia* spp. such as *Borrelia miyamotoi*, for which no zooprophylactic ability of ruminants could be detected (Richter and Matuschka, 2010).

Although the dilution effect reduces vector infection rates, it does not necessarily reduce the population densities of ticks. The European bison (*Bison bonasus*), red deer, roe deer and fallow deer (*Dama dama*) are considered to be reservoir-incompetent for *Borrelia* spp. (Nelson et al., 2000; Bhide et al., 2005; Gern, 2008; Pound et al., 2010; Alonso et al., 2012), but these are important hosts for a variety of tick species positively influencing population density (Smith et al., 1990; Pichon et al., 1999; Ruiz-Fons et al., 2006; Gern, 2008; Pound et al., 2010). Big game seems to be favored by adult females, because continuous and large blood meals support the production of large numbers of eggs (Dobson et al., 2006).

In nature, this dilution effect is most likely supported by an increased biodiversity (Daszak et al., 2000, 2001; Ostfeld and Keesing, 2000; Wood and Lafferty, 2012). Schmidt and Ostfeld (2001) showed that increasing species richness, but not evenness, leads to a reduced disease risk, since dilution effects are most pronounced when alternative hosts have negative influences (e.g. predation or competition) on dominant reservoir hosts within the community. It is also possible that species which are expected to be dead-end or dilution hosts for TBPs potentially provide a platform for non-systemic pathogen transmission among co-feeding ticks (Kiffner et al., 2010). This may explain why, for instance, at large spatial scales there is a positive relationship between LD incidence in humans and roe deer density, which are not competent hosts for *B. burgdorferi* (Vor et al., 2010).

The dilution effect theory has, however, been challenged by different studies which show that the loss of biodiversity in some communities led to a decrease in disease risk (Ostfeld and LoGiudice, 2003; Foley et al., 2009). This happens when pathogen transmission is greater within species than between species, particularly when a suitable host species is dominant, highly abundant and widespread (Keesing et al., 2006; Foley et al., 2009).

Recently, the generality of this concept was strongly attacked by Randolph and Dobson (2012) who, based on theoretical and empirical evidence, argued that the dilution effect theory applies only in certain, limited circumstances. In a pointed rejoinder, Ostfeld (2013) argued that, at least with respect to LD in the eastern USA, Randolph and Dobson had distorted and omitted relevant information and included information which was not applicable, thus biasing their analysis.

Salkeld et al. (2013) conducted a meta-analysis with 16 biodiversity-diseases relationships including two studies on LD and one on *A. phagycatophilum*. The authors found only very weak support for the dilution effect theory but they did find strong evidence for heterogeneity in the effects. This implies that different processes were acting during different studies. The dilution effect does not simply depend on biodiversity itself but on the composition of a specific community, which might dilute or amplify disease risk, because individual species have specific and contingent effects on other species within the community (LoGiudice et al., 2003). The relationship between biodiversity and zoonotic disease risk is therefore a specific rather than a general phenomenon and the understanding of ecological dynamics of specific disease systems is critical for predicting zoonotic disease risk (Salkeld et al., 2013).

3.2.4. Acquired resistance against pathogens

Although some pathogens may benefit from suppression of the host's immune defenses by ticks, the complement present in the blood of several host species has been shown to be the active component in pathogen-host specificity (Gern, 2008). Wikel et al. (1997) indicated that tick infestation can lead to resistance against pathogens by infesting BALB/c mice, first with uninfected and then with *B. burgdorferi*-infected *I. scapularis* ticks. The control group was only infested with infected nymphs and all host individuals became infected with *B. burgdorferi*. The experimental group, which had been previously infested with uninfected ticks, showed an infection prevalence of only 16.7% after being infested with infected ticks. The acquired resistance against ticks can also cause resistance to pathogens, which might be caused by a stimulated immune system (Wikel and Bergman, 1997).

Rubaire-Akiiki (1990) tested the effects of acquired resistance against tick infestation on the susceptibility of vectors to infection with pathogens. They infested two *B. taurus* calves with *Hyalomma anatolicum* nymphs and used a third calf as a control without primary tick infestation. All calves were inoculated with a stabilate of *Theileria annulata*, the agent of bovine theileriosis, and became infected. After that, nymphs were applied and examined after engorgement. Nymphs from the calves which developed a certain level of tick resistance after previous *Hyalomma* infestation were significantly less susceptible to infection by *T. annulata* than nymphs from the control calf, which indicates that acquired resistance against ticks leads to a reduced vector capacity in the ticks. Acquired resistance at the individual level and circulating tick-reactive antibodies determine the persistence and transmission likelihood for TBD agents (Wikel et al., 1997; Gern, 2008).

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

4. The influence of anthropogenic changes to the environment and host-tick-pathogen dynamics

Superimposed on natural environmental dynamics such as seasonal changes, there are major anthropogenic influences such as habitat fragmentation, urbanization, de- and reforestation, other land use changes and climate modification which influence host-tick-pathogen interactions (Barbour and Fish, 1993; Patz et al., 2004; Olson and Patz, 2010). These factors span a wide range of disciplines, including physical and human geography, meteorology, sociology, veterinary and human medicine, as well as ecology. Their relative importance, although currently an area of intensive study, remains largely obscure.

4.1. Small scale dynamics

4.1.1. Habitat fragmentation

Fragmentation describes the loss of large tracts of connected habitat caused by dividing continuous areas into smaller fragments which are isolated from each other, for example through road construction or building development (Watling and Donnelly, 2006). This has a substantial impact both on the populations and communities of organisms living in an area (Bennett and Saunders, 2010; Bergerot et al., 2010). The fragmented patches are scattered through a matrix of modified habitats, while the conditions surrounding the fragment, including connectivity between patches, determine the extent to which exterior environmental conditions penetrate the patch (Baskent, 1999). The unaffected grain of the area, called the core habitat, is determined by the fragment size and shape and the ecosystem of the surrounding matrix. The environmental characteristics of the affected bordering zones (edges) have numerous important effects on climate and organisms (Ewers and Didham, 2006; Vogt et al., 2006). Fragment size is not the only factor defining the community structure of fragment-dwelling organisms; in fact it is a functional interaction of numerous factors of the core-zones and edges of the patch influenced by the surrounding matrix, habitat area and edge effects (Vogt et al., 2006).

Traditionally edges have been considered beneficial to wildlife, including tick hosts, because diversity generally increases near habitat edges. Explanations for this edge effect include greater vegetation complexity or the simultaneous availability of more than one landscape element, as well as microclimatic factors (Gray et al., 1999; Nelson et al., 2000; Ewers and Didham, 2006). However, edges can have negative effects on wildlife due to disturbance, the possible isolation of patches and corridors modifying distribution and dispersal, increasing predation and parasitism (Yahner, 1988; Gray et al., 1999). How the dynamics of the individual host populations change is therefore variable, depending on the circumstances. Large herbivores such as deer profit from the vegetative complexity delivered by edge effects, but also from nearby, accessible field crops, reduced hunting pressure near suburban or urban habitats, and the presence of ornamental vegetation as winter forage and cover (Alverson et al., 1988; Fuller and Gill, 2001; Rooney, 2001; Allan et al., 2003; Vor et al., 2010).

Habitats of mosaic-shaped landscapes are considered to experience higher tick densities than homogeneous forested landscapes, which may be in part due to high host numbers for adult tick feeding and reproduction (Wilson et al., 1984). In highly fragmented landscapes of the eastern USA, the density of nymphal *I. scapularis*, the incidence of *Borrelia*-infections, as well as the density of infected nymphs was significantly negatively correlated with forest patch size resulting in a higher risk of LD in smaller patches (Allan et al., 2003). This also involved an elevated risk of humans entering tick habitat (Allan et al., 2003). Forest fragmentation leads to the loss of many vertebrate species from the remaining habitat patch, whereby white-footed mice (*P. leucopus*), the typical nymphal host and reservoir for a variety of pathogens in the eastern USA, appears not to be negatively affected by fragmentation and consequently mouse abundance in small patches tends to be higher than in larger habitat areas, leading to high densities of infected nymphs (Lewellen and Vessey, 1998; Nupp and Swihart, 1998; Allan et al., 2003). Furthermore, the lack of other vertebrate species occurring as predators or competitors can lead to high absolute densities of mice and therefore potentially to an increase in the number of infected nymphs (Allan et al., 2003).

Trying to characterize the environmental factors driving the distribution of Crimean-Congo hemorrhagic fever (CCHF) in Turkey, Estrada-Peña et al. (2010) found that neither single climatic nor vegetation variables, nor any individual seasonal component, were key factors in the distribution of the TBP, but that high habitat fragmentation with well-connected patches was positively correlated with case incidence.

4.1.2. Urbanization

The human population has more than doubled since the second part of the 20th century and this expansion is expected to continue through the forthcoming decades before reaching 10 billion around 2070 (Bongaarts, 2009). As a result of this increase, associated with social and economic changes, there has been a strong migration into cities (Sutherst, 2004).

The enormous expansion of urban areas corresponds with the rapid and dramatic conversion of landscape from natural to anthropogenic, hallmarked by built-up areas, industry and its associated infrastructure (Bradley and Altizer, 2007). The consequences that arise from these environmental changes include dramatic alterations in faunal and floral diversity and abundance, degradation and loss of natural habitat and shifts in (micro-) climatic conditions (e.g. heat island effects) (Uspensky, 2008, Ticks (Acari: Ixodoidea) as urban pests and vectors with special emphasis on ticks outside their geographical range. Proceedings of the 6th International Conference on Urban Pests, Hungary, pp. 333–348.)

Due to the intense landscape modifications resulting in a complex mosaic pattern of heterogeneous landscapes (Klausnitzer, 1993), habitats within urban and suburban areas are often unsuitable for many species, leading to an overall loss of wildlife biodiversity and abundance and, therefore, to a decline in sources of TBP reservoirs (Zygutiene et al., 2008). Some species, however, are capable of adapting to the new environment. Populations of urban-adapted hosts can reach densities in urban and suburban areas that are much higher than observed in undisturbed areas (Riley et al., 1998; Deplazes et al., 2004). Moreover, an abundance of certain resources is available in the city areas throughout the year via human waste or intentional feeding by citizens (Contesse et al., 2004). These can additionally support thriving urban-adapted animal populations (Deplazes et al., 2004; Bradley and Altizer, 2007) and can lead to increased contact with humans.

In the developed world, urbanization is typically implemented in a structured way, often with green areas, whereas in developing countries the expansion of urban areas happens much faster, is less structured and can lead to poor infrastructure, poor housing, high human density, impoverished suburbs and highly polluted city centres (Gubler, 1998; Sutherst, 2004). Both types of expansion can create conditions suitable for tick and host existence and thus lead to the emergence of TBDs (Patz et al., 2004; Bradley and Altizer, 2007; Uspensky, 2008, Proceedings, see above).

Within urban areas in the developed world green zones such as parks, forest patches and gardens are kept up to elevate the living standards of citizens. Tick populations such as those of *I. ricinus* are mainly restricted to these areas within cities, as this is where they find favorable microclimatic conditions (Dautel and Kahl, 1999, Ticks (Acari: Ixodoidea) and their medical importance in the urban

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

environment. Proceedings of the 3rd International Conference on Urban Pests, Czech Republic, pp. 73–82.), substrate for questing and abundant hosts (Prusinski et al., 2006).

European hedgehogs, for example, are a common, well-adapted component of urban ecosystems (Pfäffle et al., 2009). As indicated in Section 3.2.2 they are frequently infested with two species of ticks, *I. ricinus* and *I. hexagonus* (e.g. Gern et al., 1997; Pfäffle et al., 2011), which are both proven vectors of several tick-borne pathogens (Skuballa et al., 2009; Silaghi et al., 2012) and are known to host a variety of zoonotic TBPs, including TBEV, *A. phagocytophilum* and several *B. burgdorferi* s.l. genospecies (Skuballa et al., 2007, 2010). These pathogens have been found in hedgehogs from Berlin, (Germany) Budapest (Hungary) and Hamburg (Germany) and are thus involved in the urban cycle of TBDs (Skuballa et al., 2007, 2009, 2010; Földvari et al., 2011; Silaghi et al., 2012; Speck et al. 2013).

Populations of white footed mice in North America tend to reach high densities in fragmented areas, especially in small, isolated woodland patches surrounded by urban environments (Nupp and Swihart, 1998; Lewellen and Vessey, 1998; LoGiudice et al., 2003), thus providing a basis for both the feeding of immature ticks and the maintenance of pathogens.

Another factor facilitating completion of the tick life cycle in urban areas is the availability of medium to large-sized hosts. As deer species, the main hosts for the adult stages of *I. ricinus*, are typically absent from city centres, hedgehogs might act as surrogate hosts for adult *I. ricinus* in central European urban habitats (Földvari et al., 2011). This establishment of a shift in the core host–parasite association can in turn lead to changes in pathogen prevalence and composition in urban areas, as has been shown by the unusually high prevalences of *Borrelia spielmanii* found in the English Garden in Munich, Germany (Fingerle et al., 2008).

Deer, as well as wild pigs, however, are abundant in less disturbed suburban areas, and populations thrive in areas closely associated with human habitations. As a result, deer- associated ticks such as *A. americanum* and *I. scapularis* have become endemic in many suburban areas in the southern USA, together with the pathogens they transmit, such as *E. chaffeensis* (Comer, 2001). European wild boar (*Sus scrofa*) are also associated with a variety of TBPs (e.g. *Anaplasma* spp. and *Rickettsia* spp.), as well as ticks such as *H. marginatum*, *Rhipicephalus bursa* and *D. marginatus* (Hubalek et al., 2002; De la Fuente et al., 2004; Meng et al., 2009). Through the intersection of deer and wild pig habitats with suburban and urban areas the disease risk for humans increases (De la Fuente et al., 2004; Ruiz-Fons et al., 2006; Meng et al., 2009).

In some cases, the original transmission dynamics of TBPs can even shift towards urban adapted ticks and therefore cause a change in disease distribution. Rocky Mountain spotted fever is a TBD persistent in the USA and caused by *R. rickettsii*. It originally occurred in the northwestern and northern-central states of the USA (Wolbach, 1919). Typically, the disease was transmitted by the Rocky Mountain wood tick, *Dermacentor andersoni*, but there has been a geographical shift in the disease distribution to the more highly populated areas in the southern-central, southern and eastern parts of the USA, facilitated by a change in the main vector in these regions to *D. variabilis*, the American dog tick (Gratz, 1999), thus increasing the risk of infection by urban ticks.

It is not only the landscape but also the mean temperature in urban environments that differs from the surrounding areas, being between 1 and 6.5 °C higher on warm days (Santamouris, 2001; Frumkin, 2002). This heat island effect is presumably caused by heat absorption from dark surfaces in built-up areas and its subsequent re-radiation as thermal infrared radiation, together with the lack of vegetation (Frumkin, 2002). This temperature pattern might influence the survival, activity and distribution of ticks in cities, with a possible impact on reproductive success, the period of tick activity both from a daily and an annual perspective, and thus have an effect on pathogen prevalences. *Borrelia burgdorferi* s.l. has been shown to impart survival advantages to *I. ricinus* ticks under challenging thermohygrometric conditions (Herrmann and Gern, 2010), which might lead to an increase in the number of infected ticks and an increased risk of transmission at the edges of tick-suitable habitat patches within cities. Unfortunately, research in this area is scarce (Bradley and Altizer, 2007).

The contamination of tick habitats by increased environmental pollution with heavy metals from industry and cars can lead to exoskeleton abnormalities in ticks (Zharkov et al., 2000). Ticks bearing such cuticular anomalies are more susceptible to infection with a variety of TBPs, including a higher prevalence of multi-infection, while also showing behavioural changes, such as enhanced activity, that increase the risk of human infection (Alekseev and Dubinina, 2008).

As cities expand, human populations encroach upon their rural, peri-urban and suburban surroundings, invading natural and semi-natural environments such as forests and former agricultural land (Frumkin, 2002). This urban sprawl (Brueckner, 2000) can lead to an increased exposition of humans to vector ticks and TBPs due to the general increase of contact zones between wildlife and humans or domestic animals (Meerburg et al., 2009; Munderloh and Kurtti, 2011; Tack et al., 2012). Even though urbanization decreases the abundance and diversity of wildlife parasites, pathogen transmission can increase among urban-adapted hosts (Bradley and Altizer, 2007), resulting in the emergence of urban zoonotic disease cycles and the spread of infectious agents such as TBPs in urbanized areas (Lederberg et al., 1992; Reye et al., 2010). A number of studies in the northeastern part of the USA have confirmed the hypothesis of human-made infection risk in suburban areas by showing that the likelihood of infection with *B. burgdorferi* s.l. is especially high in suburban residential areas (e.g. Falco and Fish, 1989; Allan et al., 2003; LoGiudice et al., 2003). The creation of ecotones between human-altered and natural landscapes represents an ecological setting of special importance, favoring the transmission of LD by the aggregated and overlapping presence of host and vector species within relatively restricted spatial limits (Estrada-Peña, 2001a; Despommier et al., 2006).

This pattern of expansion and associated risk of infection with TBPs seems to be consistent for other parts of the world: it is thought that in the Sagar-Sorab area in India, the central focus of Kyasanur forest disease (KFD) was established mainly due to the encroachment of human settlements on forest areas (Pattnaik, 2006). The ecotones generated provide a suitable habitat for both the tick vector, *Haemaphysalis spinigera*, as well as large populations of reservoir hosts such as wild monkeys, enhancing the likelihood of the establishment of stable enzootic transmission cycles in this area (Pattnaik, 2006).

4.1.3. Land use

Human interventions in the natural balance of landscapes started in prehistoric times with land tillage, forest clearing and irrigation, with growing human population densities exacerbating the situation (Misana et al., 2003; Foley et al., 2005). Yet even such a limited human impact on natural ecosystems can lead to new habitats for animals and plants. In Europe, extensive pasture in former times formed important habitats for thermophilic species in the northern part and in the central and southern regions of Germany, serving as refuges for pre-glacial relict species until now (Beierkuhnlein, 2007). Large-scale harvesting of forests in the first half of the 19th century created large open areas of heathland and farmland providing a suitable environment for many native steppe elements, such as the European brown hare (*Lepus europaeus*) (Ellenberg, 2010; Petney et al., 2012).

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Today reforestation, together with habitat fragmentation, may lead to an increase in tick-suitable habitats and thus potentially to a rise in pathogen prevalence (Estrada-Peña et al., 2010). In Europe, the first large-scale forest harvesting started during the 7th century with the aim of gaining arable farmland and space for settling, followed by a second phase of deforestation as a result of increased commodity demand by a growing human population (Ellenberg, 2010). In North America, many areas were degraded due to European settlement during the 17th and 18th centuries, showing a complex east–west gradient of disturbance (Hall et al., 2002). Large-scale deforestation increased during the green revolution when agricultural production dominated in many countries of the world (Tilman, 1999), followed by agricultural intensification and reforestation in the 20th century (Daszak et al., 2001). The re-colonization of abandoned land and reforestation to ensure sustainability of forests are also considered as key factors in the emergence of TBDs via the creation of suitable tick habitats, for example for *I. ricinus* and *I. scapularis* (Fish and Childs, 2009; Committee on Lyme Disease and Other Tick-Borne Diseases: The State of the Science; Institute of Medicine, 2011; Léger et al., 2013).

In addition to the conversion of non-agricultural ecosystems into arable land, the exponential rise in the demand for food could only be ensured by the intensification of farming methods using monocultures (Misana et al., 2003). The loss of herbs is related to a substantial loss of biodiversity not only of plants but also of animals (Pegel, 1986). Wild ungulates, such as deer and wild boars, however, benefit especially from the cultivation of crops including wheat, and the expansion of farmland (Pegel, 1986; Daszak et al., 2001; Foley et al., 2009).

In general, land use change influences both the microclimate and the potential host species for ticks in an area. In cases of monoculture with hostile microclimatic conditions, tick populations are likely to suffer. Indeed, agricultural land is highly unsuitable for *I. ricinus* (Sumilo et al., 2006). Reforestation, however, is likely to open up new areas with a suitable microclimate and host populations allowing the establishment of ticks and the epidemiological cycle of TBDs (Allan et al., 2003; Estrada-Peña et al., 2010; Léger et al., 2013).

4.1.4. Domestic animals

Animal husbandry is assumed to have been a source of human exposure to zoonoses since ancient times (Munderloh and Kurtti, 2011). Among the large variety of vertebrates that can act as amplification hosts for different zoonotic TBDs, pets and livestock represent some of the largest reservoirs for human infection (Jongejan and Uilenberg, 2004; Chomel et al., 2006). In developing countries, densely populated urban and peri-urban slums are a common side effect of urbanization which often harbour high densities of domestic animals such as poultry, pigs or small ruminants (Foeken and Mwangi, 2000). These are bred in small-scale private farms and serve, amongst others things, as a source of food, income and security. They live in close contact with humans (Ghirotti, 1999). This scenario with plenty of hosts, especially for adult ticks, provides excellent conditions for tick existence (Uspensky, 2008. Ticks (Acari: Ixodoidea) as urban pests and vectors with special emphasis on ticks outside their geographical range. Proceedings of the 6th International Conference on Urban Pests, Hungary, pp. 333–348), and the close contact to humans can result in the emergence of TBDs.

As human contact with livestock typically takes places among farmers and associated occupational groups, it is not surprising that people at highest risk of contracting Crimean-Congo hemorrhagic fever (CCHF) infection comprise agricultural workers, and in particular farmers living in endemic rural areas in various parts of the world (Whitehouse, 2004; Ergönül, 2006) where vector ticks, including those of the genus *Hyalomma*, are abundant. For example, high CCHF antibody prevalences in a South African rural community were predominantly found in farmers and this has been shown to correlate with handling lambs (Fisher-Hoch, 1992).

In the context of close contact to animals and exposure to TBDs, argasid ticks play a special role: a number of soft tick species, such as *Ornithodoros moubata*, can be found in close association with humans and within human dwellings (McCall et al., 2007). This and certain other species of the genus are capable of transmitting tick-borne relapsing fevers (TBRF), caused by at least 15 different *Borrelia* spp. (Barbour and Hayes, 1986; Parola and Raoult, 2001; Dworkin et al., 2008). TBRF *Borrelia* in Central Tanzania can use domestic animals (chickens and pigs) as reservoir hosts and *Ornithodoros* tick populations may act as a bridging vector between animals and humans in this region (McCall et al., 2007). However, humans can also benefit from the vicinity of domestic animals: goats and cattle can eliminate spirochete infection from ticks (Richter and Matuschka, 2010), thus holding the potential to decrease the risk of infection with LD *Borrelia*.

Besides the role of livestock, close contact with companion animals can also change the human risk of TBD acquisition as these animals represent potential reservoirs for several zoonotic TBD agents and thus can alter the rate of human exposure to TBDs. These include borreliosis, ehrlichiosis, rickettsiosis including Rocky Mountain spotted fever, and TBE (Shaw et al., 2001). However, the relative contribution to increased human risk of disease infection also depends on the transmission cycle of the respective pathogen and especially the behavioural traits of the vector tick. Shaw et al. (2001) defined three different epidemiological scenarios, posing different extents of threats of TBD infection in humans. The first involves the transmission of a pathogen by exophilic ticks with a broad host spectrum, such as that found for *I. ricinus* (Süss, 2003). In this setting, pets can serve as sentinels for human infection risk. The second involves the transmission of pathogens by exposure to tick contents due to damaging ticks by the grooming of infested animals or inappropriate removal of ticks by humans. Transmission of *Coxiella burnetii*, the agent of Q-fever, occurs relatively frequently in shearers who can cut open the ticks or cause an aerosol of tick faeces in the process of removing wool from sheep (Schulz et al., 2005; Runge and Ganter, 2008). The third and putatively most important form of increased exposure, with the greatest potential for transmission of zoonotic pathogens, involves pets as hosts for nidiculous or endophilic tick vectors such as *R. sanguineus*. These ticks live in close association with dogs and can reach high densities within kennels or animal shelters, and even in human homes occupied by dogs (Peter et al., 1984). Another important aspect relating to *R. sanguineus* is its ability to produce up to four generations per year under optimal conditions and the fact that males can take up several blood meals on different dogs, which adds to the potential frequency of pathogen transmission (Dantas-Torres, 2010). In this scenario, dogs can significantly increase the human-tick interface, thus leading to an increased risk of transmitting zoonotic pathogens such as *R. conorii* and *R. rickettsii* (Dantas-Torres, 2010; Nicholson et al., 2010).

Cats are abundant throughout the world (Denny and Dickman, 2010), being amongst the most common companion animals, predominantly in developed countries (Gratz, 1999). They usually live in close association with their owners (Day, 2011), where they represent another source of human infection with pathogens (Gage et al., 2000; Elmore et al., 2010). Cats have been shown to be capable of harboring a variety of different TBPs, including *Borrelia* spp., *Bartonella* spp., *Ehrlichia* spp. and *Rickettsia* spp. (Day, 2011), and cat ownership was associated with LD risk even before this diseases was known to be tick-borne (Fish, 1995). *Bartonella henselae*, which causes cat-scratch disease (Jameson et al., 1995), has long been known as a flea-transmitted disease but recently it was shown to be transmitted by cat-infesting *I. ricinus* ticks as well

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

(Cotté et al., 2008). Additionally, *B. henselae*-infected ixodid ticks were shown to have the ability to carry co-infections with the human pathogenic *B. burgdorferi* s.l. and *A. phagocytophilum* (Holden et al., 2006).

4.1.5. Human behavior

In addition to parameters such as the population density of ticks and the prevalence of infected ticks, the incidence of human TBD in a particular area depends on social factors that determine the likelihood of contact between infected ticks and humans (Bröker and Gniel, 2003; Bayles et al., 2013). Therefore, the way in which humans interact with their environment plays an important role in determining the risk of a tick bite and infection (Stoddard et al., 2009).

Employment is one way in which humans are confronted with tick-infested habitats, often on a regular and/or frequent basis. Rangers, hunters or lumberjacks, for whom the forest is the designated place of work, are among the highest-risk occupations for contracting TBDs (Fingerle et al., 1997; Deutz et al., 2003; Cisak et al., 2005; Lindgren and Jaenson, 2006; Thorin et al., 2008). The most important factor contributing to the high levels of seropositivity for various TBDs in these working groups is most likely the close contact with vegetation (Thorin et al., 2008), especially the areas within a tick infested habitat in which a tick bite is most likely to occur. A study from Austria (Deutz et al., 2003) indicated that even when compared with other risk groups, hunters seem to be particularly prone to contracting TBPs, as they showed comparably high levels of seropositivity for *B. burgdorferi* s.l., *Ehrlichia* spp. and *F. tularensis*. This pattern is consistent with findings from Schwartz and Goldstein (1990), where seropositivity for LD among several groups of outdoor workers was compared and found to be present most frequently in hunters. The authors considered that this was likely to be the result of the amount of time spent in tick habitats in general, together with vicinity to the carcasses of tick hosts, and the duration of stay within brushy vegetation where the risk of contact with ticks is high.

Besides encountering tick-infested habitats on a professional basis, domestic activities such as walking the dog or collecting firewood in tick habitat are regarded as sources of increased exposure to ticks in their natural habitat (Pattnaik, 2006; Piesman, 2006). Villagers in the Karnataka state of India frequently become infected with Kyasanur forest disease through the bites from *H. spinigera* ticks when they visit nearby forests to collect firewood (Pattnaik, 2006).

Leisure activities such as fishing, jogging or hiking that typically take place in natural tick habitats have also been identified as risk factors for infection (Smith et al., 1988). Seropositivity for LD has been found to increase in proportion to the hours per week spent outdoors during recreational activities such as fishing and hiking (Schwartz and Goldstein, 1990). However, compared with the occupational risk of infection, leisure activities are likely to pose a minor threat to human beings, due to the low duration and frequency of stay, as well as the spatial focus of activity within the tick habitat (Sumilo et al., 2008b). Hikers and joggers spend most of their time on trails and not within the coppices and shrubbery where ticks are typically found questing during their active period.

The rapid and extensive growth of urban areas all over the world, together with the vast increase in people living in built-up environments, has contributed a great deal to an increasingly "nature-hungry" population and the rising popularity of outdoor recreation (Ibrahim and Cordes, 2008) with the potential to provide a source of social and health benefits (Godbey, 2009). These activities typically take place in natural and semi-natural habitats such as forests or parks. Green areas within cities are frequently visited and intensively used for a large variety of recreational activities including barbecues, picnics, sunbathing or ball games. As mentioned in the section on urbanization, ticks can, under appropriate environmental circumstances, establish stable populations within cities, even in the absence of large hosts (Falco and Fish, 1989; Dautel and Kahl, 1999. Ticks (Acari: Ixodoidea) and their medical importance in the urban environment. In: Proceedings of the 3rd International Conference on Urban Pests, Czech Republic, pp 73–82.; Uspensky, 2008, Ticks (Acari: Ixodoidea) as urban pests and vectors with special emphasis on ticks outside their geographical range. Proceedings of the 6th International Conference on Urban Pests, Hungary, pp. 333–348), and pathogen prevalences can reach high levels (Fingerle et al., 2008), not least due to the patchy environmental characteristics present (Estrada-Peña et al., 2010).

Changes in human behavior caused by war, social disruptions and conflicts, together with their environmental consequences, are assumed to be among the major factors that lead to CCHF outbreaks in the past (Hoogstraal, 1979). When Soviet troops during World War II began to reoccupy the Crimean steppe, they encountered large areas of fallow land where agricultural properties had been abandoned in reaction to fighting. As a result, large wild hare populations had established together with *Hyalomma* ticks, respectively hosts and vectors of CCHF. It is assumed that these conditions contributed to the CCHF epidemic among military personnel, affecting signalmen and surveyors in particular, who frequently moved within thick undergrowth and coppices (Hoogstraal, 1979; Leblebicioglu, 2010).

Later, changing human activities due to the socio-economic transition that followed the end of the soviet leadership were widely associated with epidemiologically relevant sociological changes in relation to increases in both wealth and leisure as well as unemployment and poverty (Randolph, 2004b, 2010b), impacting on work and leisure activities. This was accompanied by a significant increase in the incidence of human TBE from 2- to 30-fold in many central and eastern European (CEE) countries around the early 1990s (Sumilo et al., 2008b). In addition, people progressively started individual farming for economic reasons, leading to an increase in sheep and goat numbers (Randolph, 2002). These animals often grazed in tick-infested areas at the edges of forests (Kohl et al., 1996). The consumption of raw milk from TBE-infected stock animals is a special, but rather rare (Kriz et al., 2004), source of TBE infection for humans (Labuda et al., 2002). Nevertheless, there is an epidemiological significance of alimentary TBEV infections, for example in Slovakia (Kohl et al., 1996) and probably in other CEE countries. The same is potentially true for Q-fever which can also be caused by the consumption of raw milk products (Runge and Ganter, 2008).

Other, and perhaps more important, consequences of the vast upheavals in large parts of eastern Europe during the 1990s included increasing outdoor activities for either recreation or economic reasons such as the gathering of wild fruit and mushrooms, which are both associated with frequent visits to tick-infested habitats (Randolph, 2002).

With increasing levels of awareness of TBDs, the self-perception of risk allows people to actively avoid exposing themselves and companion animals to habitats where ticks and TBPs are abundant. There is increasing evidence that when faced with potentially lethal or novel pathogens, people change their behavior to try to reduce their risk of contracting disease (Ferguson, 2007). This pattern is consistent with observations from several studies that have shown that the risk of disease can attenuate over time in risk groups, as well as in the general public, due to behavioural changes and vaccination (Piacentino and Schwartz, 2002). The latter has proven to be effective in Austria, where extensive vaccination efforts have helped to drastically reduce the number of TBE cases (Bröker and Gniel, 2003; Heinz et al., 2013).

Following the independence from Soviet rule, the increase in TBE cases observed in the Baltic States was followed by a steep

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

decrease, exceeding vaccination rates and acquired immunity in the population (Sumilo et al., 2008a). Together with the fact that high exposure rates to TBDs had been found to coincide with unemployment and a low income as well as not being vaccinated, Sumilo et al. (2008a) concluded that behavioural changes for risk avoidance must have driven the decrease in TBE incidence.

In the developing world, where public health efforts are low compared with Europe or the USA, the establishment of avoidance behavior can also be observed. In rural areas in central Tanzania some people prefer to sleep outdoors during the hot season to avoid being bitten by soft ticks living in their homes. These *Ornithodoros* ticks are the vectors of TBRF *Borrelia* spp. including*B. duttoni* (Kisinza et al., 2003).

4.2. Global scale changes

4.2.1. Climate change

The role of climate change for TBD epidemiology is a controversial topic (Harvell et al., 2009; Randolph, 2010a). As we have seen, TBD systems are very sensitive to, and limited by, climatic and linked microclimatic conditions. Over the last century, precipitation worldwide has increased by approximately 1% and the trend for maximum temperature shows an increase of approximately 0.88 °C and that of minimum temperatures of 1.86 °C per 100 years (Easterling et al., 1997; Khasnis and Nettleman, 2005) indicating that these conditions are changing systematically.

There are several studies which indicate that the distribution of ticks and TBPs in Europe and North America is increasing. Incidences of TBE have considerably increased since the early 1980s in Sweden. This has been associated with climatic changes, mostly to higher average temperatures, milder winters and spring temperatures favoring the development of ticks (Lindgren et al., 2000). The milder winters, which are due to stronger global warming effects in winter in the north, might have led to a reduction in overwintering mortality of tick hosts and the extension of the active period of ticks (Githeko et al., 2000). *Ixodes ricinus* has apparently also spread to higher latitudes in Sweden, which might have affected the dynamics of TBE transmission and, therefore, increased the risk of infection in these regions. However, these studies have been limited in their scope and the changes reported could also been have due to other factors such as an increase in roe deer density and increased human activity in tick habitats (Githeko et al., 2000; Jaenson et al., 2012).

Although winter activity of *I. ricinus* is common at the southern limit of its distribution (Gray, 1991), only limited information on this topic is available for central and northern Europe (e.g. Szell et al., 2006). Dautel et al. (2008) provided the first systematic study of the winter activity of questing *I. ricinus* larvae and nymphs in central Europe. They found more or less continuous activity in *I. ricinus* throughout the winter from October 2006 to March 2007 in a forest in Berlin, Germany. This was related to a mild winter with only 2 days in the whole period with temperatures below 0 °C, while mean daily temperatures were approximately 4.6 °C higher than the long-term mean, resembling a Mediterranean winter. The daily maximum temperatures for December, January and February were 7.5, 7.7 and 6.6 °C, respectively (Dautel et al., 2008), which approximate the threshold for questing activity of *I. ricinus* (Süss et al., 2008). Increased winter temperatures in central Europe might therefore prolong the annual length of questing of *I. ricinus* and shift the seasonality of this tick towards earlier in the year.

From 1993 to 2001, a twofold increase of TBE incidence was observed in the Czech Republic compared with the years 1984–1992, with a total increase in cases in known TBE areas, an increase in TBE cases in areas where it had not occurred before and a re-emergence of the disease in areas where TBE cases had been only sporadically observed since the 1970s (Daniel et al., 2003). Additionally, an increase in the distribution of *I. ricinus* to higher altitudes was observed, thereby expanding the range of TBE into Bohemian mountain areas. Danielova et al. (2008) were not able to ascribe this change to socio-economic shifts or land use changes but it was correlated with increased monthly temperatures, especially in the period of maximum *I. ricinus* activity. Daniel et al. (2008) reported that similarly to the situation in Sweden, milder winters were slightly correlated with an increase in TBE incidence in Bohemia, which the authors related to the decreased winter mortality of small mammal hosts during milder winters, leading to a higher probability of larvae finding a suitable host. Nevertheless, human outdoor activities are also weather-dependent, providing a possible source of confusion.

Given the lack of long-term studies which incorporate sytematic global climate change, modeling is a major option in attempting to understand potential changes in the host-tick-pathogen system. Dobson and Randolph (2011) modeled the potential role of climate change and the impact of increasing numbers of roe deer hosts on tick population density and concluded that both abiotic and biotic environmental changes may have contributed to recent increases in tick populations.

In the USA, the Rocky Mountain wood tick, *D. andersoni*, serves as a vector of several human pathogens including *F. tularensis* (tularemia), *R. rickettsii*, as well as the Colorado tick fever virus in its natural range in North America (Hopla, 1974; Burgdorfer, 1977). Based on climate change estimates in Colorado (USA), climate warming is expected to result in rapid changes in the spatial patterns of abundance and distribution of *D. andersoni* (Eisen, 2008), which is likely to expand the risk areas for pathogens transmitted by this vector.

Although climate change will affect the distribution of vectors and TBDs in one way or the other, for example by opening up new territories for vectors (Brownstein et al., 2005) or altering the timing and duration of the peak risk of exposure to tick-borne pathogens (Gage et al., 2008), it is difficult to estimate how strongly these changes will be expressed, since adequate, long-term data are missing. The reasons for this are multiple: (i) it is difficult to distinguish between climate change and climate variability, so that every climate change signal is superimposed on the background noise of climate variability (Kovats et al., 2001), (ii) the relationship between TBDs such as LD and climate change is difficult to determine due to diagnostic problems and limited reporting in various countries (Gray et al., 2009), and (iii) TBD systems are extremely complex, meaning that climatic factors are not the only factors responsible for changes in tick populations and TBD dynamics (Sumilo et al., 2007; Knap et al., 2009; Randolph, 2010a). This complexity makes a linear response to climate change unlikely and an exclusive focus on climate change might result in the neglect of social phenomena that may be more amenable to effective action aimed at reducing the incidence of disease (Randolph, 2008).

Again it is important that long-term data be collected from different areas because global warming is not uniform and changes can be more extreme depending on, for example, latitude, with higher northern latitudes expected to undergo more extreme warming (American Meterological Society, http://www.ametsoc.org/policy/2012climatechange.html, accessed 23 April 2013). An increase in temperature in certain areas, leading to a hotter and drier climate, might limit the population density of ticks and thus the risk of TBPs (Olwoch et al., 2008).

4.2.2. Mobility, travel and trade

Today, world citizens move 23 billion km/year in total, and it is expected that by 2050 that figure will have grown to 105 billion km/year (Schafer and Victor, 2000), resulting in an enhanced risk

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

of spreading vectors and pathogens throughout the world (Sutherst, 2004; Cunningham, 2005). The preconditions for successful invasions of ticks and TBDs are that the tick population is large enough and able to adapt to the new environmental conditions, and that susceptible hosts are present (Léger et al., 2013).

Reports on the introduction of infected ticks without hosts and the subsequent emergence of disease in the invaded area have not been found. It seems rather that the anthropogenic related movement of host animals over long distances leads to the introduction of ticks to new areas (Nicholson et al., 2010; Burridge, 2011). The massive translocation of livestock has already led to the introduction and geographical spread of ticks and their associated pathogens into new areas.*Amblyomma variegatum*, which is a vector of African tick bite fever (Raoult et al., 2001) and CCHF (Estrada-Peña and Jongejan, 1999) to humans has been introduced to and become established in several regions including the Caribbean, Madagascar and Yemen (Pegram et al., 1982; Barré et al., 1995). It is regarded as the second most invasive tick species on the planet, after *R.* (*B.*) *microplus* and the most important tick in Africa, as it is has the widest distribution with endemic occurrence in over 30 countries. The invasion of the Caribbean region began around the 19th century with the introduction of infested cattle from African countries to Guadeloupe and neighboring islands. Then in the 1950s the tick spread across wide parts of the Caribbean. This might be attributed to some extent to the increase in the numbers of cattle egret (*Bubulcus ibis*), a bird that commonly serves as a host for *A. variegatum* immature stages which could have facilitated dissemination of the tick (Barré et al., 1995; Deem, 1998; Léger et al., 2013). The reasons for the successful translocation of this tick include its ability to survive long periods without feeding, its adaptation to a wide variety of habitats and hosts, and the ability of engorged females to lay up to 20,000 eggs (Jongejan and Uilenberg, 2004; Léger et al., 2013). This pattern of spread is likely to continue not only for *A. variegatum* but also for several other African tick species as an increase in suitable habitat together with changes in climatic conditions are predicted, holding the potential for future dissemination of ticks and their associated pathogens (Cumming and Van Vuuren, 2006).

Another aspect of increasing mobility is travel health. International travellers represent a group potentially at high risk of disease acquisition wherever they enter endemic areas, because they tend to have limited knowledge about health risks in the destination area (Hamer and Connor, 2004) and are easily exposed to tick-infested habitats (Goddard, 1989). Tick-borne infections may be taken home where they can be misdiagnosed or not diagnosed at all by physicians who lack experience with non-endemic TBDs (Randolph, 2002; Bröker and Gniel, 2003).

5. Conclusions

One of the problems which we see at the moment is a tendency to relegate hypotheses to a status of low significance if data sets do not provide an immediate indication of their importance. We consider this to be true for both climate change, for which the current data may or may not be indicative of changes in tick distribution and abundance due to global warming, and to the role of biodiversity in reducing the incidence of TBD. It is remarkably easy to criticize limited data sets, and most of our data sets are limited, and it is extremely difficult to design really comprehensive field studies, and analyze them adequately, let alone find the funding to carry them out.

Another problem is that over one-third of ixodid tick species are known to feed on humans, with this value rising to above 50% for the genera *Rhipicephalus*, *Dermacentor* and *Hyalomma* (Guglielmone et al., in press), many of which can transmit pathogens. Most of our information on the host-tick-pathogen system comes from very few species, and these are dominated by *I. ricinus* and *I. scapularis*. The genus *Ixodes* (the only one in the Prostriata; all other ixodid tick genera belong to the Metastriata) (Nava et al., 2009), have certain ecological characteristics, for example mating off-host, which are not shared by members of the Metastriata. Thus, our concentration on this group may lead to a bias which does not reflect the complex dynamics of other host-tick-pathogen systems.

TBDs develop within a complex, dynamic system involving the characteristics of vectors, hosts and the abiotic and biotic environment. To fully understand this system both long-term, i.e. long enough to assess both natural and progressive annual variability, small and large-scale studies incorporating the factors influencing TBD dynamics are required. These studies must include interdisciplinary teams with expertise not only in tick ecology and the molecular determination of TBPs, but also in physical and human geography, meteorology, sociology, veterinary and human medicine, as well as public health management in addition to ecology. The very complexity of the system and its significance for human and animal health should allow it to become a meeting point for difference fields of expertise and a model for holistic studies.

Acknowledgements

We would like to thank the Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg, Germany and its program BWPLUS for funding M.P. and N.L.

References

Adeyeye, O.A., Phillips, J.S., 1996. Photoperiodic response in the soft tick, *Ornithodoros turnicata*. Int. J. Parasitol. 26, 629–635.
Alekseev, A.N., Dubinina, H.V., 2008. Enhancement of risk of tick-borne infection: environmental and parasitological aspects of the problem. J. Med. Entomol. 45, 812–815.
Allan, B.F., Keesing, F., Ostfeld, R.S., 2003. Effect of forest fragmentation on Lyme disease risk. Conserv. Biol. 17, 267–272.
Allen, S.R., Khalil, H.A., Wikel, S.K., 1979. Langerhans cells trap tick salivary gland antigens in tick-resistant guinea pigs. J. Immunol. 122, 563–565.
Alonso, S., Marquez, F.J., Solano-Gallego, L., 2012. *Borrelia burgdorferi* serosurvey in wild deer in England and Wales. Vector Borne Zoonotic Dis. 12, 448–455.
Alverson, W.S., Waller, D.M., Solheim, S.L., 1988. Forests too deer: edge effects in northern Wisconsin. Conserv. Biol. 2, 348–358.
Andrews, R.H., Petney, T.N., Bull, C.M., 1982. Niche changes between parasite populations: an example from ticks on reptiles. Oecologia 55, 77–80.
Bacon, R.M., Kugler, K.J., Mead, P.S., 2008. Surveillance for Lyme disease – United States, 1992–2006. MMWR 57 (SS10), 1–9.
Barbour, A.G., Fish, D., 1993. The biological and social phenomenon of Lyme disease. Science 260, 1610–1616.
Barbour, A.G., Hayes, S.F., 1986. Biology of *Borrelia* species. Microbiol. Rev. 50, 381–400.
Barré, N., Garris, G., Camus, E., 1995. Propagation of the tick *Amblyomma variegatum* in the Caribbean. Rev. Sci. Tech. 14, 841–855.
Baskent, E., 1999. Controlling spatial structure of forested landscapes: a case study towards landscape management. Landsc. Ecol. 14, 83–97.
Bayles, B.R., Evans, G., Allan, B.F., 2013. Knowledge and prevention of tick-borne diseases vary across an urban-to-rural human land-use gradient. Ticks Tick Borne Dis., 1–7.
Beierkuhnlein, C., 2007. Biogeographie: Die räumliche Organisation des Lebens in einer sich verändernden Welt. Ulmer Eugen, Stuttgart.
Bennett, A.F., Saunders, D.A., 2010. Habitat fragmentation and landscape change. In: Navjot, S., Ehrlich, S., Ehrlich, P.R. (Eds.), Conservation Biology for All. Oxford University Press, Oxford, pp. 88–106.
Bergerot, B., Julliard, R., Baguette, M., 2010. Metacommunity dynamics: decline of functional relationship along a habitat fragmentation gradient. PLoS ONE 5, e11294. http://dx.doi.org/10.1371/journal.pone.0011294.
Bhide, M.R., Travnicek, M., Levkutova, M., Curlik, J., Revajova, V., Levkut, M., 2005. Sensitivity of *Borrelia* genospecies to serum complement from different animals and human: a host–pathogen relationship. FEMS Immunol. Med. Microbiol. 43, 165–172.
Bjöersdorff, A., Bergström, S., Massung, R.F., Haemig, P.D., Olsen, B., 2001. *Ehrlichia*-infected ticks on migrating birds. Emerg. Infect. Dis. 7, 877–879.
Bongaarts, J., 2009. Human population growth and the demographic transition. Philos. Trans. R. Soc. 364, 2985–2990.

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Bown, K.J., Begon, M., Bennett, M., Birtles, R.J., Burthe, S., Lambin, X., Telfer, S., Woldehiwet, Z., Ogden, N.H., 2006. Sympatric *Ixodes trianguliceps* and *Ixodes ricinus* ticks feeding on field voles (*Microtus agrestis*): potential for increased risk of *Anaplasma phagocytophilum* in the United Kingdom? Vector-Borne Zoonotic Dis. 6, 404–410.
Bradley, C., Altizer, S., 2007. Urbanization and the ecology of wildlife diseases. Trends Ecol. Evol. 22, 95–102.
Breshears, D.D., Rich, P.M., Barnes, F.J., Campbell, K., 1997. Overstory-imposed heterogeneity in solar radiation and soil moisture in a semiarid woodland. Ecol. Appl. 7, 1201–1215.
Breshears, D.D., Nyhan, J.W., Heil, C.E., Wilcox, B.P., 1998. Effects of woody plants on microclimate in a semiarid woodland: soil temperature and evaporation in canopy and intercanopy patches. Int. J. Plant Sci. 159, 1010–1017.
Bröker, M., Gniel, D., 2003. New foci of tick-borne encephalitis virus in Europe: consequences for travellers from abroad. Travel Med. Infect. Dis. 1, 181–184.
Brossard, M., Wikel, S.K., 2004. Tick immunobiology. Parasitology 129, 161–176.
Brown, S.J., Galli, S.J., Gleich, G.J., Askenase, P.W., 1982. Ablation of immunity to *Amblyomma americanum* by anti-basophil serum: cooperation between basophils and eosinophils in expression of immunity to ectoparasites (ticks) in guinea pigs. J. Immunol. 129, 790–796.
Brownstein, J.S., Holford, T.R., Fish, D., 2005. Effect of Lyme disease risk in North America. EcoHealth 2, 38–46.
Brueckner, J., 2000. Urban sprawl: diagnosis and remedies. Int. Reg. Sci. Rev. 23, 160–171.
Burgdorfer, W., 1977. Tick-borne diseases in the United States: rocky mountain spotted fever and Cloroado tick fever. A review. Acta Trop. 34, 103–126.
Burgdorfer, W., Barbour, A.G., Hayes, S.F., Benach, J.L., Grunwaldt, E., Davis, J.P., 1982. Lyme disease: a tick-borne spirochetosis? Science 216, 1317–1319.
Burri, C., Basti, V., Maeder, G., Patalas, E., Gern, L., 2011. Microclimate and the zoonotic cycle of tick-borne encephalitis virus in Switzerland. J. Med. Entomol. 48, 615–627.
Burridge, M.J., 2011. Non-native and Invasive Ticks: Threats to Human and Animal Health in the United States. Florida University Press, Gainesville.
Campbell, A., Glines, M.V., 1979. Development, survival, and oviposition of the rabbit tick, *Haemaphysalis leporispalustris* (Packard) (Acari: Ixodidae), at constant temperatures. J. Parasitol. 65, 777–782.
Chen, J., Saunders, S.C., Crow, T.R., Naiman, R.J., Brosofske, K.D., Mroz, G.D., Brookshire, B.L., Franklin, J.F., 1999. Microclimate in forest ecosystem and landscape ecology. Bioscience 49, 288–297.
Chilton, N.B., Bull, C.M., 1994. Influence of environmental factors on oviposition and egg development in *Ambylomma limbatum* and *Amblyomma hydrosauri* (Acari: Ixodidae). Int. J. Parasitol. 24, 83–90.
Chilton, N.B., Andrews, R.H., Bull, C.M., 2000. Influence of temperature and relative humidity on the moulting success of *Amblyomma limbatum* and *Aponomma hydrosauri* (Acari: Ixodidae) larvae and nymphs. Int. J. Parasitol. 30, 973–979.
Chomel, B.B., Boulouis, H.-J., Maruyama, S., Breitschwerdt, E.B., 2006. *Bartonella* spp. in pets and effect on human health. Emerg. Infect. Dis. 12, 389–394.
Chumakov, M.P., Seitlenok, N.A., 1940. Tick-borne human encephalitis in the European part of USSR and Siberia. Science 92, 263–264.
Cisak, E., Chmielewska-Badora, J., Zwolinski, J., Wojcik-Fatla, A., Polak, J., Dutkiewicz, J., 2005. Risk of tick-borne bacterial diseases among workers of Roztocze National Park (south-eastern Poland). Ann. Agric. Environ. Med. 12, 127–132.
Comer, J., 2001. Urban zoonoses caused by *Bartonella*, *Coxiella*, *Ehrlichia*, and *Rickettsia* species. Vector Borne Zoonotic Dis. 1, 91–118.
Committee on Lyme Disease and Other Tick-Borne Diseases: The State of the Science; Institute of Medicine, 2011. Critical needs and naps in understanding prevention, amelioration, and resolution of Lyme and other tick-borne diseases: the short-term and long-term outcomes: workshop report. National Academies Press (US), Washington, DC.
Contesse, P., Hegglin, D., Gloor, S., Bontadina, F., Deplazes, P., 2004. The diet of urban foxes (*Vulpes vulpes*) and the availability of anthropogenic food in the city of Zurich, Switzerland. Mamm. Biol. 69, 81–95.
Cotté, V., Bonnet, S., Le Rhun, D., Le Naour, E., Chauvin, A., Boulouis, H.J., Lecuelle, B., Lilin, T., Vayssier-Taussat, M., 2008. Transmission of *Bartonella henselae* by *Ixodes ricinus*. Emerg. Inf. Dis. 14, 1074–1080.
Cumming, G., Van Vuuren, D., 2006. Will climate change affect ectoparasite species ranges? Global Ecol. Biogeogr. 15, 486–497.
Cunningham, A., 2005. A walk on the wild side – emerging wildlife diseases. BMJ 331, 1214–1215.
Daniel, M., Danielova, V., Kriz, B., Jirsa, A., Nozicka, J., 2003. Shift of the tick *Ixodes ricinus* and tick-borne encephalitis to higher altitudes in Central Europe. Eur. J. Clin. Microbiol. Infect. Dis. 22, 327–328.
Daniel, M., Dusabek, F., 1994. Micrometerological and microhabitat factors affecting maintenance and dissemination of tick-borne diseases in the environment. In: Sonenshine, D.E., Mather, T.E. (Eds.), Ecological Dynamics of Tick-borne Zoonoses. Oxford University Press, Oxford, pp. 91–138.
Daniel, M., Kriz, B., Valter, J., Kott, I., Danielova, V., 2008. The influence of meteorological conditions of the preceding winter on the incidences of tick-borne encephalitis and Lyme borreliosis in the Czech Republic. Int. J. Med. Microbiol. 298, 60–67.
Danielova, V., Kliegrova, S., Daniel, M., Benes, C., 2008. Influence of climate warming on tick-borne encephalitis expansion to higher altitudes over the last decade (1997–2006) in the Highland region (Czech Republic). Cent. Eur. J. Public Health 16, 4–11.
Dantas-Torres, F., 2010. Biology and ecology of the brown dog tick, *Rhipicephalus sanguineus*. Parasit. Vectors 3, 1–11.
Dantas-Torres, F., Otranto, D., 2011. Cold-stress response of engorged females of *Rhipicephalus sanguineus*. Exp. Appl. Acarol. 54, 313–318.
Daszak, P., Cunningham, A.A., Hyatt, A.D., 2000. Emerging infectious diseases of wildlife – threats to biodiversity and human health. Science 287, 443–449.
Daszak, P., Cunningham, A.A., Hyatt, A.D., 2001. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. Acta Trop. 78, 103–116.
Dautel, H., Knülle, W., 1997. Cold hardiness, supercooling ability and causes of low-temperature mortality in the soft tick, *Argas reflexus*, and the hard tick, *Ixodes ricinus* (Acari: Ixodidea) from Central Europe. J. Insect Physiol. 43, 834–854.
Dautel, H., Dippel, C., Kämmer, D., Werkhausen, A., Kahl, O., 2008. Winter activity of *Ixodes ricinus* in a Berlin forest. Int. J. Med. Microbiol. 298, 50–54.
Day, M.J., 2011. One health: the importance of companion animal vector-borne diseases. Parasit. Vectors 4, 49–54.
Deem, S.L., 1998. A review of heartwater and the threat of introduction of *Cowdria ruminantium* and *Amblyomma* spp. ticks to the American mainland. J. Zoo Wildl. Med. 29, 109–113.
De la Fuente, J., Estrada-Peña, A., Venzal, J.M., Kocan, K.M., Sonenshine, D.E., 2008. Overview: ticks as vectors of pathogens that cause disease in humans and animals. Front. Biosci. 13, 6923–6946.
De la Fuente, J., Naranjo, V., Ruiz-Fons, F., Vicente, J., Estrada-Peña, A., Almazan, C., Kocan, K.M., Martin, M.P., Gortazar, C., 2004. Prevalence of tick-borne pathogens in ixodid ticks (Acari: Ixodidae) collected from European wild boar (*Sus scrofa*) and Iberian red deer (*Cervus elaphus hispanicus*) in central Spain. Eur. J. Wildl. Res. 50, 187–196.
De Meeus, T., Koffi, B.B., Barré, N., De Garine-Wichatitsky, M., Chevillon, C., 2010. Swift sympatric adaptation of a species of cattle tick to a new deer host in New Caledonia. Infect. Genet. Evol. 10, 976–983.
Denny, E.A., Dickman, C.R., 2010. Review of Cat Ecology and Management Strategies in Australia: a Report for the Invasive Animals Cooperative Research Centre. Invasive Cooperative Research Centre, Canberra.
Deplazes, P., Hegglin, D., Gloor, S., Romig, T., 2004. Wilderness in the city: the urbanization of *Echinococcus multilocularis*. Trends Parasitol. 20, 77–84.
Despommier, D., Ellis, B.R., Wilcox, B.A., 2006. The role of ecotones in emerging infectious diseases. EcoHealth 3, 281–289.
Deutz, A., Fuchs, K., Nowotny, N., 2003. Seroepidemiologische Untersuchungen von Jägern auf Zoonosen: Vergleich mit Untersuchungen bei Tierärzten, Landwirten und Schlachthofarbeitern. Wien. Klin. Wochenschr. 115, 61–67.
Dizij, A., Kurtenbach, K., 1995. *Clethrionomys glareolus* but not *Apodemus flavicollis*, acquires resistance to *Ixodes ricinus* L., the main European vector of *Borrelia burgdorferi*. Parasite Immunol. 17, 177–183.
Dobbelaere, D.A.E., Shapiro, S.Z., Buscher, G., 1987. Acquired resistance to *Rhipicephalus appendiculatus* (Acari: Ixodidae): identification of an antigen eliciting resistance in rabbits. J. Med. Entomol. 24, 147–154.
Dobson, A., Cattadori, I., Holt, R.D., Ostfeld, R.S., Keesing, F., Krichbaum, K., Rohr, J.R., Perkins, S.E., Hudson, P.J., 2006. Sacred cows and sympathetic squirrels: the importance of biological diversity to human health. PLoS Med. 3, e231. http://dx.doi.org/10.1371/journal.pmed.0030231.
Dobson, A., Randolph, S.E., 2011. Modelling the effects of recent changes in climate, host density and acaricide treatments on population dynamics of *Ixodes ricinus* in the UK. J. Appl. Ecol. 48, 1029–1037.
Duffy, D.C., Campbell, S.R., Clark, D., Dimotta, C., Gurney, S., 1994. *Ixodes scapularis* (Acari: Ixodidae) deer tick mesoscale populations in natural areas: effects of deer, area, and location. J. Med. Entomol. 31, 152–158.
Durden, L.A., 2006. Taxonomy, host associations, life cycles and vectorial importance of ticks parasitizing small mammals. In: Morand, S., Krasnov, B.R., Poulin, R. (Eds.), Micromammals and Macroparasites. From Evolutionary Ecology to Management. Springer Verlag, Tokyo, pp. 91–102.
Durden, L.A., Keirans, J.E., 1996. Host–parasite coextinction and the plight of tick conservation. Am. Entomol. 42, 87–91.
Dworkin, M.S., Schwan, T.G., Anderson, D.E., Borchardt, S.M., 2008. Tick-borne relapsing fever. Infect. Dis. Clin. North Am. 22, 449–468.
Easterling, D.R., Horton, B., Jones, P.D., Peterson, T.C., Karl, T.R., Parker, D.E., Salinger, M.J., Razuvayev, V., Plummern, N., Jamason, P., Folland, C.K., 1997. Maximum and minimum temperature trends for the globe. Science 277, 364–367.
Eisen, L., 2008. Climate change and tick-borne diseases: a research field in need of long-term empirical field studies. Int. J. Med. Microbiol. 298, 12–18.
Eisen, L., Eisen, J., Lane, R.S., 2002. Seasonal activity patterns of *Ixodes pacificus* nymphs in relation to climatic conditions. Med. Vet. Entomol. 16, 235–244.
Ellenberg, H., 2010. Vegetation Mitteleuropas mit den Alpen: In ökologischer, dynamischer und historischer Sicht, sixth ed. UTB, Stuttgart.
Elmore, S.A., Jones, J.L., Conrad, P.A., Patton, S., Lindsay, D.S., Dubey, J.P., 2010. *Toxoplasma gondii*: epidemiology, feline clinical aspects, and prevention. Trends Parasitol. 26, 190–196.
Ergönül, Ö., 2006. Crimean-Congo haemorrhagic fever. Lancet Infect. Dis. 6, 203–214.
Estrada-Peña, A., 2001a. Forecasting habitat suitability for ticks and prevention of tick-borne diseases. Vet. Parasitol. 98, 111–132.
Estrada-Peña, A., 2001b. Distribution, abundance, and habitat preferences of *Ixodes ricinus* (Acari: Ixodidae) in northern Spain. J. Med. Entomol. 38, 361–370.
Estrada-Peña, A., 2002. Increasing habitat suitability in the United States for the tick that transmits Lyme disease: a remote sensing approach. Environ. Health Perspect. 110, 635–640.

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Estrada-Peña, A., 2003. The relationships between habitat topology, critical scales of connectivity and tick abundance *Ixodes ricinus* in a heterogeneous landscape in northern Spain. Ecography 5, 661–671.
Estrada-Peña, A., Ayllón, N., de la Fuente, J., 2012a. Impact of climate trends on tick-borne pathogen transmission. Front. Physiol. 3, 1–12.
Estrada-Peña, A., Jongejan, F., 1999. Ticks feeding on humans: a review of records on human-biting Ixodoidea with special reference to pathogen transmission. Exp. Appl. Acarol. 23, 685–715.
Estrada-Peña, A., Vatansever, Z., Gargili, A., Ergönul, Ö., 2010. The trend towards habitat fragmentation is the key factor driving the spread of Crimean-Congo haemorrhagic fever. Epidemiol. Infect. 138, 1194–1203.
Estrada-Peña, A., Venzal, J.M., Nava, S., Mangold, A., Guglielmone, A.A., Labruna, M.B., De la Fuente, J., 2012b. Reinstatement of *Rhipicephalus* (*Boophilus*) *australis* (Acari: Ixodidae) with redescription of the adult and larval stages. J. Med. Entomol. 49, 794–802.
Ewers, R.M., Didham, R.K., 2006. Confounding factors in the detection of species responses to habitat fragmentation. Biol. Rev. Camb. Philos. Soc. 81, 117–142.
Falco, R.C., Fish, D., 1989. Potential for exposure to tick bites in recreational parks in a Lyme disease endemic area. Am. J. Public Health 79, 12–15.
Ferguson, N., 2007. Capturing human behaviour. Nature 446, 733.
Fielden, L.J., Rechav, Y., 1996. Survival of six species of African ticks in relation to saturation deficits. Exp. Appl. Acarol. 20, 625–637.
Fingerle, V., Goodman, J.L., Johnson, R.C., Kurtti, T.J., Munderloh, U.G., Wilske, B., 1997. Human granulocytic ehrlichiosis in southern Germany: increased seroprevalence in high-risk groups. J. Clin. Microbiol. 35, 3244–3247.
Fingerle, V., Schulte-Spechtel, U.C., Ruzic-Sabljic, E., Leonhard, S., Hofmann, H., Weber, K., Pfister, K., Strle, F., Wilske, B., 2008. Epidemiological aspects and molecular characterization of *Borrelia burgdorferi* s.l. from southern Germany with special respect to the new species *Borrelia spielmanii* sp. nov. Int. J. Med. Microbiol. 298, 279–290.
Fish, D., 1995. Environmental risk and prevention of Lyme disease. Am. J. Med. 98, 2–9.
Fish, D., Childs, J.E., 2009. Community-based prevention of Lyme disease and other tick-borne diseases through topical application of acaricide to white-tailed deer: background and rationale. Vector Borne Zoonotic Dis. 9, 357–364.
Fisher-Hoch, S., 1992. Risk of human infections with Crimean-Congo hemorrhagic fever virus in a South African rural community. Am. J. Trop. Med. Hyg. 47, 337–345.
Fivaz, B.H., Tucker, S., Petney, T., 1991. Cross-resistance between instars of the brown ear-tick *Rhipicephalus appendiculatus* (Acarina: Ixodidae). Exp. Appl. Acarol. 11, 323–326.
Foeken, D., Mwangi, A., 2000. Increasing food security through urban farming in Nairobi. In: Bakker, N., Dubbeling, M., Gündel, S., Sabel Koschella, U., Zeeuw, H. (Eds.), Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda: a Reader on Urban Agriculture. DSE, Feldafing, pp. 303–328.
Földvari, G., Rigo, K., Jablonszky, M., Biro, N., Majoros, G., Molnar, V., Toth, M., 2011. Ticks and the city: ectoparasites of the Northern white-breasted hedgehog (*Erinaceus roumanicus*) in an urban park. Ticks Tick-Borne Dis. 2, 231–234.
Foley, J.A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574.
Foley, J.E., Nieto, N.C., Foley, P., 2009. Emergence of tick-borne granulocytic anaplasmosis associated with habitat type and forest change in northern California. Am. J. Trop. Med. Hyg. 81, 1132–1140.
Fourie, L.J., Kok, D.J., Krugel, L., Synman, A., Van der Lingen, F., 1996. Control of Karoo paralysis ticks through vegetation management. Med. Vet. Entomol. 10, 39–43.
Fujimoto, K., 1989. Ecological studies on ixodid ticks. 6. The effects of temperature on the oviposition, development and survival of *Ixodes ovatus* Neumann (Acarina: Ixodidae). Jpn. J. Sanit. Zool. 40, 187–193.
Fuller, R., Gill, R., 2001. Ecological impacts of increasing numbers of deer in British woodland. Forestry 74, 193–199.
Frumkin, H., 2002. Urban sprawl and public health. Public Health Rep. 117, 201–217.
Gage, K.L., Dennis, D.T., Orloski, K.A., Ettestad, P., Brown, T.L., Reynolds, P.J., Pape, W.J., Fritz, C.L., Carter, L.G., Stein, J.D., 2000. Cases of cat-associated human plague in the Western US, 1977–1998. Clin. Inf. Dis. 30, 893–900.
Gage, K.L., Burkot, T.R., Eisen, R.J., Hayes, E.B., 2008. Climate and vectorborne diseases. Am. J. Prev. Med. 35, 436–450.
Geiger, R., 1965. The Climate Near the Ground. Harvard University Press, Cambridge.
Gern, L., 2008. *Borrelia burgdorferi* sensu lato, the agent of Lyme borreliosis: life in the wilds. Parasite 15, 244–247.
Gern, L., Humair, P.F., 2002. Ecology of *Borrelia burgdorferi* sensu lato in Europe. In: Gray, J., Kahl, O., Lane, R.S., Stanek, G. (Eds.), Lyme Borreliosis: Biology, Epidemiology and Control. CABI Publishing, Wallingford, pp. 149–174.
Gern, L., Rouvinez, E., Toutoungi, L.N., Godfroid, E., 1997. Transmission cycles of *Borrelia burgdorferi* sensu lato involving *Ixodes ricinus* and/or *I. hexagonus* ticks and the European hedgehog, *Erinaceus europaeus*, in suburban and urban areas in Switzerland. Folia Parasitol. 44, 309–314.
Ghirotti, M., 1999. Making better use of animal resources in a rapidly urbanizing world: a professional challenge. World Anim. Rev. 92, 2–14.
Githeko, A.K., Lindsay, S.W., Confalonieri, U.E., Patz, J.A., 2000. Climate change and vector-borne diseases: a regional analysis. Bull. World Health Organ. 78, 1136–1147.
Godbey, G., 2009. Outdoor recreation, health, and wellness: understanding and enhancing the relationship. RFF Discussion Paper No. 9–21. Available from: <http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=20803>.
Goddard, J., 1989. Ticks and Tickborne Diseases Affecting Military Personnel. USAF School of Aerospace Medicine, Texas.
Goddard, J., Varela-Stokes, A.S., 2009. Role of the lone star tick, *Amblyomma americanum* (L.), in human and animal diseases. Vet. Parasitol. 160, 1–12.
Gould, E.A., Higgs, S., Buckley, A., Gritsun, T.S., 2006. Potential arbovirus emergence and implications for the United Kingdom. Emerg. Infect. Dis. 12, 549–555.
Granström, M., 1997. Tick-borne zoonoses in Europe. Clin. Microbiol. Infect. 3, 156–169.
Gratz, N.G., 1999. Emerging and resurging vector-borne diseases. Annu. Rev. Entomol. 44, 51–75.
Gray, J.S., 1981. The fecundity of *Ixodes ricinus* (L.) (Acari: Ixodidea) and the mortality of its developmental stages under field conditions. Bull. Entomol. Res. 71, 533–542.
Gray, J.S., 1991. The development and seasonal activity of the tick *Ixodes ricinus*: a vector of Lyme borreliosis. Rev. Med. Vet. Entomol. 79, 323–333.
Gray, J.S., Dautel, H., Estrada-Peña, A., Kahl, O., Lindgren, E., 2009. Effects of climate change on ticks and tick-borne diseases in Europe. Interdiscip. Perspect. Infect. Dis.. http://dx.doi.org/10.1155/2009/593232.
Gray, J.S., Kirstein, F., Robertson, J.N., Stein, J., Kahl, O., 1999. *Borrelia burgdorferi* sensu lato in *Ixodes ricinus* ticks and rodents in a recreational park in south-western Ireland. Exp. Appl. Acarol. 23, 717–729.
Gubler, D.J., 1998. Resurgent vector-borne diseases as a global health problem. Emerg. Infect. Dis. 4, 442–450.
Guerra, M., Walker, E., Jones, C., Paskewitz, S., Cortinas, M.R., Stancil, A., Beck, L., Bobo, M., Kitron, U., 2002. Predicting the risk of Lyme disease: habitat suitability for *Ixodes scapularis* in the North Central United States. Emerg. Infect. Dis. 8, 289–297.
Guglielmone, A.A., Robbins, R.G., Apanaskevich, D.A., Petney, T.N., Estrada-Peña, A., Horak, I.G., in press. Hard ticks (Acari: Ixodida: Ixodidae) of the world. Springer, Heidelberg.
Guglielmone, A.A., Robbins, R.G., Apanaskevich, D.A., Petney, T.N., Estrada- Peña, A., Horak, I.G., Shao, R.F., Barker, S.C., 2010. The Argasidae, Ixodidae and Nuttalliellidae (Acari: Ixodida) of the world: a list of valid species names. Zootaxa 2528, 1–28.
Hall, B., Motzkin, G., Foster, D.R., Syfert, M., Burk, J., 2002. Three hundred years of forest and land-use change in Massachusetts, USA. J. Biogeogr. 29, 1319–1335.
Hamer, D.H., Connor, B.A., 2004. Travel health knowledge, attitudes and practices among United States travelers. J. Travel Med. 11, 23–26.
Hanincova, K., Schäfer, S.M., Etti, S., Sewell, H.-S., Taragelova, V., Ziak, D., Labuda, M., Kurtenbach, K., 2003. Association of *Borrelia afzelii* with rodents in Europe. Parasitology 126, 11–20.
Harvell, D., Altizer, S., Cattadori, I.M., Harrington, L., Weil, E., 2009. Climate change and wildlife disease: when does the host matter the most? Ecology 90, 912–920.
Heinz, F.X., Stiasny, K., Holzmann, H., Grgic-Vitek, M., Kriz, B., Essl, A., Kundi, M., 2013. Vaccination and tick-borne encephalitis, central Europe. Emerg. Infect. Dis. 19, 69–76.
Herrmann, C., Gern, L., 2010. Survival of *Ixodes ricinus* (Acari: Ixodidae) under challenging conditions of temperature and humidity is influenced by *Borrelia burgdorferi* sensu lato infection. J. Med. Entomol. 47, 1196–1204.
Hillel, D., 1980. Applications of Soil Physics. Academic Press, New York.
Hoch, A.L., Barker, R.W., Hair, J.A., 1971. Measurement of physical parameters to determine the suitability of modified woodlots as Lone star tick habitat. J. Med. Entomol. 8, 725–730.
Holden, K., Boothby, J.T., Kasten, R.W., Chomel, B.B., 2006. Co-detection of *Bartonella henselae*, *Borrelia burgdorferi*, and *Anaplasma phagocytophilum* in *Ixodes pacificus* ticks from California, USA. Vector Borne Zoonotic Dis. 6, 99–102.
Hoogstraal, H., 1967. Ticks in relation to human diseases caused by *Rickettsia* species. Annu. Rev. Entomol. 12, 377–420.
Hoogstraal, H., 1979. The epidemiology of tick-borne Crimean-Congo hemorrhagic fever in Asia, Europe and Africa. J. Med. Entomol. 15, 307–414.
Hopla, C.E., 1974. The ecology of tularemia. Adv. Vet. Sci. Comp. Med. 18, 25–53.
Hubalek, Z., Treml, F., Juricova, Z., Hunady, M., 2002. Serological survey of the wild boar (*Sus scrofa*) for tularaemia and brucellosis in South Moravia, Czech Republic. Vet. Med. (Praha) 47, 60–66.
Hughes, V.L., Randolph, S.E., 2001a. Testosterone increases the transmission potential of tick-borne parasites. Parasitology 123, 365–371.
Hughes, V.L., Randolph, S.E., 2001b. Testosterone depresses innate and acquired resistance to ticks in natural rodent hosts: a force for aggregated distributions of parasites. J. Parasitol. 87, 49–54.
Humair, P.-F., Gern, L., 1998. Relationship between *Borrelia burgdorferi* sensu lato species, red squirrels (*Sciurus vulgaris*) and *Ixodes ricinus* in enzootic areas in Switzerland. Acta Trop. 69, 213–227.
Humair, P.-F., Rais, O., Gern, L., 1999. Transmission of *Borrelia afzelii* from *Apodemus* mice and *Clethrionomys* voles to *Ixodes ricinus* ticks: differential transmission pattern and overwintering maintenance. Parasitology 118, 33–42.
Hunter, P.R., 2003. Climate change and waterborne and vector-borne diseases. J. Appl. Microbiol. 94, 37–46.
Ibrahim, H., Cordes, K.A., 2008. Outdoor Recreation, third ed. Sagamore Publishing, Champaign.
Jaenson, T.G.T., Jaenson, D.G.E., Eisen, L., Petersson, E., Lindgren, E., 2012. Changes in the geographical distribution and abundance of the tick Ixodes ricinus during

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

the past 30 years in Sweden. Parasite Vector 5. http://dx.doi.org/10.1186/1756-3305-5-8.

Jameson, P., Greene, C., Regnery, R., Dryden, M., Marks, A., Brown, J., Cooper, J., Glaus, B., Greene, R., 1995. Prevalence of *Bartonella henselae* antibodies in pet cats throughout regions of North America. J. Inf. Dis. 172, 1145–1149.

Jones, C.J., Kitron, U.D., 2000. Population of *Ixodes scapularis* (Acari: Ixodidae) are modulated by drought at a Lyme disease focus in Illinois. J. Med. Entomol. 37, 408–415.

Jongejan, F., Uilenberg, G., 2004. The global importance of ticks. Parasitology 129, S3–S14.

Jouda, F., Perret, J.-L., Gern, L., 2004. *Ixodes ricinus* density, and distribution and prevalence of *Borrelia burgdorferi* sensu lato infection along an altitudinal gradient. J. Med. Entomol. 41, 162–169.

Kahl, O., Knülle, W., 1988. Wirtssuchaktivität der Schildzecke, *Ixodes ricinus* (Acari, Ixodidae) und ihre Durchseuchung mit Lyme-Spirochäten und dem Frühsommer-Meningoencepahlitis (FSME)-Virus in Berlin (West). Mitt. Dtsch. Ges. Allg. Angew. Entomol. 6, 223–225.

Kazmierczak, J.J., Burgess, E., 1989. Antibodies to *Borrelia* sp. in wild foxes and coyotes from Wisconsin and Minnesota. J. Wildl. Dis. 25, 108–111.

Keesing, F., Holt, R.D., Ostfeld, R.S., 2006. Effects of species diversity on disease risk. Ecol. Lett. 9, 485–498.

Khasnis, A.A., Nettleman, M.D., 2005. Global warming and infectious disease. Arch. Med. Res. 36, 689–696.

Kiffner, C., Lödige, C., Alings, M., Vor, T., Rühe, F., 2010. Abundance estimation of *Ixodes* ticks (Acari: Ixodidae) on roe deer (*Capreolus capreolus*). Exp. Appl. Acarol. 52, 73–84.

Kiffner, C., Lödige, C., Alings, M., Vor, T., Rühe, F., 2011a. Attachment site selection of ticks on roe deer, *Capreolus capreolus*. Exp. Appl. Acarol. 53, 79–94.

Kiffner, C., Vor, T., Hagedorn, P., Niedrig, M., Rühe, F., 2011b. Factors affecting patterns of tick parasitism on forest rodents in tick-borne encephalitis risk areas, Germany. Parasitol. Res. 108, 323–335.

Kirstein, F., Rijpkema, S., Molkenboer, M., Gray, J.S., 1997. Local variations in the distribution and prevalence of *Borrelia burgdorferi* sensu lato genomospecies in *Ixodes ricinus* ticks. Appl. Environ. Microbiol. 63, 1102–1106.

Kitron, U., Kazmierczak, J.J., 1997. Spatial analysis of the distribution of Lyme disease in Wisconsin. Am. J. Epidemiol. 145, 558–566.

Kisinza, W.N., McCall, P., Mitani, H., 2003. An epidemiological study of tick-borne relapsing fever in Dodoma District, Central Tanzania. Tanzan. Health Res. Bull. 5, 5–7.

Klausnitzer, B., 1993. Ökologie der Großstadtfauna, second ed. Gustav Fischer Verlag, Jena, Stuttgart.

Knap, N., Durmisi, E., Saksida, A., Korva, M., Petrovec, M., Avsic-Zupanc, T., 2009. Influence of climatic factors on dynamics of questing *Ixodes ricinus* ticks in Slovenia. Vet. Parasitol. 164, 275–281.

Knülle, W., 1966. Equilibrium humidities and survival of some tick larvae. J. Med. Entomol. 4, 335–338.

Knülle, W., Rudolph, D., 1982. Humidity relationships and water balance of ticks. In: Obenchain, F.D., Galun, R. (Eds.), Physiology of Ticks. Pergamon, Oxford, pp. 43–70.

Koch, H.G., Dunn, J.C., 1980. Oviposition, egg hatch, and larval survival of Lone star ticks held at different temperatures and humidities. Southwest Entomol. 5, 169–174.

Kohl, I., Kozuch, O., Elecková, E., Labuda, M., Zaludko, J., 1996. Family outbreak of alimentary tick-borne encephalitis in Slovakia associated with a natural focus of infection. Eur. J. Epidemiol. 12, 373–375.

Kolonin, G.V., 2009. Fauna of ixodid ticks of the world (Acari, Ixodidae). Moscow, a web-book at www.kolonin.org.

Kolonin, G.V., Bolotin, E.I., Kushnarev, E.L., Matyushina, O.A., 1981. Contribution to ecology of the tick *Haemaphysalis japonica* in Primor'ye region (translated from Russian). Med. Parzit. Moskva 50, 61–66.

Kovats, R.S., Campbell-Lendrum, D.H., McMichael, A.J., Woodward, A., Cox, J.St.H., 2001. Population biology of emerging en re-emerging pathogens. Philos. Trans. R. Soc. Lond. B 356, 1057–1068.

Krasnov, B., Khokhlova, I., Shenbrot, G., 2002. The effect of host density on ectoparasite distribution: an example of a rodent parasitized by fleas. Ecology 83, 164–175.

Kriz, B., Benesa, C., Danielova, V., 2004. Socio-economic conditions and other anthropogenic factors influencing tick-borne encephalitis incidence in the Czech Republic. Int. J. Med. Microbiol. 293, 63–68.

Kröber, T., Guerin, P., 2007. The tick blood meal: from a living animal or from a silicone membrane? ALTEX 25, Special Issue, 39–41.

Kurtenbach, K., Hanincova, K., Tsao, J.I., Margos, G., Fish, D., Ogden, N.H., 2006. Fundamental processes in the evolutionary ecology of Lyme borreliosis. Nature 4, 660–669.

Kurtenbach, K., Sewell, H.S., Ogden, N.H., 1998. Serum complement sensitivity as a key factor in Lyme disease ecology. Infect. Immun. 66, 1248–1251.

Labuda, M., Jones, L.D., Williams, T., Danielova, V., Nuttall, P.A., 1993a. Efficient transmission of tick-borne encephalitis virus between cofeeding ticks. J. Med. Entomol. 30, 295–299.

Labuda, M., Nuttall, P.A., Kozuch, O., Eleckova, E., Williams, T., Zuffova, E., Sabo, A., 1993b. Non-viraemic transmission of tick-borne encephalitis virus: a mechanism for arbovirus survival in nature. Experentia 49, 802–805.

Labuda, M., Eleckova, E., Lickova, M., Sabo, A., 2002. Tick-borne encephalitis virus foci in Slovakia. Int. J. Med. Microbiol. 291, 43–47.

Leblebicioglu, H., 2010. Crimean-Congo haemorrhagic fever in Eurasia. Int. J. Antimicrob. Agents 36, S43–S46.

Lederberg, J., Shope, R.E., Oaks, S.C.J., 1992. Emerging Infections: Microbial Threats to Health in the United States. National Academy Press, Washington, DC.

Léger, E., Vourc'h, G., Vial, L., Chevillon, C., McCoy, K.D., 2013. Changing distributions of ticks: causes and consequences. Exp. Appl. Acarol. 59, 219–244.

Leta, S., De Clercq, E.M., Madder, M., 2013. High-resolution predictive mapping for *Rhipicephalus appendiculatus* (Acari: Ixodidae) in the Horn of Africa. Exp. Appl. Acarol.. http://dx.doi.org/10.1007/s10493-013-9670-1.

Lewellen, R.H., Vessey, S.H., 1998. The effect of density dependence and weather on population size of a polyvoltine species. Ecol. Monogr. 68, 571–594.

Lindgren, E., Jaenson, T., 2006. Lyme Borreliosis in Europe: Influences of Climate and Climate Change, Epidemiology, Ecology and Adaptation Measures. World Health Organization, Copenhagen.

Lindgren, E., Tälleklint, L., Polfeldt, T., 2000. Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick *Ixodes ricinus*. Environ. Health Perspect. 108, 119–123.

Lindquist, L., Vapalahti, O., 2008. Tick-borne encephalitis. Lancet 371, 1861–1871.

Lindström, A., Jaenson, T.G.T., 2003. Distribution of the common tick, *Ixodes ricinus* (Acari: Ixodidae), in different vegetation types in Southern Sweden. J. Med. Entomol. 40, 375–378.

LoGiudice, K., Ostfeld, R.S., Schmidt, K.A., Keesing, F., 2003. The ecology of infectious disease: effects of host diversity and community composition on Lyme disease risk. Proc. Natl. Acad. Sci. USA 100, 567–571.

L'vov, D.K., Gostinshchikova, G.V., 1970. Contemporary concepts on the role of ticks as vectors of arboviruses (Translation from Russian). Tezisy Dokl. 2. Akarol. Soveshch. 1, 290–292.

Madder, M., Speybroeck, N., Bilounga, A., Helleputte, D., Berkvens, D., 2005. Survival of unfed *Rhipicephalus appendiculatus* and *Rhipicephalus zambeziensis* adults. Med. Vet. Entomol. 19, 245–250.

Mahy, B.W., Brown, C.C., 2000. Emerging zoonoses: crossing the species barrier. Rev. Sci. Tech. 19, 33–40.

McCabe, G.J., Bunnell, J.E., 2004. Precipitation and the occurrence of Lyme disease in the Northeastern United States. Vector-Borne Zoonotic Dis. 4, 143–148.

McCall, P.J., Hume, J.C.C., Motshegwa, K., Pignatelli, P., Talbert, A., Kisinza, W., 2007. Does tick-borne relapsing fever have an animal reservoir in East Africa? Vector Borne Zoonotic Dis. 7, 659–666.

McCoy, K.D., Boulinier, T., Chardine, J.W., Danchin, E., Michalakis, Y., 1999. Dispersal and distribution of the tick *Ixodes uriae* within and among seabird host populations: the need for a population genetic approach. J. Parasitol. 85, 196–202.

McCoy, K.D., Boulinier, T., Tirard, C., Michalakis, Y., 2001. Host specificity of a generalist parasite: genetic evidence of sympatric host races in the seabird tick *Ixodes uriae*. J. Evol. Biol. 14, 395–405.

Meerburg, B.G., Singleton, G.R., Kijlstra, A., 2009. Rodent-borne diseases and their risks for public health. Crit. Rev. Microbiol. 35, 221–270.

Meng, X.J., Lindsay, D.S., Sriranganathan, N., 2009. Wild boars as sources for infectious diseases in livestock and humans. Philos. Trans. R. Soc. Lond. B. 364, 2697–2707.

Meyer, J.A., Lancaster, J.L., Simco, J.S., 1982. Comparison of habitat modification, animal control, and standard spraying for control of the Lone star tick. J. Econ. Entomol. 75, 524–529.

Mihalca, A.D., Gherman, C.M., Cozma, V., 2011. Coendangered hard ticks: threatened or threatening? Parasit. Vectors 4, 71. http://dx.doi.org/10.1186/1756-3305-4-71.

Miller, H.C., Conrad, A.M., Barker, S.C., Daugherty, C.H., 2007. Distribution and phylogenetic analyses of an endangered tick, *Amblyomma sphenodonti*. N.Z. J. Zool. 34, 97–105.

Misana, S.B., Majule, A.E., Lyaruu, H.V., 2003. Linkages between changes in land use, biodiversity and land degradation on the slopes of Mount Kilimanjaro, Tanzania. LUCID Working Paper 38, International Livestock Research Institute, Kenya.

Munderloh, U.G., Kurtti, T.J., 2011. Emerging and re-emerging tick-borne diseases: new challenges at the interface of human and animal health. In: Committee on Lyme disease and other tick-borne diseases: The state of science; Institute of Medicine (Eds.), Critical needs and gaps in understanding prevention, amelioration, and resolution of Lyme and other tick-borne diseases: the short-term and long-term outcomes: Workshop report. The National Academies Press, Washington, DC, pp. 376–404.

Mysterud, A., 1999. Seasonal migration pattern and home range of roe deer (*Capreolus capreolus*) in an altitudinal gradient in southern Norway. J. Zool. 247, 479–486.

Nava, S., Guglielmone, A.A., Mangold, A.J., 2009. An overview of the systematics and evolution of ticks. Front. Biosci. 14, 2857–2877.

Needham, G.R., Teel, P.D., 1991. Off-host physiological ecology of ixodid ticks. Annu. Rev. Entomol. 36, 659–681.

Nelson, M.E., Mech, L.D., Frame, P.F., 2004. Tracking of white-tailed deer migration by global positioning system. J. Mammal. 85, 505–510.

Nelson, D.R., Rooney, S., Miller, N.J., Mather, T.N., 2000. Complement-mediated killing of *Borrelia burgdorferi* by nonimmune sera from sika deer. J. Parasitol. 86, 1232–1238.

Nicholson, W.L., Allen, K.E., McQuiston, J.H., Breitschwerdt, E.B., Little, S.E., 2010. The increasing recognition of rickettsial pathogens in dogs and people. Trends Parasitol. 26, 205–212.

Nithiuthai, S., Allen, J.R., 1985. Langerhans cells present tick antigens to lymph node cells from tick-sensitized guinea-pigs. Immunology 55, 157–163.

Norval, R.A.I., 1977. Studies on the ecology of the tick *Amblyomma hebraeum* Koch in the Eastern Cape Province of South Africa. II. Survival and development. J. Parasitol. 63, 740–747.

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Nosek, J., Lichard, M., Sztankay, M., 1967. The ecology of ticks in the Tribec and Hronsky Inovec mountains. Bull. World Health Org. 36, 49–59.
Nupp, T.E., Swihart, R.K., 1998. Effects of forrest fragmentation on population attributes of white-footed mice and eastern chipmunks. J. Mammal. 79, 1234–1243.
O'Connell, S., Granström, M., Gray, J.S., Stanek, G., 1998. Epidemiology of European lyme borreliosis. Zentralbl. Bl. Bakteriol. 287, 229–240.
Ogden, N.H., Barker, I.K., Beauchamp, G., Brazeau, S., Charron, D.F., Maarouf, A., Morshed, M.G., O'Callaghan, C.J., Thompson, R.A., Waltner-Toews, D., Waltner-Toews, M., Lindsay, L.R., 2006a. Investigation of ground level and remote-sensed data for habitat classification and prediction of survival of *Ixodes scapularis* in habitats of Southeastern Canada. BioOne 43, 403–414.
Ogden, N.H., Bigras-Poulin, M., Hanincova, K., Maarouf, A., O'Callaghan, C.J., Kurtenbach, K., 2008a. Projected effects of climate change on tick phenology and fitness of pathogens transmitted by the North American tick *Ixodes scapularis*. J. Theor. Biol. 254, 621–632.
Ogden, N.H., Lindsay, L.R., Beauchamp, G., Charron, D., Maarouf, A., O'Callaghan, C.J., Waltner-Toews, D., Barker, I.K., 2004. Investigation of relationships between temperature and developmental rates of tick *Ixodes scapularis* (Acari: Ixodidae) in the laboratory and field. J. Med. Entomol. 41, 622–633.
Ogden, N.H., Lindsay, L.R., Hanincová, K., Barker, I.K., Bigras-Poulin, M., Charron, D.F., Heagy, A., Francis, C.M., O'Callaghan, C.J., Schwartz, I., Thompson, R.A., 2008b. Role of migratory birds in introduction and range expansion of *Ixodes scapularis* ticks and of *Borrelia burgdorferi* and *Anaplasma phagocytophilum* in Canada. Appl. Environ. Microbiol. 74, 1780–1790.
Ogden, N.H., Maarouf, A., Barker, I.K., Bigras-Poulin, M., Lindsay, L.R., Morshed, M.G., O'Callaghan, C.J., Ramay, F., Waltner-Toews, D., Charron, D.F., 2006b. Climate change and the potential of range expansion of the Lyme disease vector *Ixodes scapularis* in Canada. Int. J. Parasitol. 36, 63–70.
Ogden, N.H., Nuttall, P.A., Randolph, S.E., 1997. Natural Lyme disease cycles maintained via sheep by co-feeding ticks. Parasitology 115, 591–599.
Oliver Jr., J.H., 1989. Biology and systematics of ticks (Acari: Ixodida). Ann. Rev. Ecol. Syst. 30, 397–430.
Olsen, B., Jaenson, T.G.T., Bergström, S., 1995. Prevalence of *Borrelia burgdorferi* sensu lato-infected ticks on migrating birds. Appl. Environ. Microbiol. 61, 3082–3087.
Olson, S.H., Patz, J.A., 2010. Global environmental change and tick-borne disease incidence. In: Committee on Lyme disease and other tick-borne diseases: The state of science; Institute of Medicine (Eds.), Critical needs and gaps in understanding prevention, amelioration, and resolution of Lyme and other tick-borne diseases: the short-term and long-term outcomes: Workshop report. The National Academies Press, Washington, DC, pp. 267–290.
Olwoch, J.M., Reyers, B., Engelbrecht, F.A., Erasmus, B.F.N., 2008. Climate change and the tick-borne disease, Theileriosis (East Coast fever) in sub-Saharan Africa. J. Arid Environ. 72, 108–120.
Ostfeld, R.S., 2013. A Candide response to Panglossian accusations by Randolph and Dobson: biodiversity buffers disease. Parasitology, 1–3. doi: 10.1017/S0031182013000541.
Ostfeld, R.S., Canham, C.D., Oggenfuss, K., Winchcombe, R.J., Keesing, F., 2006. Climate, deer, rodents, and acorns as determinants of variation in Lyme-disease risk. PLoS Biol. 4, e145.
Ostfeld, R., LoGiudice, K., 2003. Community disassembly, biodiversity loss, and the erosion of an ecosystem service. Ecology 84, 1421–1427.
Ostfeld, R.S., Keesing, F., 2000. Biodiversity and disease risk: the case of Lyme disease. Conserv. Biol. 14, 722–728.
Paddock, C.D., Telford, S.R. III, 2011. Through a glass darkly: the global incidence of tick-borne disease. In: Committee on Lyme disease and other tick-borne diseases: The state of science; Institute of Medicine (Eds.), Critical needs and gaps in understanding prevention, amelioration and resolution of Lyme and other tick-borne diseases: the short-term and long-term outcomes: Workshop report. The National Academic Press, Washington, DC, pp. A2–A43.
Parola, P., Raoult, D., 2001. Ticks and tickborne bacterial diseases in humans: an emerging infectious threat. Clin. Infect. Dis. 32, 897–928.
Parola, P., Socolovschi, C., Jeanjean, L., Bitam, I., Fournier, P.-E., Sotto, A., Labauge, P., Raoult, D., 2008. Warmer weather linked to tick attack and emergence of severe rickettsioses. PLoS Negl. Trop. Dis. 2, e338. http://dx.doi.org/10.1371/journal.pntd.0000338.
Pattnaik, P., 2006. Kyasanur forest disease: an epidemiological view in India. Rev. Med. Virol. 16, 151–165.
Patz, J.A., Daszak, P., Tabor, G.M., Aguirre, A.A., Pearl, M., Epstein, J., Wolfe, N.D., Kilpatrick, A.M., Foufopoulos, J., Molyneux, D., Bradley, D.J., 2004. Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. Environ. Health Perspect. 112, 1092–1098.
Peavey, C.A., Lane, R.S., 1996. Field and laboratory studies on the timing of oviposition and hatching of the western black-legged tick, *Ixodes pacificus* (Acari: Ixodidae). Exp. Appl. Acarol. 20, 695–711.
Pegel, M., 1986. Der Feldhase (*Lepus europaeus* Pallas) im Beziehungsgefüge seiner Um-und Mitweltfaktoren. Systematische Untersuchungen über die Existenz- und Gefährdungskriterien einheimischer Wildtiere. Enke, Stuttgart.
Pegram, R.G., Hoogstraal, H., Wassef, H.Y., 1982. Ticks (Acari: Ixodoidea) of the Yemen Arab Republic. I. Species infesting livestock. Bull. Entomol. Res. 72, 215–227.
Perkins, S.E., Cattadori, I.M., Tagliapietra, V., Rizzoli, A.P., Hudson, P.J., 2003. Empirical evidence for key hosts in persistence of a tick-borne disease. Int. J. Parasitol. 33, 909–917.
Perret, J.-L., Rais, O., Gern, L., 2004. Influence of climate on the proportion of *Ixodes ricinus* nymphs and adults questing in a tick population. J. Med. Entomol. 41, 361–365.
Perry, B.D., Kruska, R., Lessard, P., Norval, R.A.I., Kundert, K., 1991. Estimating the distribution and abundance of *Rhipicephalus appendiculatus* in Africa. Prev. Vet. Med. 11, 261–268.
Peter, O., Burgdorfer, W., Aeschlimann, A., Chatelanat, P., 1984. *Rickettsia conorii* isolated from *Rhipicephalus sanguineus* introduced into Switzerland on a pet dog. Z. Parasitenkd. 70, 265–270.
Petney, T.N., Fourie, L.J., 1990. The dispersion of the Karoo paralysis tick, *Ixodes rubicundus*, within a naturally infested flock of sheep in South Africa. Vet. Parasitol. 34, 345–352.
Petney, T.N., Robbins, R.G., Guglielmone, A.A., Apanaskevich, D.A., Estrada-Peña, A., Horak, I.G., Shao, R., 2011. A look at the world of ticks. In: Mehlhorn, H. (Ed.), Progress in Parasitology. Springer Verlag, Berlin Heidelberg, pp. 283–296.
Petney, T.N., Skuballa, J., Muders, S., Pfäffle, M., 2012. The changing distribution patterns of ticks (Ixodida) in Europe in relation to emerging tick-borne diseases. In: Mehlhorn, H. (Ed.), Arthropods as Vectors of Emerging Diseases. Springer, Berlin Heidelberg, pp. 151–166.
Petney, T.N., van Ark, H., Spickett, A.M., 1990. Niche changes between parasite populations: an example from ticks on reptiles. Oecologia 55, 77–80.
Pfäffle, M., Petney, T., Elgas, M., Skuballa, J., Taraschewski, H., 2009. Tick-induced blood loss leads to regenerative anaemia in the European hedgehog (*Erinaceus europaeus*). Parasitology 136, 443–452.
Pfäffle, M., Petney, T.N., Skuballa, J., Taraschewski, H., 2011. Comparative population dynamics of a generalist (*Ixodes ricinus*) and specialist tick (*I. hexagonus*) species from European hedgehogs. Exp. Appl. Acarol. 54, 151–164.
Piacentino, J.D., Schwartz, B.S., 2002. Occupational risk of Lyme disease: an epidemiological review. Occup. Environ. Med. 59, 75–84.
Pichon, B., Mousson, L., Figureau, C., Rodhain, F., Perez-Eid, C., 1999. Density of deer in relation to the prevalence of *Borrelia burgdorferi* s.l. in *Ixodes ricinus* nymphs in Rambouillet forest, France. Exp. Appl. Acarol. 23, 267–275.
Piesman, J., 2006. Response of nymphal *Ixodes scapularis*, the primary tick vector of Lyme disease spirochetes in North America, to barriers derived from wood products or related home and garden items. J. Vector Ecol. 31, 412–417.
Pierson, F.B., Wight, J.R., 1991. Variability of near-surface soil temperature on sagebrush rangeland. J. Range Manage. 44, 491–497.
Pound, J.M., George, J.E., Kammlah, D.M., Lohmeyer, K.H., Davey, R.B., 2010. Evidence for role of white-tailed deer (Artiodactyla: Cervidae) in epizootiology of cattle ticks and southern cattle ticks (Acari: Ixodidae) in reinfestations along the texas/mexico border in south texas: a review and update. J. Econ. Entomol. 103, 211–218.
Prusinski, M.A., Chen, H., Drobnack, J.M., Kogut, S.J., Means, R.G., Howard, J.J., Oliver, J., Lukacik, G., Backenson, P.B., White, D.J., 2006. Habitat structure associated with *Borrelia burgdorferi* prevalence in small mammals in New York State. Environ. Entomol. 35, 308–319.
Randolph, S.E., 1994. Density-dependent acquired resistance to ticks in natural hosts, independent of concurrent infection with *Babesia microti*. Parasitology 108, 413–419.
Randolph, S.E., 1998. Ticks are not insects: consequences of contrasting vector biology for transmission potential. Parasitol. Today 14, 186–192.
Randolph, S.E., 1999. Epidemiological uses of a population model for the tick *Rhipicephalus appendiculatus*. Trop. Med. Int. Health 4, 34–42.
Randolph, S.E., 2001. The shifting landscape of tick-borne zoonoses: tick-borne encephalitis and Lyme borreliosis in Europe. Philos. Trans. R. Soc. Lond. B Biol. Sci. 356, 1045–1056.
Randolph, S.E., 2002. Predicting the risk of tick-borne diseases. Int. J. Med. Microbiol. 291, 6–10.
Randolph, S.E., 2004a. Tick ecology: processes and patterns behind the epidemiological risk posed by by ixodid ticks as vectors. Parasitology 129, S37–S65.
Randolph, S.E., 2004b. Evidence that climate change has caused "emergence" of tick-borne diseases in Europe? Int. J. Med. Microbiol. 293, 5–15.
Randolph, S.E., 2008. Dynamics of tick-borne disease systems: minor role of recent climate change. Rev. Sci. Tech. Off. Int. Epiz. 27, 367–381.
Randolph, S.E., 2010a. To what extent has climate change contributed to the recent epidemiology of tick-borne diseases? Vet. Parasitol. 167, 92–94.
Randolph, S.E., 2010b. Human activities predominate in determining changing incidence of tick-borne encephalitis in Europe. Euro. Surveill. 15, 24–31.
Randolph, S.E., Dobson, A.D.M., 2012. Pangloss revisited: a critique of the dilution effect and the biodiversity-buffers-disease paradigm. Parasitology 139, 847–863.
Raoult, D., Fournier, P.E., Fenollar, F., Jensenius, M., Prioe, T., De Pina, J.J., Caruso, G., Jones, N., Laferl, H., Rosenblatt, J.E., Marrie, T.J., 2001. *Rickettsia africae*, a tick-borne pathogen in travelers to sub-Saharan Africa. N. Engl. J. Med. 344, 1504–1510.
Rauter, C., Hartung, T., 2005. Prevalence of *Borrelia burgdorferi* sensu lato genospecies in *Ixodes ricinus* ticks in Europe: a metaanalysis. Appl. Environ. Microbiol. 71, 7203–7216.
Reye, A.L., Hübschen, J.M., Sausy, A., Muller, C.P., 2010. Prevalence and seasonality of tick-borne pathogens in questing *Ixodes ricinus* ticks from Luxembourg. Appl. Environ. Microbiol. 76, 2923–2931.
Ribeiro, J.M.C., 1989. Role of saliva in tick/host interactions. Exp. Appl. Acarol. 7, 15–20.

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Richter, D., Matuschka, F.-R., 2010. Elimination of Lyme disease spirochetes from ticks feeding on domestic ruminants. Appl. Environ. Microbiol. 76, 7650–7652.
Richter, D., Schlee, D.B., Allgower, R., Matuschka, F.-R., Allgöwer, R., 2004. Relationships of a novel Lyme disease spirochete, *Borrelia spielmani* sp. nov., with its hosts in Central Europe. Appl. Environ. Microbiol. 70, 6414–6419.
Riek, R.F., 1962. Studies on the reactions of animals to infestation with ticks. VI. Resistance of cattle to infestation with the tick *Boophilus microplus* (Canestrini). Aust. J. Agric. Res. 13, 532–550.
Riley, S.P., Hadidian, J., Manski, D.A., 1998. Population density, survival, and rabies in raccoons in an urban national park. Can. J. Zool. 76, 1153–1164.
Rizzoli, A., Hauffe, H.C., Tagliapietra, V., Neteler, M., Rosa, R., 2009. Forest structure and roe deer abundance predicting tick-borne encephalitis risk in Italy. PLoS ONE 4, e4336. http://dx.doi.org/10.1371/journal.pone.0004336.
Rooney, T.P., 2001. Deer impacts on forest ecosystems: a North American perspective. Forestry 74, 201–208.
Runge, M., Ganter, M., 2008. Q-Fieber. J. Verbr. Lebensm. 3, 185–189.
Rubaire-Akiiki, C.M., 1990. The effects of bovine tick resistance on the susceptibility of *Hyalomma anatolicum anatolicum* to infection with *Theileria annulata* (Ankara). Vet. Parasitol. 34, 273–288.
Ruiz-Fons, F., Fernandez-de-Mera, I.G., Acevedo, P., Höfle, U., Vicente, J., De la Fuente, J., Gortazar, C., 2006. Ixodid ticks parasitizing Iberian red deer (*Cervus elaphus hispanicus*) and European wild boar (*Sus scrofa*) from Spain: geographical and temporal distribution. Vet. Parasitol. 140, 133–142.
Salkeld, D.J., Padgett, K.A., Holland Jones, J., 2013. A meta-analysis suggesting that the relationship between biodiversity and risk of zoonotic pathogen transmission is idiosyncratic. Ecol. Lett. 16, 679–686.
Santamouris, M., 2001. Energy and Climate in the Urban Built Environment. James & James Ltd., London.
Schafer, A., Victor, D.G., 2000. The future mobility of the world population. Transport. Res. A 32, 171–205.
Schmidt, K.A., Ostfeld, R.S., 2001. Biodiversity and the dilution effect in disease ecology. Ecology 82, 609–619.
Schulz, J., Runge, M., Schröder, C., Ganter, M., Hartung, J., 2005. Detection of *Coxiella burnetii* in the air of a sheep barn during shearing. Dtsch. Tierärztl. Wochenschr. 112, 470–472.
Schulze, T.L., Jordan, R.A., 2003. Meterologically mediated diurnal questing of *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) nymphs. J. Med. Entomol. 40, 395–402.
Schulze, T.L., Jordan, R.A., Hung, R.W., 2001. Effects of selected meteorological factors on diurnal questing of *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae). J. Med. Entomol. 38, 318–324.
Schwartz, B.S., Goldstein, M.D., 1990. Lyme disease in outdoor workers: risk factors, preventive measures, and tick removal methods. Am. J. Epidemiol. 131, 877–885.
Schwarz, A., Maier, W.A., Kistemann, T., Kampne, H., 2009. Analysis of the distribution of the tick *Ixodes ricinus* L. (Acari: Ixodidae) in a nature reserve of western Germany using Geographic Information Systems. Int. J. Hyg. Environ. Health 212, 87–96.
Semtner, P.J., Howell, D.E., Hair, J.A., 1971. The ecology and behavior of the Lone Star tick (Acarina: Ixodidae) I. The relation between vegetative type and tick abundance and distribution in Cherokee, Co., Oklahoma. J. Med. Entomol. 8, 329–335.
Shaw, S.E., Day, M.J., Birtles, R.J., Breitschwerdt, E.B., 2001. Tick-borne infectious diseases of dogs. Trends Parasitol. 17, 74–80.
Shih, C.-M., Telford III, S.R., Spielman, A., 1995. Effect of ambient temperature on competence of deer ticks as hosts for Lyme disease spirochetes. J. Clin. Microbiol. 33, 958–961.
Silaghi, C., Skuballa, J., Thiel, C., Pfister, K., Petney, T.N., Pfäffle, M., Taraschewski, H., Passos, L.M.F., 2012. The European hedgehog (*Erinaceus europaeus*) – a suitable reservoir for variants of *Anaplasma phagocytophilum*? Ticks Tick Borne Dis. 3, 49–54.
Skuballa, J., Oehme, R., Hartelt, K., Petney, T., Bücher, T., Kimmig, P., Taraschewski, H., 2007. European hedgehogs as hosts for *Borrelia* spp. Germany. Emerg. Infect. Dis. 13, 952–953.
Skuballa, J., Petney, T., Pfäffle, M., Oehme, R., Hartelt, K., Fingerle, V., Kimmig, P., Taraschewski, H., 2012. Occurrence of different *Borrelia burgdorferi* sensu lato genospecies including *B. afzelii*, *B. bavariensis*, and *B. spielmanii* in hedgehogs (*Erinaceus* spp.) in Europe. Ticks Tick Borne Dis. 3, 8–13.
Skuballa, J., Petney, T., Pfäffle, M., Taraschewski, H., 2010. Molecular detection of *Anaplasma phagocytophilum* in the European hedgehog (*Erinaceus europaeus*) and its ticks. Vector Borne Zoonotic Dis. 10, 1055–1057.
Smith, P.F., Benach, J.L., White, D.J., Stroup, D.F., Morse, D.L., 1988. Occupational risk of Lyme disease in endemic areas of New York State. Ann. NY Acad. Sci. 539, 289–301.
Smith, R.P., Rand, P.W., Lacombe, E.H., 1990. Potential for Lyme disease in Maine: deer survey of distribution of *Ixodes dammini*, the tick vector. Am. J. Public Health 80, 333–335.
Socolovschi, C., Kernif, T., Raoult, Didier, Parola, Philippe, 2012. *Borrelia*, *Rickettsia*, and *Ehrlichia* species in bat ticks, France, 2010. Emerg. Infect. Dis. 18. doi: 10.3201/eid1812.111237.
Socolovschi, C., Raoult, D., Parola, P., 2009. Influence of temperature on the attachment of *Rhipicephalus sanguineus* ticks on rabbits. CMI 15 (Suppl. 2), 326–327.
Sood, S.H., 2002. Effective retrieval of Lyme disease information on the Web. Clin. Infect. Dis. 35, 451–464.
Speck, S., Perseke, L., Petney, T., Skuballa, J., Pfäffle, M., Taraschewski, H., Bunnell, T., Essbauer, S., Dobler, G., 2013. Detection of *Rickettsia helvetica* in ticks collected from European hedgehogs (*Erinaceus europaeus*, Linnaeus, 1758). Ticks Tick Borne Dis. 4, 222–226.
Stoddard, S.T., Morrison, A.C., Vazquez-Prokopec, G.M., Paz Soldan, V., Kochel, T.J., Kitron, U., Elder, J.P., Scott, T.W., 2009. The role of human movement in the transmission of vector-borne pathogens. PLoS Negl. Trop. Dis. 3, e481. http://dx.doi.org/10.1371/journal.pntd.0000481.
Süss, J., 2003. Epidemiology and ecology of TBE relevant to the production of effective vaccines. Vaccine 21, S19–S35.
Süss, J., Gerstengarbe, F.-W., Werner, P.C., 2008. What makes ticks tick? Climate change, ticks, and tick-borne diseases. J. Travel. Med. 15, 39–45.
Sumilo, D., Asokliene, L., Avsic-Zupanc, T., Bormane, A., Vasilenko, V., Lucenko, I., Golovljova, I., Randolph, S.E., 2008a. Behavioural responses to perceived risk of tick-borne encephalitis: vaccination and avoidance in the Baltics and Slovenia. Vaccine 26, 2580–2588.
Sumilo, D., Asokliene, L., Bormane, A., Vasilenko, V., Golovljova, I., Randolph, S.E., 2007. Climate change cannot explain the upsurge of tick-borne encephalitis in the Baltics. PLoS ONE 2, e500. http://dx.doi.org/10.1371/journal.pone.0000500.
Sumilo, D., Bormane, A., Asokliene, L., Lucenko, I., Vasilenko, V., Randolph, S., 2006. Tick-borne encephalitis in the Baltic states: identifying risk factors in space and time. Int. J. Med. Microbiol. 296, 76–79.
Sumilo, D., Bormane, A., Asokliene, L., Vasilenko, V., Golovljova, I., Avsic-Zupanc, T., Hubalek, Z., Randolph, S.E., 2008b. Socio-economic factors in the differential upsurge of tick-borne encephalitis in Central and Eastern Europe. Rev. Med. Virol. 18, 81–95.
Sutherst, R., 2004. Global change and human vulnerability to vector-borne diseases. Clin. Microbiol. Rev. 17, 136–173.
Szell, Z., Sreter-Lancz, Z., Marialigeti, K., Sreter, T., 2006. Temporal distribution of *Ixodes ricinus*, *Dermacentor reticulatus* and *Haemaphysalis concinna* in Hungary. Vet. Parasitol. 141, 377–379.
Szep, T., Moller, A., 1999. Cost of parasitism and host immune defence in the sand martin *Riparia riparia*: a role for parent-offspring conflict? Oecologia 119, 9–15.
Tack, W., Madder, M., Baeten, L., De Frenne, P., Verheyen, K., 2012. The abundance of *Ixodes ricinus* ticks depends on tree species composition and shrub cover. Parasitology 139, 1273–1281.
Taylor, L.H., Latham, S.M., Woolhouse, M.E.J., 2001. Risk factors for human disease emergence. Philos. Trans. R. Soc. Lond. B 356, 983–989.
Thorin, C., Rigaud, E., Capek, I., André-Fontaine, G., Oster, B., Gastinger, G., Abadia, G., 2008. Seroprevalence of Lyme borreliosis and tick-borne encephalitis in workers at risk, in Eastern France. Med. Maladies Infect. 38, 533–542.
Tilman, D., 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proc. Natl. Acad. Sci. USA 96, 5995–6000.
Tonteri, E., Jääskeläinen, A.E., Tikkakoski, T., Voutilainen, L., Niemimaa, J., Henttonen, H., Vaheri, A., Vapalahti, O., 2011. Tick-borne encephalitis virus in wild rodents in winter, Finland, 2008–2009. Emerg. Infect. Dis. 17, 72–75.
Ulmanen, I., Saikku, P., Vikberg, P., Sorjonen, J., 1977. *Ixodes lividus* colonies (Acari) in sand martin in Fennoscandia. Oikos 28, 20–26.
Vanwambeke, S., Sumilo, D., Bormane, A., Lambin, E.F., Randolph, S.E., 2010. Landscape predictors of tick-borne encephalitis in Latvia: land cover, land use, and land ownership. Vector Borne Zoonotic Dis. 10, 497–506.
Vial, L., 2009. Biological and ecological characteristics of soft ticks (Ixodida: Argasidae) and their impact for predicting tick and associated disease burden. Parasite 16, 191–202.
Vogt, P., Riitters, K.H., Estreguil, C., Kozak, J., Wade, T.G., Wickham, J.D., 2006. Mapping spatial patterns with morphological image processing. Landsc. Ecol. 22, 171–177.
Vor, T., Kiffner, C., Hagedorn, P., Niedrig, M., Rühe, F., 2010. Tick burden on European roe deer (*Capreolus capreolus*). Exp. Appl. Acarol. 51, 405–417.
Watling, J.I., Donnelly, M.A., 2006. Fragments as islands: a synthesis of faunal responses to habitat patchiness. Conserv. Biol. 20, 1016–1025.
Whitehouse, C.A., 2004. Crimean-Congo hemorrhagic fever. Antiviral Res. 64, 145–160.
Wikel, S.K., 1996. Host immunity to ticks. Ann. Rev. Entomol. 41, 1–22.
Wikel, S.K., Bergman, D., 1997. Tick–host immunology: significant advances and challenging opportunities. Parasitol. Today 13, 383–389.
Wikel, S.K., Ramachandra, R.N., Bergman, D.K., Burkot, T.R., Piesman, J., 1997. Infestation with pathogen-free nymphs of the tick *Ixodes scapularis* induces host resistance to transmission of *Borrelia burgdorferi* by ticks. Infect. Immun. 65, 335–338.
Williams, S.C., Ward, J.S., 2010. Effects of Japanese barberry (Ranunculales: Berberidaceae) removal and resulting microclimatic changes on *Ixodes scapularis* (Acari: Ixodidae) abundances in Connecticut, USA. Environ. Entomol. 39, 1911–1921.
Wilson, K., Bjornstad, O.N., Dobson, A.P., Merler, S., Poglayen, G., Randolph, S.E., Read, A.F., Skorping, A., 2002. Heterogeneities in macroparasite infections: patterns and proceeds. In: Hudson, P.J., Rizzoli, A., Grenfell, B.T., Heesterbeek, H., Dobson, A.P. (Eds.), The Ecology of Wildlife Diseases. Oxford University Press, Oxford, pp. 6–44.
Wilson, M.L., Levine, J.F., Spielman, A., 1984. Effect of deer reduction on abundance of the deer tick (*Ixodes dammini*). Yale J. Biol. Med. 57, 697–705.
Wood, C.L., Lafferty, K.D., 2012. Biodiversity and disease: a synthesis of ecological perspectives on Lyme disease transmission. Trends Ecol. Evol. 28, 239–247.
Wolbach, S., 1919. Studies on Rocky Mountain spotted fever. J. Med. Res. XLI, 1–218.

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

Yahner, R., 1988. Changes in wildlife communities near edges. Conserv. Biol. 2, 333–339.

Yoder, J.A., Bozic, Z.D., Butch, L.C., Rellinger, E.J., Tank, J.L., 2006. Demonstration of an enhanced ability to tolerate high temperature in unfed larvae of the Brown dog (kennel) tick, *Rhipicephalus sanguineus* (Acari: Ixodidae). Int. J. Acarol. 32, 417–423.

Zharkov, S., Dubinina, H.V., Alekseev, A.N., Jensen, P., 2000. Anthropogenic pressure and changes in Ixodes tick populations in the Baltic region of Russia and Denmark. Acarina 8, 137–141.

Zygutiene, M., Alekseev, A.N., Dubinina, H.V., Kazlauskiene, R., 2008. Evidence for a risk of tick-borne infection in the city parks of Vilnius, Lithuania. Ekologija 54, 40–43.

Please cite this article in press as: Pfäffle, M., et al. The ecology of tick-borne diseases. Int. J. Parasitol. (2013), http://dx.doi.org/10.1016/j.ijpara.2013.06.009

LogID 6214

RESEARCH TECHNICAL REPORT

Environmental Impact of Automatic Fire Sprinklers

FM Global

TECHNICAL REPORT

Environmental Impact of Automatic Fire Sprinklers

By:

Christopher J. Wieczorek
Benjamin Ditch
Robert G. Bill, Jr.

FM Global Research Division

March 2010

Environmental Impact of Automatic Fire Sprinklers

by
Christopher J. Wieczorek, Benjamin Ditch, Robert G. Bill, Jr.

FM Global
Research Division
1151 Boston-Providence Turnpike
Norwood, MA 02062

DISCLAIMER

The research presented in this report, including any findings and conclusions, is for informational purposes only. Any references to specific products, manufacturers or contractors do not constitute a recommendation, evaluation or endorsement by Factory Mutual Insurance Company (FM Global) of such products, manufacturers or contractors. FM Global makes no warranty, expressed or implied, with respect to any product or process referenced in this report. FM Global assumes no liability by or through the use of the information in this report.

EXECUTIVE SUMMARY

Currently, efforts to improve sustainability and reduce lifecycle carbon emissions are achieved primarily by increasing the energy efficiency of an occupancy and reducing embodied carbon. Recently, a methodology has been developed that expands the assessment of lifecycle carbon emissions to incorporate risk factors such as fire. The methodology shows that in all occupancies, from residential dwellings, to office buildings, to high hazard facilities, the lack of proper risk management and effective fire protection, e.g., automatic fire sprinklers, statistically increases carbon emissions over the lifecycle of the occupancy.

Furthermore, typical benefits gained from "green" construction and energy efficient appliances and equipment can be negated by a single fire event. This is due to the subsequent carbon dioxide, and other greenhouse gases, generated from burning combustible material, in addition to the embodied carbon associated with disposal of damaged materials and reconstruction.

To further support the risk factor methodology, an experimental study was conducted to quantify the environmental impact of automatic fire sprinklers. Large-scale fire tests were conducted using identically constructed and furnished residential living rooms. In one test, fire extinguishment was achieved solely by fire service intervention. In the other test, a single residential fire sprinkler controlled the fire until final extinguishment was achieved by the fire service.

Quantification of the environmental benefit of automatic fire sprinklers was based on comparisons between the two tests, including total greenhouse gas production, quantity of water required to extinguish the fire, quality of water runoff, potential impact of wastewater runoff on groundwater and surface water, and mass of materials requiring disposal.

The use of automatic fire sprinklers reduced the peak heat release rate from 13,200 kW to 300 kW and reduced the total energy generated by a factor of 76. The fraction of combustible material consumed in the fire was less than 3% in the sprinklered test and between 62% and 95% in the non-sprinklered test.

The total air emissions generated from the sprinklered test were lower than those from the non-sprinklered test. Of the 123 species analyzed in the air emissions, only 76 were detected in either the sprinklered or non-sprinklered tests. Of the species detected, the ratio of non-sprinklered to sprinklered levels for 24 of the species was in excess of 10:1. Eleven were detected at a ratio in excess of 50:1, and of those, six were detected at a ratio in excess of 100:1. The remaining species were detected at the same order of magnitude. The use of automatic fire sprinklers reduced the greenhouse gas emissions, consisting of carbon dioxide, methane, and nitrous oxide, and reported as equivalent mass of carbon dioxide, by 97.8%.

Comparing the water usage between the two tests, it was found that in order to extinguish the fire, the combination of sprinkler and hose stream discharge from the firefighters was 50% less than the hose stream alone. Additional analysis indicates that the reduction in water use achieved by using sprinklers could be as much as 91% if the results are extrapolated to a full-sized home. Furthermore, fewer persistent pollutants, such as heavy metals, and fewer solids were detected in the wastewater sample from the sprinklered test compared to that of the non-sprinklered test. The pH value of the non-sprinklered test wastewater exceeded the allowable discharge range of 5.5 to 9.0 required by most environmental agencies and was four orders of magnitude higher in alkalinity than the wastewater from the sprinklered test. The non-sprinklered test wastewater represents a serious environmental concern.

Analysis of the solid waste samples indicated that the ash/charred materials from neither the sprinklered nor the non-sprinklered test would be considered "hazardous waste," and that the wastes are not anticipated to significantly leach once disposed of in landfills.

In the sprinklered room, flashover never occurred; however, in the non-sprinklered test, flashover occurred at approximately five minutes after ignition. The occurrence of flashover prior to fire service intervention is an indication that the fire would have propagated to adjacent rooms, resulting in greater production of greenhouse gases, greater water demand to extinguish the fire, and additional materials to be disposed of in landfills. However, in the sprinklered test where the fire was confined to the area of origin, the damage, greenhouse gas production, and water consumption represent maximum values independent of additional rooms.

The greater fire damage in the non-sprinklered test has a direct impact on the carbon emissions of the building. This is due to the embodied carbon associated with the building materials necessary for reconstruction and those associated with the manufacturing of furnishings and contents.

It has been known for years that automatic fire sprinklers provide life safety and limit property damage; the current study has shown quantitatively that automatic fire sprinklers are also a key factor in achieving sustainability. Although the current study was conducted using a residential setting, the environmental benefits of automatic fire sprinklers apply to other occupancies as well.

FOREWORD

Since 1996, the nonprofit Home Fire Sprinkler Coalition (HFSC) has been helping the public understand the need for, and the unique value of, fire sprinkler systems in new houses. The HFSC's effort is necessary because thousands of lives are lost in house fires every year, yet only a tiny fraction of new houses are built with sprinkler protection – a technology proven to save lives if a fire starts.

For as long as data has been collected, the U.S. fire death problem has been a residential one. The numbers have dropped over the past 30 years, but the rate has remained steady. More than eight out of every 10 civilian structure fire deaths and most civilian fire injuries occur in homes. On a percentage basis, these properties are also the most dangerous fireground scene for firefighters. Obviously, these are the properties we must target if we are going to make inroads to the overall fire problem.

Fire sprinklers could save lives if more systems were installed in homes. Increasing awareness about sprinklers leads to more home installations and that protects public safety and improves communities. But educating new homebuyers and others about fire sprinklers isn't simple. Surveys over the years have consistently shown that most people don't believe a fire will happen in their own home or understand that a house fire can grow to deadly flashover within a few minutes.

There is also the challenge of education on fire sprinkler cost, activation and maintenance. Recognizing these outreach challenges, HFSC works to find new partnerships and innovative methods to help the public understand how dangerous house fires truly are, and how critical fire sprinklers are to life safety.

The idea to explore the environmental impact of sprinklered and non-sprinklered house fires was born a few years ago during an HFSC strategic planning session. We were confident that home fire sprinklers are also indeed "green" and we wanted to tap into the nation's heightened interest in the environment as a means to draw attention to their overall benefit. But we wanted to make a scientific case for it.

That led us to FM Global and to a lengthy joint effort that has made it possible to prove, without doubt, that sprinklers not only save lives and protect property; they also protect our planet.

We are grateful to FM Global, one of the world's largest business property insurers, for partnering with HFSC in this residential safety effort. One of the reasons we turned to FM Global is because of the leadership role they have taken in fire sprinkler research over the past 50 years. And we knew the remarkable scientific testing facilities at FM Global's Research Campus would benefit our study and ensure its findings would be unimpeachable.

As you'll see when you read this technical report, the fire safety community's efforts to increase awareness of all aspects of home fire sprinkler technology will benefit from this new environmental data. Consumers, homebuilders, the fire service, and local officials now have a new and important way to view home fire sprinkler protection.

This research would not have been possible were it not for the generosity of FM Global, specifically the management leadership of Dr. Lou Gritzo and the personal commitment of Dr. Christopher Wieczorek. Thanks to their vision, professionalism and dedication, HFSC now has the data to prove that sprinklers are indeed "green" in addition to the benefit they offer to protect lives and property.

Gary S. Keith
Chair, Home Fire Sprinkler Coalition Board of Directors

ABSTRACT

The present study examines the relationship of automatic fire sprinkler technology to environmental sustainability. The work includes the evaluation of risk factors, such as fires, on the total lifecycle carbon emissions of a typical single- or two-family home. Additionally, an experimental quantification of the environmental benefits achieved by the use of automatic fire sprinklers was conducted.

Large-scale fire tests were conducted using identically constructed and furnished residential living rooms. In one test, fire extinguishment was achieved solely by fire service intervention, and in the other, a single residential automatic fire sprinkler was used to control the fire until final extinguishment was achieved by the fire service. Comparisons of the total greenhouse gas production, quantity of water required to extinguish the fire, quality of water runoff, potential impact of wastewater runoff on groundwater and surface water, and mass of materials requiring disposal between the two tests were made.

The results show that in addition to providing life safety and limiting property damage, the use of automatic fire sprinklers is a key factor in achieving sustainability.

ACKNOWLEDGEMENTS

This project would not have been successful without the efforts and contributions of numerous individuals. The authors would like to thank Mr. Gary Keith, Ms. Peg Paul, and the entire board of directors of the nonprofit Home Fire Sprinkler Coalition (HFSC) who worked in partnership with FM Global to define the scope and objectives of this project. The input from the board members in planning the testing was greatly appreciated.

The authors would like to especially thank Mr. Richard Chmura, Mr. Jeffery Chaffee, Mr. Michael Skidmore, Mr. Robert Harriman, and the entire staff of the FM Global Research Campus Large Burn Laboratory and the Calorimetry Laboratory. This project would not have been possible without their efforts and technical abilities.

A special thanks to Mr. Wayne Milette, and all of the firefighters at the Research Campus, along with Mr. Dana Haagensen of the Massachusetts State Fire Marshal's Office, for their input and consultation on appropriate firefighting techniques.

The contributions of Mr. Richard Osburn, Mr. Robert Migliaccio, Mrs. Denise Bernier, and Mr. Joe Marte in documenting the project via photographs and videos beyond the standard practice also are greatly appreciated. Furthermore, the extra efforts of Mr. Richard Osburn in processing and editing the videos for various presentations deserves acknowledgement.

The authors would also like to acknowledge the services of Woodard and Curran, in particular Mr. Zareh Maserejian, Ms. Lisa M. McIntosh, and Mr. Tom Ennis for their assistance in the environmental analysis.

As always, the efforts of Mrs. Cheryl McGrath in processing this report are greatly appreciated.

x

TABLE OF CONTENTS

Section	Title	Page
EXECUTIVE SUMMARY		i
FOREWORD		v
ABSTRACT		vii
ACKNOWLEDGEMENTS		ix
TABLE OF CONTENTS		xi
LIST OF FIGURES		xv
LIST OF TABLES		xvii
NOMENCLATURE		xix
1	INTRODUCTION AND BACKGROUND	1
1.1	PROBLEM STATEMENT	1
1.2	BACKGROUND	1
1.2.1	Methodology for Estimating LCE Including Risk Factors	2
1.2.2	Effect of Automatic Sprinklers on LCE	5
1.2.3	Quantification of TCE in One- and Two-Family Dwellings	6
1.2.4	Effect of Fire on LCE in Homes	9
1.2.5	Improved Sustainability with Automatic Sprinklers	11
1.3	OBJECTIVES	12
2	FIRE TEST SETUP AND PROCEDURES	13
2.1	FACILITY	13
2.2	TEST CONFIGURATION	15
2.2.1	Living Room Construction	15
2.2.2	Room Furnishings	18
2.2.2.1	Primary Fuel Items	20
2.2.2.2	Secondary Fuel Items	21
2.2.2.3	Decorative Items	23

2.2.2.4 Ignition Package 24

2.3 FIREFIGHTING 24

2.3.1 Sprinkler Protection 24

2.3.2 Fire Service Response Tactics 25

2.4 INSTRUMENTATION 28

2.4.1 Gas Analysis Measurements within the Duct 29

2.4.1.1 FM Global Instrumentation 29

2.4.1.2 External Instrumentation 30

2.4.2 Gas Analysis Measurements within the Room 30

2.4.3 Ceiling and Room Thermocouples 31

2.4.4 Heat Flux Measurements 31

2.4.5 Smoke Detectors 33

2.4.6 Water Collection System 33

2.4.7 Water Quality Analysis 35

2.4.8 Solid Waste Analysis 36

2.4.9 Video and Photography Details 36

3 EXPERIMENTAL RESULTS 38

3.1 FIRE TEST CHRONOLOGIES 38

3.2 SPECIES MEASUREMENTS WITHIN THE DUCT 39

3.3 HEAT RELEASE RATE AND TOTAL ENERGY 40

3.4 ROOM GAS MEASUREMENTS 42

3.5 CEILING TEMPERATURES 45

3.6 FLASHOVER 47

3.7 WATER USAGE 48

3.8 AIR EMISSION RESULTS 50

3.9 WATER QUALITY RESULTS 55

3.10 SOLID WASTE ANALYSIS 60

4 DISCUSSION 61

4.1 IMPACT ON GREENHOUSE GASES 61

4.2 WATER USE EXTRAPOLATION 63

4.3 FIRE DAMAGE 63

4.5 LANDFILL IMPACTS 69

4.6 ROOM TENABILITY 71

5 CONCLUSIONS 76

6 REFERENCES 79

LIST OF FIGURES

Figure	Title	Page
Figure 1:	Contribution of risk factors to total lifecycle carbon emissions.	3
Figure 2:	Illustrations of the large burn laboratory test sites.	13
Figure 3:	Room position relative to 20-MW calorimeter.	14
Figure 4:	Room exterior walls (south and east walls).	16
Figure 5:	Location of room exterior door, archway, and windows.	16
Figure 6:	Room frame construction.	17
Figure 7:	Furnishing positions and locations within the enclosure.	20
Figure 8:	Images of the "Big Easy" recliner and "Kick Back" sofa and loveseat combination (from store website, not to scale).	21
Figure 9:	Images of secondary fuel items: coffee, console, end tables, and bookcase (from store website, not to scale).	22
Figure 10:	Images of secondary fuel items: 37-inch LCD TV and TV stand (from store website, not to scale).	23
Figure 11:	Orientation of decorative items on console table, bookcases, and coffee table.	23
Figure 12:	(a) Ignition source and (b) Magazine rack relative to loveseat and curtain.	24
Figure 13:	Tyco Fire Suppression & Building Products Residential Sprinkler (TY4234).	25
Figure 14:	Timeline of fire development versus typical fire service response (taken from http://www.illinoisfireinspectors.org/ifia.htm).	27
Figure 15:	Instrumentation layout within the room.	29
Figure 16:	Heat flux gage installation at the floor.	32
Figure 17:	Smoke detector and ceiling heat flux gage locations.	33
Figure 18:	Revised water collection pan setup for sprinklered test.	35
Figure 19:	Baffled water collection pan setup for non-sprinklered test (b).	35
Figure 20:	Video camera positions relative to the room.	37
Figure 21:	Duct concentrations of CO_2 and CO for the non-sprinklered test.	39
Figure 22:	Duct concentrations of CO_2 and CO for the sprinklered test.	40
Figure 23:	Chemical heat release rate as a function of time for the sprinklered and non-sprinklered tests.	41

Figure 24: Total chemical energy as a function of time for the sprinklered and non-sprinklered tests. 42
Figure 25: Carbon dioxide, carbon monoxide, and unburned hydrocarbon concentrations as a function of time within the room for the non-sprinklered test. 43
Figure 26: Carbon dioxide, carbon monoxide, and unburned hydrocarbon concentrations as a function of time within the room for the sprinklered test. 44
Figure 27: Oxygen concentrations as a function of time within the room for the sprinklered and non-sprinklered tests. 45
Figure 28: Near-ceiling thermocouple measurements for the non-sprinklered test. 46
Figure 29: Near-ceiling thermocouple measurements for the sprinklered test. 47
Figure 30: Flashover analysis of non-sprinklered test. 48
Figure 31: Total volume of water used as a function of time. 49
Figure 32: Carbon monoxide concentrations and integrated values as a function of time for the sprinklered test. 73
Figure 33: Carbon monoxide concentrations and integrated values as a function of time for the non-sprinklered test. 74
Figure 34: Air temperature as a function of time for the sprinklered and non-sprinklered test at 1.5 m (5 ft.) elevation within the center of the room. 75

LIST OF TABLES

Table	Title	Page
Table 1:	Selected values for variables in Equation 8	7
Table 2:	Home and Fire Statistics from 1999 to 2008	8
Table 3:	Manufacturer's Carpet Specifications (J&J Industries' website)	18
Table 4:	Room Furnishings	19
Table 5:	Primary Fuel Items	21
Table 6:	Secondary Fuel Items	22
Table 7:	Table 4.3.2 Staffing and Response Time taken from NFPA 1720	26
Table 8:	FM Global Gas Analyzer Measurement Ranges (Duct)	30
Table 9:	Gas Analyzer Measurement Ranges (Room)	31
Table 10:	Heat Flux Gage Information	32
Table 11:	Wastewater Analysis Taken from Reference 38	36
Table 12:	Fire Test Chronologies	38
Table 13:	Water Usage Results	50
Table 14:	Controlled Burn Air Emissions (Table 3-1 extracted from Reference 38)	51
Table 15:	Equivalent Carbon Dioxide Values for Measured Greenhouse Gases	62
Table 16:	Water Usage Estimates	63
Table 17:	Mass of Combustibles Consumed in Sprinklered Test	64
Table 18:	Mass and Carbon Dioxide Emissions from Damaged Materials in a Landfill	71
Table 19:	Physiological Effects of Carbon Monoxide Exposure and the Times Critical Levels Were Reached in the Sprinklered and Non-Sprinklered Tests	72

NOMENCLATURE

Symbol	Definition	Units
A	Average Area of a Residence	m^2
$ACE_{embodied}$	Annualized Embodied Carbon Emissions	$kg_{CO_2}/year$
$ACE_{operation}$	Annualized Carbon Emissions Associated with Normal Operations	$kg_{CO_2}/year$
$ACE''_{operation}$	Annualized Carbon Emissions Associated with Normal Operations per Unit Area	$\frac{kg_{CO_2}}{(m^2 - year)}$
$CE_{construction}$	Carbon Emissions Associated with Construction Activities	kg_{CO_2}
$CE_{decommissioning}$	Carbon Emissions Associated with Decommissioning Activities	kg_{CO_2}
$CE_{embodied}$	Embodied Carbon Emissions	kg_{CO_2}
$CE''_{embodied}$	Embodied Carbon Emissions per Unit Area	kg_{CO_2}/m^2
CE_{fire}	Carbon Emissions Associated with a Fire Event	kg_{CO_2}
$CE_{replacement}$	Carbon Emissions Associated with Reconstruction	kg_{CO_2}
$CO_{2,equivalent}$	Equivalent Mass of Carbon Dioxide for a Gas	kg_{CO_2}
e_{CO_2}	Mass of CO_2 generated per Unit Mass of Fuel Burned	kg_{CO_2}/kg_{fuel}
F_b	Fraction Burned	--
f_f	Frequency of Residential Fires	Fires/year
F_r	Fraction Replaced	--
GWP_{gas}	Global Warming Potential of a Gas	--
LCE	Lifecycle Carbon Emissions	kg_{CO_2}
$LCE_{operation}$	Lifecycle Carbon Emissions Associated with Normal Operations	kg_{CO_2}
LCE_{risk}	Lifecycle Carbon Emissions Due to Fire Risk	kg_{CO_2}
LT	Lifetime of the Structure	Years
m''_f	Fuel Load per Unit Area	kg/m^2

m_{gas}	Mass of Greenhouse Gas	kg
RF_{fire}	Fraction of Total Carbon Emissions due to Fire Risk	%
$RF_{fire,AS}$	Fraction of Total Carbon Emissions due to Fire Risk with Automatic Sprinklers	%
TCE	Total Lifecycle Carbon Emissions	kg_{CO_2}
$TCE_{construction}$	Total Carbon Emissions Associated with Construction Activities	kg_{CO_2}

1 INTRODUCTION AND BACKGROUND

1.1 PROBLEM STATEMENT

Past research in residential automatic fire sprinkler technology has identified sprinkler characteristics necessary to provide reliable life safety in residential occupancies [1,2,3]. This research further resulted in a standardization of the requirements for reliably certifying and installing residential hardware to meet desired performance requirements [4,5,6,7,8,9,10]. The present study treats a relatively new issue: the relationship of residential sprinkler technology to environmental sustainability.

1.2 BACKGROUND

To date, the use of residential automatic fire sprinkler technology has been extremely limited with less than 3% of one- and two-family dwellings taking advantage of its benefits [11]. The 2007 American Housing Survey reported sprinkler usage in 1.5% of single family detached dwellings and 2.9% in buildings with two to four units [12]. Hall [13] reports that only 1.2% of fires in the U.S. occurred in one- or two-family dwellings with automatic extinguishing systems in 2006. The effectiveness of the residential sprinkler has, however, been increasingly recognized by communities through regulations requiring installation in one- and two- family dwellings. Of particular note are the long-term ordinances for Scottsdale, Arizona, and Prince George's County, Maryland. In both cases, experience with the resulting installations led to clear documentation of the benefits to life safety and property protection (see, e.g., Reference 11 and 14). In 2006, the NFPA model codes, i.e., NFPA 1, *Fire Code*, NFPA 101, *Life Safety Code*, and NFPA 5000, *Building Construction and Safety Code*, adopted the requirement for residential fire sprinklers in one- and two-family dwellings [15,16,17]. The United States Fire Administration (USFA) has supported the position that: "All homes should be equipped with both smoke alarms and automatic fire sprinklers" [18]. Such support led to the approval of a requirement in the International Code Council (ICC), *International Residential Code*, on September 21, 2008, for residential sprinklers in all new one- and two-family homes and townhouses [19]. However, only about 400 out of the thousands of jurisdictions in the U.S. were mandating the installation of residential sprinklers in 2008 [18].

A new factor to be considered in the assessment of the value of residential sprinklers is the desire to achieve sustainability through the potential positive impact of sprinklers on the lifecycle carbon emissions of homes. As part of the sustainability assessment, carbon emissions from a facility are estimated under normal operating conditions. Recently, Gritzo *et al.* [20] have shown that, in industrial and commercial facilities (including light hazard, i.e., hotels and condos), the impact of fire on lifecycle carbon emissions is significant and needs to be accounted for due to the release of emissions during the fire and the carbon associated with rebuilding or reconstruction. Thus, in addition to their life safety and property protection functions, sprinklers promote sustainability.

1.2.1 Methodology for Estimating LCE Including Risk Factors

The construction, renovation, or improvement of facilities increasingly includes measures to improve sustainability by reducing environmental impact over their operational lifecycle. Of primary environmental concern is the emission of greenhouse gases associated with the consumption of energy during normal operations, or required for the production and transportation of materials, and construction. Emphasis to date has focused on reduction in emissions related to energy consumption during normal operations, with a secondary emphasis on reducing carbon emissions associated with the fabrication and transport of construction materials, construction processes, and facilities decommissioning, i.e., the "embodied carbon emissions." Within the United States, the Leadership in Engineering and Environmental Design Organization (LEED) has established metrics and certification levels for construction and renovation [21]. LEED certification checklists provide guidance for options and measures to reduce the environmental impact of facility construction and operations on carbon emissions. Gritzo *et al.* [20] supplemented the analysis of normal operations with an analysis taking into account risk factors of such events as fire, wind, and flood as well as the use of mitigating technologies such as sprinklers.

The impact of risk factors on lifecycle carbon emission, LCE, is illustrated in Figure 1. The plot indicates the carbon emission for an occupancy as a function of time. Note that proportions are not to scale, but are expanded for readability. The lower curve may be considered the carbon emissions under normal conditions; the upper curve shows the deviation from that of normal conditions due to a fire.

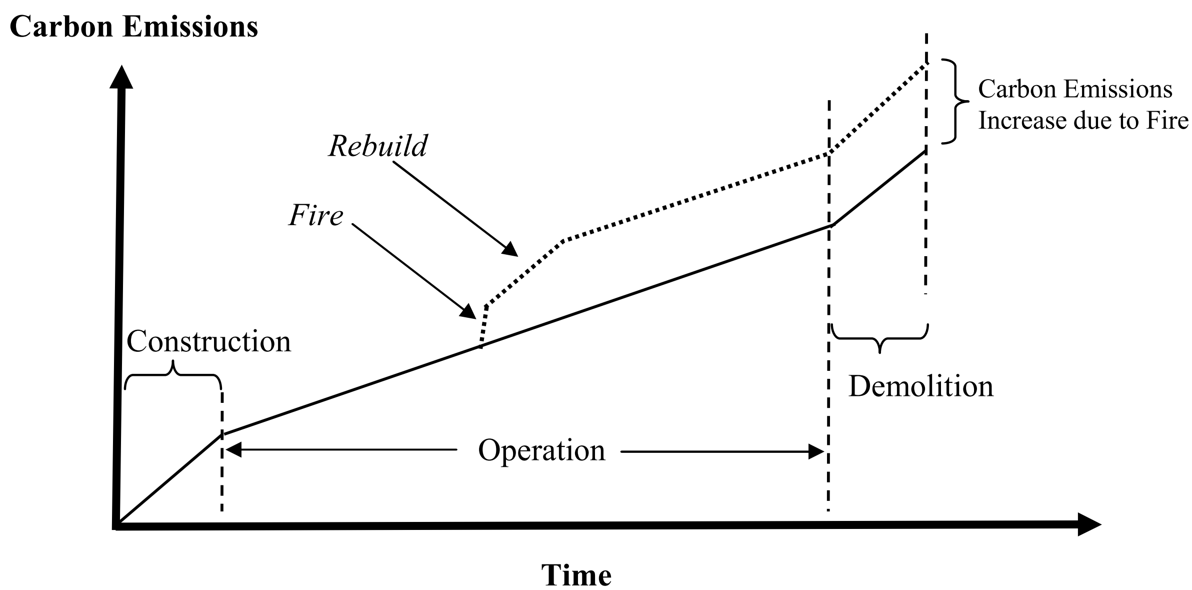


Figure 1: Contribution of risk factors to total lifecycle carbon emissions.

The carbon emission cycle can be divided into three portions: 1) that due to construction, $CE_{construction}$ (including that associated with manufacture of material, transportation, and equipment usage), 2) that due to normal operation over the lifetime of the occupancy, $LCE_{operation}$ (primarily power consumption, utilities, and maintenance if applicable), and 3) that due to decommissioning, $CE_{decommissioning}$ (including that due to equipment usage for demolition, and transportation for disposal).

Thus the total lifetime carbon emissions (TCE) are given as

$$TCE = CE_{construction} + LCE_{operation} + CE_{decommissioning} \qquad (1)$$

The carbon emissions associated with normal operations are typically estimated on an annual basis, $ACE_{operation}$, in which case, $LCE_{operation}$ depends on the lifetime of the occupancy, LT:

$$LCE_{operation} = LT \cdot ACE_{operation} \tag{2}$$

The annual rate of emission for operation is typically referred to as the "carbon footprint." Due to the primary importance of energy consumption on emissions associated with normal operations, annual rates of carbon emissions can readily be determined using standard guidance [22].

The emissions due to construction and decommissioning are typically considered one time events and referred to as embodied emissions, $CE_{embodied}$, given their inclusion in the physical facility rather than resulting from normal operations. Hence,

$$CE_{embodied} = CE_{construction} + CE_{decommissioning} \tag{3}$$

Note that the embodied emissions are estimated in the literature on a per unit area basis (see e.g., Reference 22) and can be annualized over the lifetime, LT, of a facility:

$$ACE_{embodied} = \frac{CE''_{embodied} \cdot A}{LT} \tag{4}$$

The event of a fire requires taking into account additional considerations in the analysis, namely, the carbon emissions associated with the fire, CE_{fire}, and those associated with replacement of the damage caused by the fire, $CE_{replacement}$. These may be estimated as

$$CE_{fire} = F_b \cdot m''_f \cdot e_{CO_2} \cdot A \tag{5}$$

and

$$CE_{replacement} = F_r \cdot CE_{embodied} \tag{6}$$

where F_b is the fraction of material burned; m''_f is the total mass of combustible material per unit area; e_{CO_2} is the carbon dioxide released per mass of material burned; and F_r is the fraction of material to be replaced during reconstruction.

Figure 1 reflects additional carbon emissions resulting from the fire, referred to as the lifecycle carbon emissions due to fire risk, LCE_{risk}. Evaluating the risk on a statistical basis over the lifetime of the structure requires knowledge of the frequency of fires, f_f. Thus,

$$LCE_{risk} = f_f \cdot LT \cdot \left(CE_{fire} + CE_{replacement}\right) \tag{7}$$

A risk factor, RF_{fire}, indicating the relative importance of carbon emissions due to risk events such as fire compared to normal operation over the lifetime can be defined as

$$\begin{aligned} RF_{fire} &= \frac{LCE_{risk}}{TCE} = \frac{f_f \cdot LT \cdot \left(CE_{fire} + CE_{replacement}\right)}{TCE} \\ &= f_f \cdot LT \cdot \left(\frac{F_b \cdot m''_f \cdot e_{CO_2} \cdot A}{TCE} + \frac{F_r \cdot CE_{embodied}}{TCE}\right) \end{aligned} . \tag{8}$$

The risk fraction, therefore, represents the increase that risk factors pose to the sustainability posture of a home over its lifetime.

1.2.2 Effect of Automatic Sprinklers on LCE

A reduction in the risk fraction can be achieved through effective risk management strategies, which can serve to reduce the fire frequency and/or serve to reduce the extent of damage produced and reconstruction required. In the context of the home, such risk management includes smoke detectors, fire retardant furnishings, and adoption of ignition source control. The latter two factors can reduce the frequency of fires; however, they cannot in themselves suppress a fire once it has occurred. Automatic fire sprinklers are the most common and cost effective method to reduce both the frequency of large fires and the severity of damage (and hence the fraction required for reconstruction). Fire frequency data implicitly include some minimum threshold for fire size, since very small or incipient fires cause minimal damage and are frequently extinguished without record. Furthermore, fire severity data are often expressed in terms of loss values, which may or may not include full cost of replacement.

The effect of automatic sprinklers on the risk factor is expressed by reductions in the fraction burned, F_b, and the replacement fraction, F_r, values used in Equation 8.

1.2.3 Quantification of TCE in One- and Two-Family Dwellings

Values used in the present study for the variables in Equation 8 are provided in Table 1. In the following sections, justification for these values will be provided relative to typical one- and two-family dwellings and the impact of sprinklers. Due to the uncertainty including variability associated with a number of variables, a lower (Case 1) and upper (Case 2) bound is provided.

Evaluating the TCEs for a typical one- and two-family dwelling from its components as in Equations 1 to 3 is quite complex given the diversity of construction and patterns of energy consumption in the U.S. For example, in a report on per capita carbon footprints from residential energy use of the 100 largest U.S. metropolitan areas, Brown *et al.* [23] indicate a factor of 5.6 between the metropolitan area with the lowest per capita emissions (0.350 metric tons carbon – Bakersfield, CA) and the highest (1.958 metric tons carbon – Washington, DC). The average per capita carbon emission from residential energy use was 0.925 metric tons. The objective of the present study was not to evaluate the range of carbon emissions resulting from such diversity in the housing population, but to provide a typical result indicative of the significance of the use of automatic sprinklers to sustainability.

Table 1: Selected values for variables in Equation 8

Symbol	Parameter (units)	Case 1	Case 2
f_f	Frequency of Residential Fires (fires/year)	0.0032	0.0032
LT	Lifetime (yr)	50	50
m_f	Fuel Density (kg/m^2)	13.2	21
e_{co2}	Mass of CO_2 Generated per Unit Mass of Fuel Burned (kg/kg)	3.0	3.0
TCE	Total Lifecycle Carbon Emissions (kg CO_2)	278,000	278,000
$CE_{embodied}$	Total Embodied Carbon Emissions (kg CO_2)	60,680	60,680
F_b	Fraction Burned, no AFS (-)	0.07	0.34
F_r	Fraction Replaced, no AFS (-)	0.11	1.0
F_{AFS}	Reduction in Property Loss Achieved by AFS (%)	51	90
$F_{b,AS}$	Fraction Burned, AFS (-)	0.03	0.034
$F_{r,AS}$	Fraction Replaced, AFS (-)	0.05	0.051
Results			
RF_{fire}	Fraction of Total Carbon Emissions due to Fire Risk, no active protection (%)	0.40	3.7
$RF_{fire,AS}$	Fraction of Total Carbon Emissions due to Fire Risk, with AS (%)	0.20	0.20

Estimates of annual greenhouse emissions characterized as $ACE_{operation}$ and $ACE_{embodied}$ are taken from Norman *et al.* [24] from a study published in 2006 comparing lifecycle energy use and greenhouse emissions in high and low density residential dwellings. In this study, the low density residential case study consisted of single detached dwellings located near the border of the city of Toronto, Ontario, Canada. All houses consisted of wooden structure and primarily brick façade. The housing is considered to be typical of current and upcoming residential construction.

The major component of TCE is typically that associated with normal operation over the lifetime of the building, $LCE_{operation}$. Norman *et al.* [24] estimate the $LCE_{operation}$ based upon total emission for the residential sector for 1997 obtained from the 2003 Office of Energy Efficiency, Natural Resources Canada. This report, however, did not distinguish between housing types. The authors proportioned the emission based upon the total residential energy use attributable to single-detached dwellings (72%). They also noted that this choice is expected to be reasonable given that the majority of residential greenhouse gas emissions results from the burning of fuel and use of electricity for heating/cooling, which are also the most significant factors in total energy use. In their analysis, they use an annualized value per unit area for $ACE''_{operation}$ of $33.9\ kg_{CO_2} / \left(m^2 - year\right)$.*

To calculate $LCE_{operation}$ the lifetime and area of the dwelling need to be taken into account. Following Norman *et al.* [24], a value of 50 years was taken for the lifetime. A reasonable estimate for the area is the average of the median area reported in the American Housing Survey (AHS), conducted by the U.S. Census Bureau, for single-detached and manufactured/mobile homes for 1999, 2001, 2003, 2005, and 2007 [12, 25, 26, 27, 28]. The data are summarized in Table 2. The average area of these dwellings was 164 m^2 (1,765 ft^2). Using these values the $ACE_{operation}$ is equal to 5,560 kg_{CO_2} per year and $LCE_{operation}$ is equal to 278,000 kg_{CO_2}.

Table 2: Home and Fire Statistics from 1999 to 2008

	Home Statistics		**Fire Loss Statistics**		**Loss Estimates**	
Year	**Average Size m^2 (ft^2)**	**Median Price**	**Number of Fires**	**Dollar Loss (In Billions)**	**Cost per Loss**	**Percentage Damaged (%)**
1999	161 (1,730)	$108,999	282,500	$5.3	$18,761	17.2
2001	161 (1,737)	$124,569	295,500	$5.7	$19,289	15.5
2003	163 (1,755)	$140,269	297,000	$5.9	$19,865	14.2
2005	167 (1,795)	$165,344	287,000	$6.4	$22,300	13.5
2007	168 (1,807)	$191,471	300,500	$6.5	$21,631	11.3
Average	**164 (1,765)**	**$146,130**	**292,500**	**$6.0**	**$20,525**	**14**

To evaluate the embodied carbon, Norman *et al.* [24] analyzed the annual greenhouse gases emitted and energy used during manufacturing of the home construction materials. Materials that did not form part of the dwelling structure, such as, appliances or carpeting, were not considered in the analysis. Materials considered in the analysis included brick, window (glass

* Note that gases other than CO_2 are considered in terms of CO_2 equivalents normalized in terms of global warming potential calculated according to the United Nations framework Convention on Climate Change. Greenhouse gases considered by Norman *et al.* were carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons [24].

and metal frames), drywall, structural concrete, reinforcing bar, structural steel, plywood, asphalt shingles, aluminum siding, hardwood flooring and stairs, insulation (fiberglass and polystyrene), high-density polyethylene vapor barrier, and sub-foundation aggregate. Of these, the first four materials accounted for between 60% and 70% of the total embodied greenhouse gases. Proportioning the greenhouse gases over a lifetime of 50 years, Norman *et al.* [24] estimated that the average equivalent annual embodied greenhouse gases per unit area is $7.4\ kg_{CO_2} / (m^2 - year)$. For a 50-year lifetime and a typical area of 164 m^2 (1,765 ft^2), the total embodied carbon emissions, $CE_{embodied}$, is 60,680 kg_{CO_2}.

No effects corresponding to decommissioning were discussed by Norman *et al.* [24]. Gritzo *et al.* [20] reported that, for office buildings, the total embodied fraction of total carbon emissions were on the order of 15% to 20%. As the ratio of $CE_{embodied} / (CE_{embodied} + LCE_{operation})$ in the present analysis is 18%, no further additions to the embodied carbon emissions are considered here.

1.2.4 Effect of Fire on LCE in Homes

Some of the parameters needed to estimate LCE_{risk} (Equations 5-7) can be obtained from NFPA [29] and AHS [12, 25-28] statistics—for example, the frequency of fires and some insight into the fraction burned, F_b. Key data needed for these estimates are summarized in Table 2. Using the same years as the AHS statistics, NFPA statistics indicate that the average number of fires per year for one- and two-family dwellings, including manufactured homes, was 294,350. The average number of occupied attached or detached single units and manufactured homes reported by the AHS for the specified years was 90,797,000. Thus, the frequency of fires per year was 0.0032.

The fraction of structural damage as a result of a fire event is not well documented; therefore, the fraction burned was estimated based on the reported dollar losses. The estimated average of total property damage per year was US$6.0 billion. This represents an average loss per fire of US$20,370. The average of the median house values reported by AHS [12, 25-28] for the same years was US$146,130, for an average loss due to fire of 14%.

It is important to recall the wide variation in fire behavior that is not represented by the average loss. The fire statistics for Prince George's County, Maryland, for the period of 1992 to 2007, in which sprinklers were mandated in newly constructed one- and two-family dwellings, provide a particularly clear example [14]. For the 15-year period, the average loss in 13,494 non-sprinklered fire incidences was US$9,983 while in 101 non-sprinklered fire incidences in which there was a fatality, the average loss was US$49,503, or an increase by a factor of five for these fires. The median value of a single-family home in Prince George's County was reported as US$145,600; therefore, the average loss due to fire is estimated to be between 7% and 34%.

Since the NFPA data indicate an average loss due to fire that is bounded by the Prince George's County data, in this analysis the fraction burned, F_b, will be assumed to be the two bounding values of 7% and 34%.

In addition to the fraction of material burned and the area of the home, estimating of the carbon emissions due to a fire event requires the total mass of combustible material per unit area, m''_f, and the carbon dioxide released per mass of material burned, e_{CO_2}. Davoodi [30] reports fuel loads of 19.0, 13.2, 21.0, 17.6, and 15.6 kg/m^2 for living rooms, family rooms, bedrooms, dining rooms, and kitchens respectively. For the present analysis the minimum, i.e., 13.2 kg/m^2, and maximum, i.e., 21.0 kg/m^2, values will be used as the bounding cases.

The carbon dioxide released per unit of material burned, e_{CO_2}, is taken as 3.0 kg/kg based upon combustion analysis and flammability data from Tewarson [31].

Finally, the replacement fraction needs to be determined. A conservative assumption is that the replacement fraction, F_r, is equal to the fraction burned, F_b; however, information indicates that after a fire event "the per-square-foot cost can increase by as much as 50 percent for readying a space for reconstruction" [32]. In this analysis, the replacement fraction is assumed to be 1.5 times the fraction burned; however, if the replacement fraction exceeds 50% it is assumed that a total constructive loss occurred and a value of 100% is used.

Based on these values, the contribution of fire risk to the total lifecycle carbon emissions of a home without sprinklers (Equation 8) is between 0.4% and 3.7%.

1.2.5 Improved Sustainability with Automatic Sprinklers

The installation of automatic sprinklers is expected to reduce LCE_{risk} (Equation 7) and the Risk Factor (Equation 8) through a reduction in the burn, and hence, replacement fractions. The reduction in burn fraction can be estimated from reduction in property loss with sprinklers. The fire statistics for Prince George's County [14] provide a significant record of the effect of residential sprinklers on fire fatalities and property damage.[†] Between 1992 and 2007, there were 13,494 fires in single-family dwellings or townhouses. There were 245 fires in such homes with residential sprinklers installed. No fatalities occurred in any of the sprinklered fires; however, there were 101 fatalities in the non-sprinklered fires. The average loss per event with a sprinkler system was US$4,883.83. Using the dollar loss values for events with and without sprinklers, the reduction in property loss achieved by automatic sprinklers is estimated to be between 51% and 90% in Prince George's County.

The contribution of a fire risk to the total lifecycle carbon emissions of a home is reduced to 0.2% when sprinklers are used, as all large fires are eliminated. In addition to saving lives, the presence of sprinklers ensures a reduction in carbon emissions and decreases the need for structural replacement as the fire will be limited to the housing contents initially ignited, and damage due to smoke and water will be minimized and limited to the room of fire origin.

† Hall [13] has analyzed the performance of automatic sprinklers in one- and two-family dwellings. He reports that, for the period of 2003 to 2006, fire damage was only reduced from an average of US$19,000 to US$14,000 as a result of automatic sprinklers. Hall comments that "only 1% of reported dwelling fires involve sprinklered properties, which means any loss estimate for sprinklered dwelling fires will tend to be statistically unstable" [13].

1.3 OBJECTIVES

The objective of the present study was to quantify the reduction in the environmental impact via the use of automatic fire sprinklers. To meet the objective, large-scale fire tests were conducted using identically constructed and furnished residential living rooms.[‡] In the non-sprinklered test, fire extinguishment was achieved only by fire service intervention, while in the sprinklered test a single residential sprinkler was used to control the fire until final extinguishment was achieved by the fire service. In the tests, the fire service initiated water application 10 minutes after the fire was detected.

Quantification of the environmental benefit of automatic fire sprinklers was based on comparisons between the sprinklered and non-sprinklered tests including total greenhouse gas production, quantity of water required to extinguish the fire, quality of water run-off, potential impact of wastewater runoff on groundwater and surface water, and mass of materials requiring disposal.

[‡] The primary analysis in this report is based on two fully instrumented tests, referred to as sprinklered and non-sprinklered. An additional, non-sprinklered test was conducted as a demonstration test. This test is referred to as non-sprinklered (b) and only used to supplement the water analysis.

2 FIRE TEST SETUP AND PROCEDURES

2.1 FACILITY

Testing was conducted under the 20-MW calorimeter in the Large Burn Laboratory (LBL) of the Fire Technology Laboratory located at the FM Global Research Campus in West Glocester, Rhode Island. The LBL measures 43 m (140 ft.) by 73 m (240 ft.) by 20.4 m (67 ft.) high and consists of three test locations: the north and south movable ceilings, and the 20-MW calorimeter. An illustration of the Large Burn Laboratory is shown in Figure 2. A separate air emission control system (AECS) is provided for each test location. The 20-MW calorimeter consists of a 10.7 m (35 ft.) diameter inlet that tapers down to a 3.05 m (10 ft.) diameter duct. The inlet to the calorimeter is at an elevation of 11.3 m (37 ft.) from the floor. Gas concentration, velocity, temperature, and moisture measurements are made within the duct downstream of an orifice. Beyond the measurement location, the exhaust duct connects to a wet electrostatic precipitator (WESP) prior to cleaned gases venting to the atmosphere. All tests were conducted with the ventilation rate set to 94.4 m^3/s (200,000 scfm).

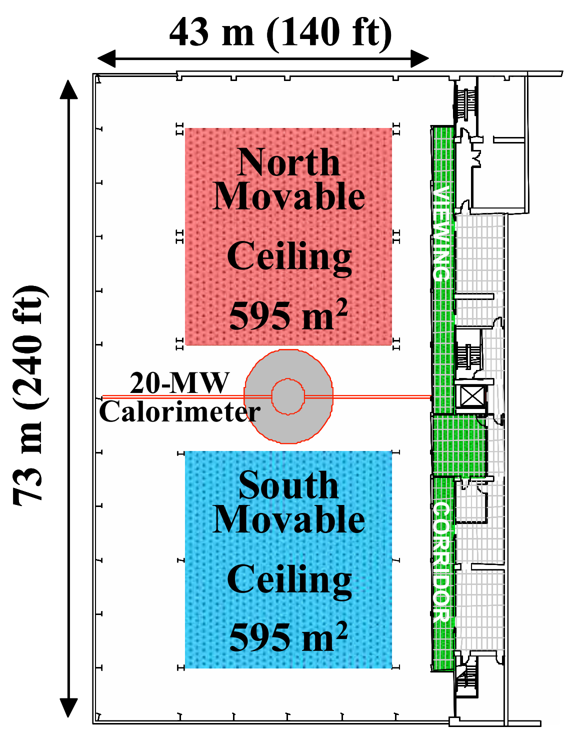


Figure 2: Illustrations of the large burn laboratory test sites.

The rooms, described in Section 2.2.1, were positioned under the 20-MW calorimeter as shown in Figure 3. The room centerline was offset relative to the calorimeter bell centerline by approximately 1.1 m (3.75 ft.) in the north-south direction to ensure that the gases exiting the room were collected within the calorimeter.

The demonstration test, non-sprinklered (b), was conducted with the room located under the north movable ceiling. The room was offset to the south-east corner of the ceiling and the movable ceiling was set to a height of 12.2 m (40 ft.).

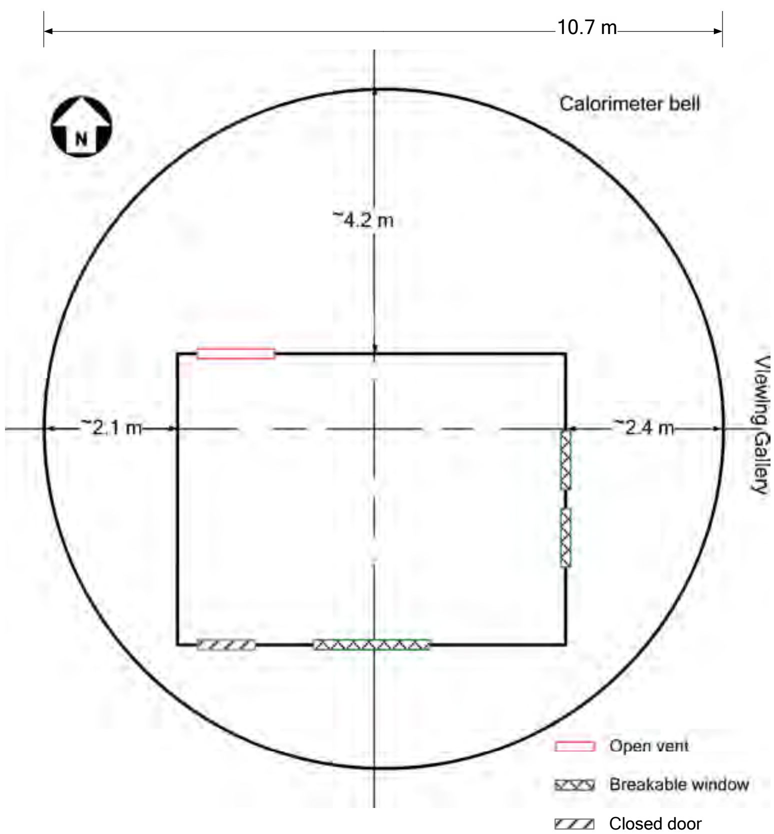


Figure 3: Room position relative to 20-MW calorimeter.

2.2 TEST CONFIGURATION

2.2.1 Living Room Construction

The living room was constructed by an outside contractor, R&R Wolf Construction, Inc. of North Attleboro, Massachusetts, using standard industry practices. The room measured 4.6 m (15 ft.) wide by 6.1 m (20 ft.) long, and had a 2.4 m (8 ft.) high ceiling. To simulate a single room of a larger house, two of the walls were considered exterior walls and included windows and an exterior door. The other two walls were considered interior house walls, with one being solid with no openings and the other having a 1.2 m wide x 2.1 m tall (4 ft. x 7 ft.) archway. Figure 4, Figure 5, and Figure 6 present illustrations of the room construction, location of the room penetrations, and a description of common construction terms.

The main deck of the enclosure had interior dimensions of 4.6 m x 6.1 m (15 ft. x 20 ft.) and was constructed with 50.8 mm x 203 mm (2 in. x 8 in.) lumber. The perimeter decking joist boards forming the box frame for the floor were constructed with 4.9 m and 6.7 m (16 ft. and 22 ft.) boards. These boards were doubled up along the perimeter and cut to provide exterior dimensions of 4.9 m x 6.4 m (16 ft. x 21 ft.). The frame was then filled with kiln dried #2 grade spruce boards spaced 406-mm (16-in.) on center, which were supported by joist hangers at each end. The framed deck was then covered with 19.1 mm (3/4 in.) CDX fir tongue-and-groove plywood flooring.

Figure 4: Room exterior walls (south and east walls).

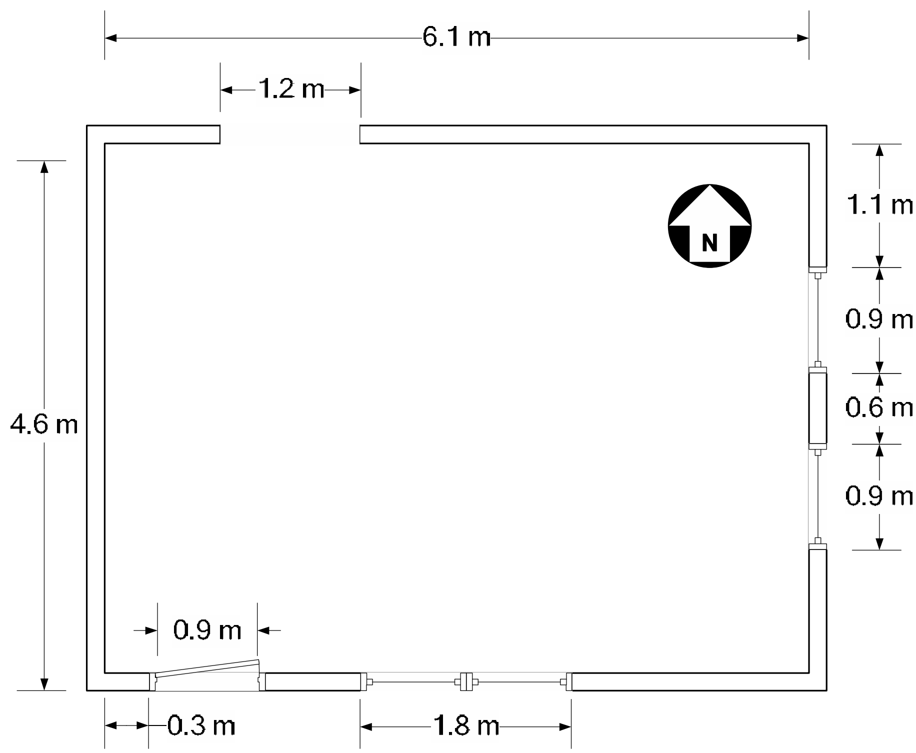


Figure 5: Location of room exterior door, archway, and windows.

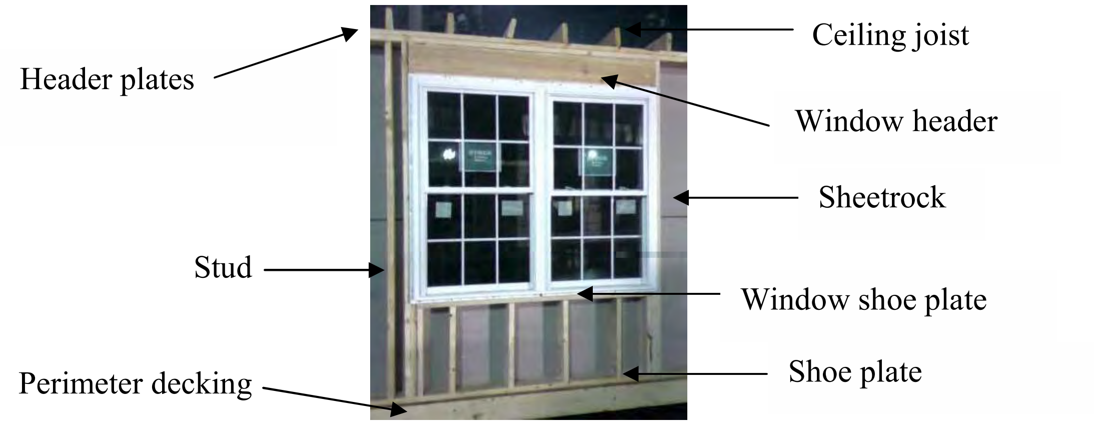


Figure 6: Room frame construction.

The enclosure sides consisted of two walls having interior dimensions of 4.6 m x 2.4 m (15 ft. x 8 ft.) and two walls with interior dimensions of 6.1 m x 2.4 m (20 ft. x 8 ft.) that were of consistent construction using 50.8 mm x 152.4 mm (2 in. x 6 in.) lumber. A shoe plate and two header plates constructed of 4.9 m (16 ft.) long boards were used for the shorter walls and 6.4 m (21 ft.) long boards for the longer walls. The walls were then filled with 2.4 m (7 ft. 8 in.) studs spaced 406-mm (16-in.) on center. The stud pattern was disrupted to allow for windows and door/archway openings. The window openings included a double shoe plate and single header, while the door and archway openings had only a single header. The inside walls were finished with 15.9 mm (5/8 in.) fire rated sheetrock that was taped, spackled, and painted a tan color.

The ceiling was constructed using 50.8 mm x 152.4 mm (2 in. x 6 in.) lumber spaced 406-mm (16-in.) on center. Since no perimeter boxing was necessary, the joists were towed-in to the wall header plates. To support the ceiling sheetrock, 25.4 mm x 76.2 mm x 4.9 m (1 in. x 3 in. x 16 ft.) spruce strapping, spaced 406-mm (16-in.) on center, was installed perpendicular to the ceiling joints. The ceiling was finished with 19.9 mm (5/8 in.) fire rated sheetrock that was taped, spackled, and painted bright white.

The two exterior walls and the ceiling were insulated using R13 and R19 fiberglass insulation respectively. The main deck also included *Alias* (Style 2760) carpeting with an Endure®Plus backing from J&J Industries. Carpet specifications taken from the manufacturer's website are provided in Table 3.

Table 3: Manufacturer's Carpet Specifications (J&J Industries' website)

Alias Style (2760)	
Yarn	100% Nylon: Encore® SD Ultima® (with recycled content) Bulked Continuous Filament
Dye Method	Solution Dyed
Surface Texture	Level Loop
Pattern Repeat	N/A
Gauge	1/8 (3.15 rows/cm)
Tufted Stitches Per Inch	8.5 (3.35 stitches/cm)
Yarn Weight	882 grams/m^2 (26 oz./yd^2)
Finished Pile Thickness	3.05 mm (0.120 in.) (ASTM D-418)
Density	7,800
Weight Density	202,800
Secondary Backing	Endure® PLUS
Special Treatments	ProTex® Fluorochemical
Width	3.66 m (12 ft.)
Flammability	Class 1
Smoke	Less Than 450 flaming
Static Generation	Less than 30 kV (AATCC-134)
ADA Compliance	Compliant For Accessible Routes

The windows installed in the room were Kasson & Keller, Inc., double hung, replacement windows measuring 0.9 m by 1.47 m (3 ft. by 4 ft. 10 in.). The windows were constructed of PVC frames with double-pane glass. The total weight of the windows was 23.6 kg (52 lb.) and the weight of the frame alone was 9.1 kg (20 lb.). The exterior door was steel clad with an insulated core and had dimensions of 0.9 m by 2.0 m (36 in. by 80 in.). The door had a 0.51 m wide by 0.9 m tall (20 in. by 36 in.) single pane window. The exact locations of the exterior door and windows are shown in Figure 4, and each was installed with a 203 mm (8 in.) sill.

2.2.2 Room Furnishings

Each of the rooms was furnished with the items listed in Table 4. The items are grouped into four categories: primary fuel items, secondary fuel items, decorative items, and ignition package. Each category of items will be discussed in detail in Sections 2.2.2.1 to 2.2.2.4. A schematic of the room with relative positions of the primary and secondary fuel items, and the ignition package is presented in Figure 7.

Table 4: Room Furnishings

Quantity	Item
Primary Fuel Items	
1	Recliner
1	Sofa
1	Loveseat
Secondary Fuel Items	
1	Coffee Table
1	Console Table
1	End Table
1	TV Stand with Shelves
2	Bookcase
1	37-inch LCD Television
Decorative Items	
1	Ceramic Table Lamp
1	Picture Frame (330 mm x 432 mm) (13 in. x 17 in.)
6	Picture Frame (127 mm x 178 mm) (5 in. x 7 in.)
1	Mirror (400 mm x 972 mm) (15 ¾ in. x 38 ¼ in.)
1	Poster Frame (610 mm x 914 mm) (24 in. x 36 in.)
1	Wall Clock (248 mm) (9 ¾ in. Diameter)
13.5 lbs	Magazines
1	Alarm Clock
8	CD Box with Lid
5	Hardcover Books
1	Plant Pot
6	Drapes
Ignition Package	
1	Magazine Rack
3	Newspapers

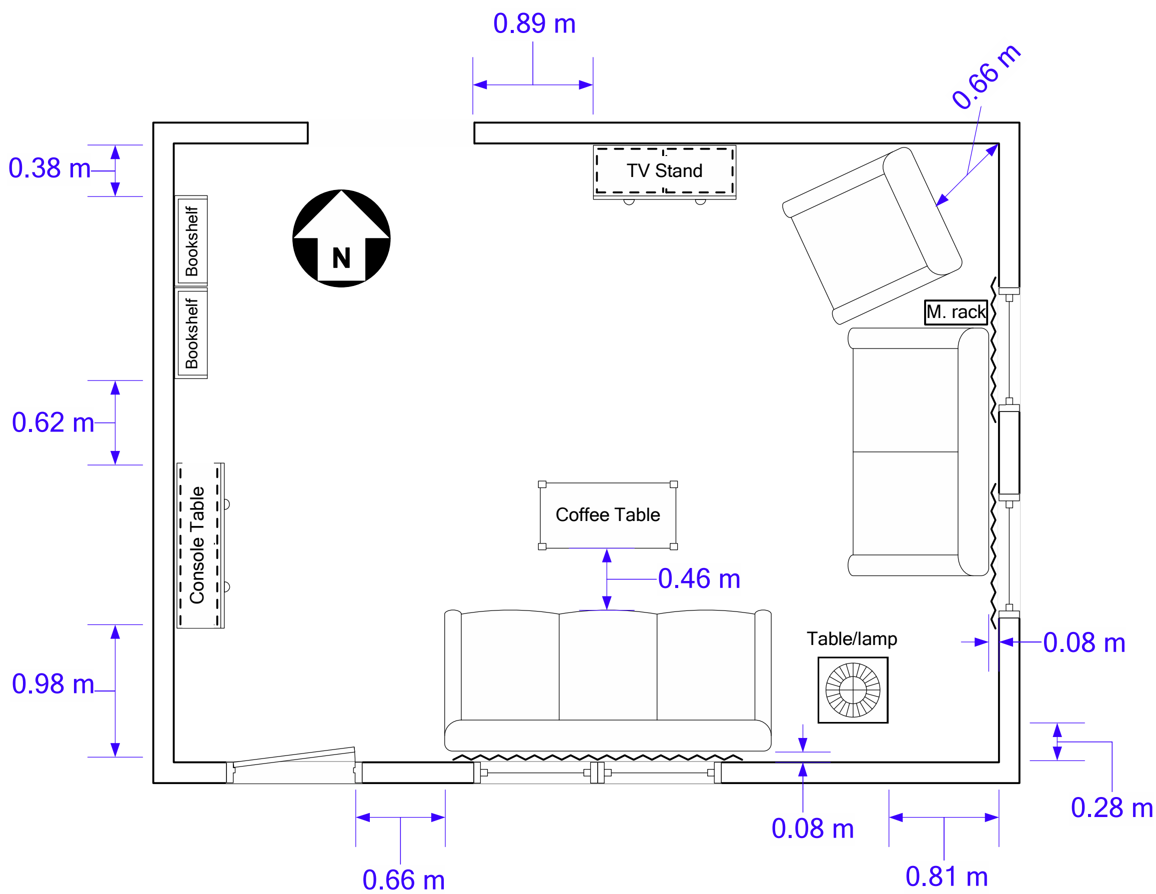


Figure 7: Furnishing positions and locations within the enclosure.

2.2.2.1 Primary Fuel Items

The primary fuel items consisted of a "Big Easy" Recliner and a "Kick Back" Sofa and Loveseat. The loveseat and sofa came with eight decorative throw pillows that are considered part of the package as shown in Figure 8. The dimensions, total weight, and major combustible materials for each item are listed in Table 5. The weights of the sofa and loveseat include four throw pillows.

Table 5: Primary Fuel Items

Item	Dimensions (L x D x H) m x m x m (in. x in. x in.)	Total Weight kg (lb.)	Principle Combustible Material
Big Easy Recliner	0.99 x 1.12 x 1.04 (39 x 44 x 41)	44.5 (98.1)	Urethane foam, wood frame
Kick Back Sofa	2.41 x 1.04 x 0.97 (95 x 41 x 38)	69.9 (154.1)	Polyurethane foam, wood frame
Kick Back Loveseat	1.83 x 1.04 x 0.97 (72 x 41 x 38)	56.9 (125.5)	Polyurethane foam, wood frame

Figure 8: Images of the "Big Easy" recliner and "Kick Back" sofa and loveseat combination (from store website, not to scale).

2.2.2.2 Secondary Fuel Items

The total mass, dimensions, and combustible material for each of the secondary fuel items are listed in Table 6. Images of each item, taken from the retail store websites, are shown in Figure 9 and Figure 10.

Table 6: Secondary Fuel Items

Item	Dimensions (L x D x H) m x m x m (in. x in. x in.)	Total Weight kg (lb.)	Principle Combustible Material
Mission Natural Coffee Table	1.0 x 0.5 x 0.4 (40.5 x 20 x 16.5)	15.1 (33.3)	Rubberwood
Mission Natural Console Table	1.2 x 0.4 x 0.8 (48 x 15.25 x 30)	15.6 (34.4)	Rubberwood
Mission Natural End Table	0.5 x 0.48 x 0.5 (20.1 x 19 x 20.1)	8.3 (18.3)	Rubberwood
TV Stand with Shelves	1.1 x 0.44 x 0.5 (41.5 x 17.25 x 20)	21.2 (46.7)	Laminated composite wood
Kilby Bookcase	0.67 x 0.24 x 1.9 (26.4 x 9.5 x 76.4)	18.5 (40.8)	Laminated composite wood
37-inch LCD Television	0.9 x 0.2 x 0.67 (36.75 x 9.5 x 26.5)	16.7 (36.8)	Unexpanded plastic

Figure 9: Images of secondary fuel items: coffee, console, end tables, and bookcase (from store website, not to scale).

Figure 10: Images of secondary fuel items: 37-inch LCD TV and TV stand (from store website, not to scale).

2.2.2.3 Decorative Items

The decorative items listed in Table 4 were arranged throughout the room as shown in Figure 11. Due to the low fire load contribution of these items to the overall heat release rate, a detailed breakdown of the individual components has not been made. The primary combustible materials were cotton, soft woods, polystyrene and polypropylene plastic, cardboard, and paper. The total weight of all of the decorative materials was 26.7 kg (59 lb.) and is based on the listed shipping weights.

Figure 11: Orientation of decorative items on console table, bookcases, and coffee table.

2.2.2.4 Ignition Package

The fire was initiated in a magazine rack filled with three rolled up newspapers (see Figure 12a), which was positioned adjacent to the loveseat as shown in Figure 12b. The dimensions of the magazine rack were 338 mm x 152 mm x 279 mm (13.3 in. x 6 in. x 11 in.). The magazine rack was constructed of medium density fiberboard and weighed 1.7 kg (3.75 lb.). The newspapers were ignited using a propane torch.

(a) (b)

Figure 12: (a) Ignition source and (b) Magazine rack relative to loveseat and curtain.

2.3 FIREFIGHTING

Fire control and suppression was achieved in the non-sprinklered test by manual fire service intervention only; in the sprinklered test, a single residential sprinkler was used to control the fire until final extinguishment was achieved by the fire service.

2.3.1 Sprinkler Protection

A single FM Approved Tyco Fire Suppression & Building Products recessed residential sprinkler (TY4234), Figure 13, was installed at the ceiling center within the living room. The sprinkler was equipped with a fast-response fusible link, which had a temperature rating of 68°C (155°F). A nominal operating pressure of 1.3 bar (19.0 psig) was used, resulting in a 4.1 mm/min (0.1 gpm/ft^2) water density, in accordance with FM Global Property Loss Prevention Data Sheet 2-5, *Installation Guidelines for Automatic Sprinklers in Residential Occupancies* [10].

Figure 13: Tyco Fire Suppression & Building Products Residential Sprinkler (TY4234).

2.3.2 Fire Service Response Tactics

In all of the tests, the fire service response was initiated via smoke detector activation. Upon activation a 10-minute response clock was started. The 10-minute delay accounted for fire service notification, dispatch, arrival, and setup and was based on nationally accepted standards, including NFPA 1710 [33], NFPA 1720 [34], and other published literature [35]. NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*, Section 5.2.4.1.1 states that “The fire department's fire suppression resources shall be deployed to provide for the arrival of an engine company within a 240-second travel time to 90 percent of the incidents” [33]. For volunteer fire departments, NFPA 1720, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments*, states that for structural firefighting of a “low-hazard occupancy such as a 2000 ft^2 (186 m^2), two-story, single-family home without a basement” [34] in urban areas shall be 9 minutes, 90% of the time, and in rural areas the response time increases to 14 minutes, 80% of the time (see Table 7). Furthermore, Section 4.3.3 states “Upon assembling the necessary resources at the emergency scene, the fire department shall have the capability to safely commence an initial attack within 2 minutes 90 percent of the time” [34].

Table 7: Table 4.3.2 Staffing and Response Time taken from NFPA 1720

Table 4.3.2 Staffing and Response Time

Demand Zone[a]	Demographics	Minimum Staff to Respond[b]	Response Time (minutes)[c]	Meets Objective (%)
Urban area	>1000 people/mi²	15	9	90
Suburban area	500–1000 people/mi²	10	10	80
Rural area	<500 people/mi²	6	14	80
Remote area	Travel distance ≥ 8 mi	4	Directly dependent on travel distance	90
Special risks	Determined by AHJ	Determined by AHJ based on risk	Determined by AHJ	90

[a] A jurisdiction can have more than one demand zone.
[b] Minimum staffing includes members responding from the AHJs department and automatic aid
[c] Response time begins upon completion of the dispatch notification and ends at the time interval shown in the table.

A publication by the Illinois Fire Inspectors Association states that the average time for firefighters to open hose nozzles after a fire is detected is 10 minutes (see Figure 14).

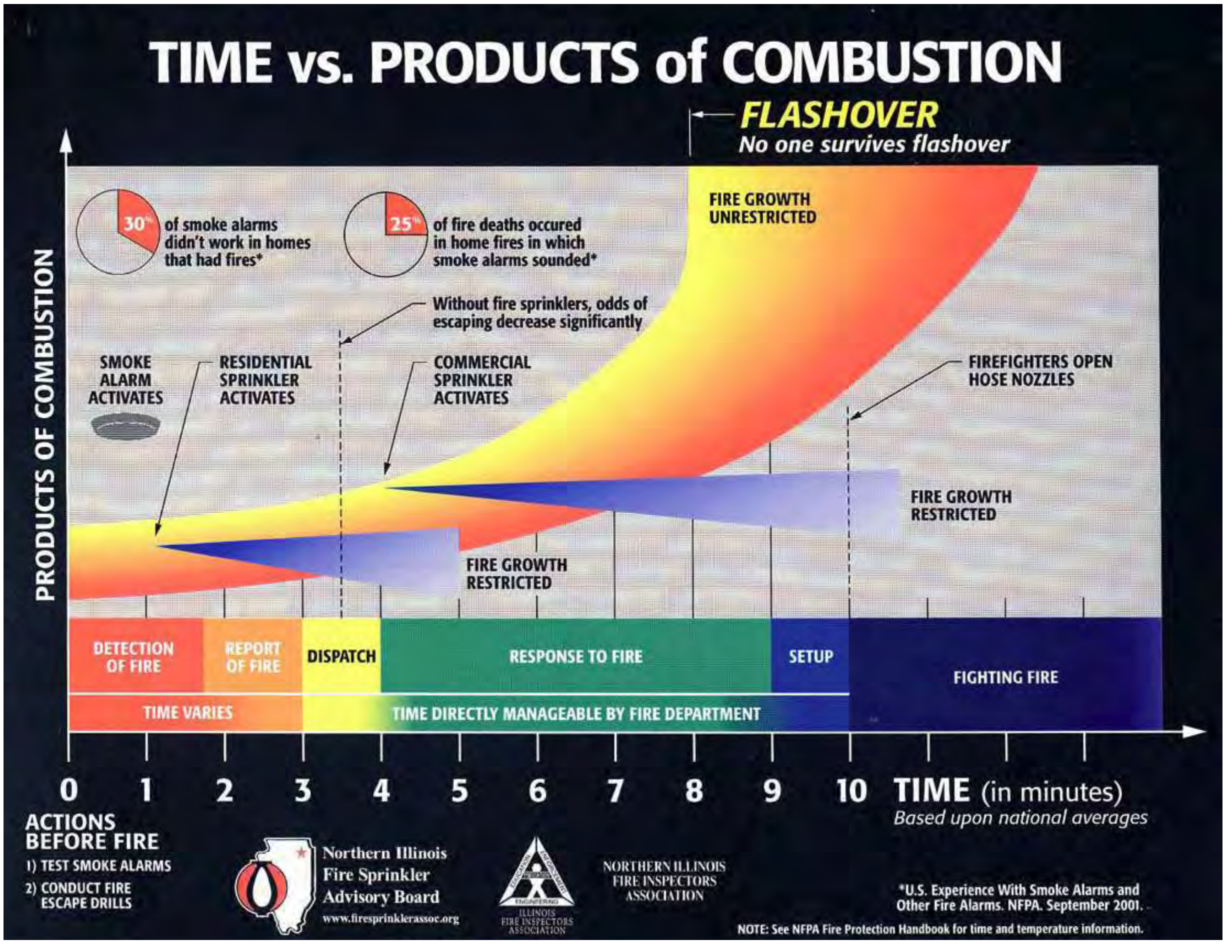


Figure 14: Timeline of fire development versus typical fire service response (taken from http://www.illinoisfireinspectors.org/ifia.htm).

Firefighting activities were in compliance with recognized fire service attack standards including NFPA and Oklahoma State University's "*Essentials of Fire Fighting and Fire Department Operations*" [35].

NFPA 1710, Section 5.2.4.2.2 recommends "establishment of an effective water flow application rate of 300 gpm from two handlines, each of which has a minimum flow rate of 100 gpm" [33]. This is for an "initial full alarm assignment to a structure fire in a typical 2000 ft^2 two story single-family dwelling" [33].

To comply, two 30.5-m (100-ft.) long, 1 ¾ in. attack handlines with Task Force Tip Thunder Fog Nozzles, model #FTS200, set at 360 lpm (95 gpm), were staffed with two trained firefighters each. A constant 6.9 bar (100 psi) nozzle pressure was supplied. For safety reasons, a third identical attack line was staffed and supported but not utilized.

During the non-sprinklered test, firefighting tactics as recommended by Reference 35 were closely followed. A realistic and aggressive interior attack occurred once deemed practical as a result of a direct exterior attack. This was executed by straight stream water application to obtain maximum cooling and darkening down of visible fire immediately at the 10-minute fire interval.

Interior entry was gained as soon as possible and a short period of 40-60 degree fog spray was applied to obtain maximum cooling and fire extinguishment. Proper ventilation had occurred as the windows and door had already burned out and fallen out of the structure. A straight stream was then applied to conduct and pursue final extinguishment.

In the sprinklered test, only an interior attack was required because of the sprinkler activation and subsequent fire control. At the 10-minute mark, firefighters approached the room, pried open the exterior door and used a single fire hose line to attack the fire. The second attack line provided backup only. A short period of 40-60 degree fog spray was applied to obtain maximum cooling and fire extinguishment. Final extinguishment occurred through direct application of a straight stream.

2.4 INSTRUMENTATION

Scientific measurements internal and external to the room were made in each test. Each room was instrumented with ceiling and elevation thermocouples, heat flux gages, and gas measurements. All instrumentation was calibrated in accordance with ISO/IEC 17025-2005 [36]. The instrumentation layout within the room is shown in Figure 15. The following sections describe each of the instruments used in the tests.

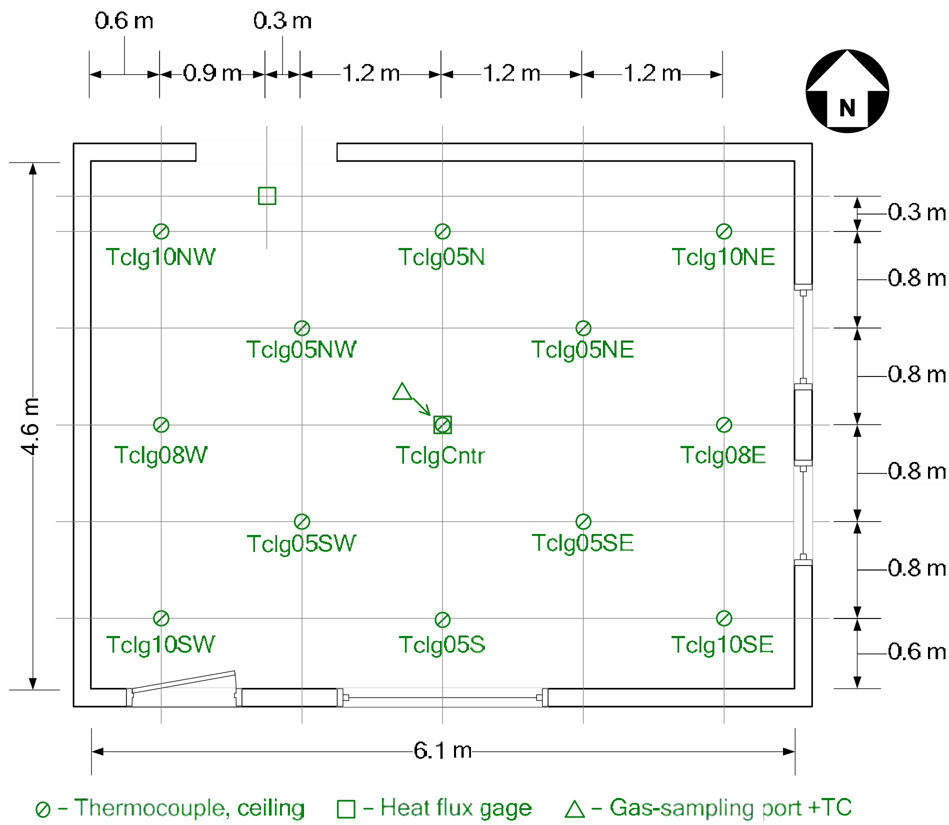


Figure 15: Instrumentation layout within the room.

2.4.1 Gas Analysis Measurements within the Duct

Multiple gas measurements were made, within the 20-MW calorimeter duct, to evaluate the products of combustion generated during the fire tests. The data was used to quantify the reduction in greenhouse gases and pollutants between the sprinklered and non-sprinklered tests, and to determine the chemical heat release rate and total energy released.

2.4.1.1 FM Global Instrumentation

Continuous real-time gas measurements within the 20-MW calorimeter duct include oxygen, carbon monoxide, carbon dioxide, and total hydrocarbons. A Rosemount Analytical MLT series analyzer, model MLT-4T-IR-IR-PO2, was used to measure carbon monoxide, carbon dioxide and oxygen. The analyzer comprises infrared sensors to measure carbon monoxide and carbon dioxide, and a paramagnetic sensor to measure oxygen. Total hydrocarbons were measured, as equivalent methane, using a Rosemount Analytical analyzer, model NGA2000 FID2. The analyzers were set to operate with ranges indicated in Table 8.

Table 8: FM Global Gas Analyzer Measurement Ranges (Duct)

Species	Range
Carbon Dioxide (ppm)	0 - 25,000
Carbon Monoxide (ppm)	0 - 5,000
Oxygen (%)	0 - 21
Total Hydrocarbons (ppm)	0 - 5,000

2.4.1.2 External Instrumentation

Standard FM Global measurements within the duct were supplemented by an outside contractor, Air Pollution Characterization and Control, Ltd. (APCC), retained by Woodard & Curran. Measurements included the following:

- Criteria Pollutants
- Volatile Organic Compounds (VOCs)
- Greenhouse Gas Pollutants
- Particulate Matter
- Heavy Metals
- Semi-Volatile Organic Compounds (SVOCs)
- Other Organic and Inorganic compounds
- Total Hydrocarbons
- Oxygen

Full details on the measurement techniques and instrumentation are reported in Reference 37.

2.4.2 Gas Analysis Measurements within the Room

Continuous real-time gas samples for measurement of carbon monoxide, carbon dioxide, oxygen, and total hydrocarbons were obtained at the center of the room at a 1.5 m (5 ft.) elevation. For the sprinklered test a Rosemount Analytical MLT series analyzer, model MLT-4T-IR-IR-PO2, was used to measure carbon monoxide, carbon dioxide, and oxygen. The analyzer comprises infrared sensors to measure carbon monoxide and carbon dioxide, and a paramagnetic sensor to measure oxygen. Total hydrocarbons were measured as equivalent methane, using a Rosemount

Analytical analyzer, model NGA2000 FID2. The analyzers were set to operate with ranges indicated in Table 9. For the non-sprinklered test, units were rented from Clean Air Instrument Rental of Palatine, Illinois. The analyzers used were Fuji Electric Systems Co., Ltd. model ZRH carbon monoxide analyzer, Horiba, Ltd. model VIA-510 carbon dioxide analyzer, J.U.M. Engineering GmbH model 3-300A total hydrocarbon analyzer, and a Servomex Ltd. model 1420C oxygen analyzer. The analyzers operated within the ranges indicated in Table 9.

Table 9: Gas Analyzer Measurement Ranges (Room)

Species	Sprinklered	Non-Sprinklered
Carbon Dioxide (ppm)	0 - 50,000	0 - 250,000
Carbon Monoxide (ppm)	0 - 10,000	0 - 100,000
Oxygen (%)	0 - 21	0 - 25
Total Hydrocarbons (ppm)	0 - 5,000	0 - 100,000

2.4.3 Ceiling and Room Thermocouples

Temperatures under the ceiling were monitored during each test using 13 20-gage Type K bare-bead thermocouples. These thermocouples have a 19-mm (0.75-in.) exposed length of wire. The time response of these thermocouples has been measured[§] and is characterized by an RTI value of 8 ±1 $(m\cdot s)^{1/2}$ (14.5 ±1.8 $(ft\cdot s)^{1/2}$). The thermocouples were positioned as shown in Figure 15 and the beads were located approximately 76 mm (3 in.) below the ceiling. The 13 thermocouple labels are identified in Figure 15.

An additional thermocouple with the same characteristics as those described above was installed adjacent to the gas sampling location at the center of the room described in Section 2.4.2.

2.4.4 Heat Flux Measurements

Heat flux gages were used to evaluate the heat transfer from the gases near the ceiling to the floor and ceiling. The gages were water cooled Schmidt-Boelter sensors. Three gages were used in each test; two were located on the floor—one at the center of the room and one at the

[§] H-Z Yu, "Sensitivity of the certified Omega 20-gage thermocouple used at LBL," Email dated June 2, 2008. Also: "RE: Sensitivity of 20-gage TCs," Email dated August 27, 2008.

archway; a third gage was located at the ceiling directly above the one installed on the floor at the archway. The floor mounted gages were installed with the top surface flush with the top of the carpet as shown in Figure 16. The model and maximum measurement value of each gage, at each location, are listed in Table 10.

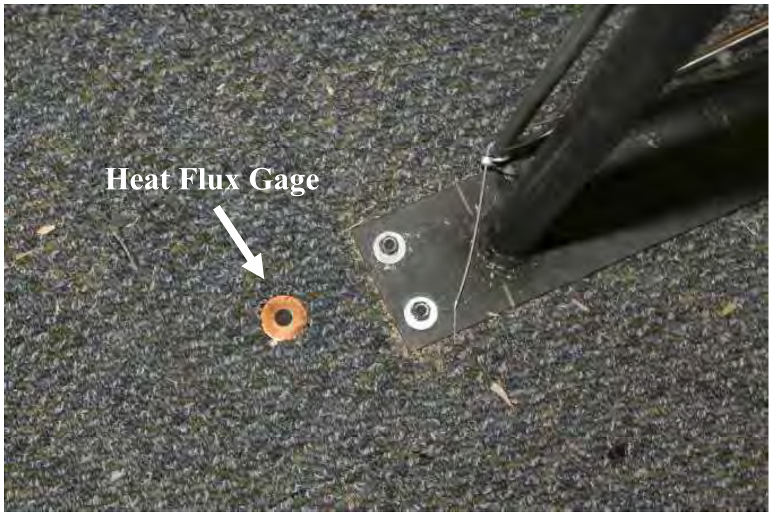


Figure 16: Heat flux gage installation at the floor.

Table 10: Heat Flux Gage Information

Location	Model	Maximum Value
Non-Sprinklered Test		
Floor (center)	64-5SB-20KS	57 kW/m^2 (5 BTU/ft^{2}s)
Floor (archway)	64-5SB-20KS	57 kW/m^2 (5 BTU/ft^{2}s)
Ceiling (archway)	64-15SB-20KS	170 kW/m^2 (15 BTU/ft^{2}s)
Sprinklered Test		
Floor (center)	64-5SB-20KS	57 kW/m^2 (5 BTU/ft^{2}s)
Floor (archway)	64-5SB-20KS	57 kW/m^2 (5 BTU/ft^{2}s)
Ceiling (archway)	64-5SB-20KS	57 kW/m^2 (5 BTU/ft^{2}s)

2.4.5 Smoke Detectors

Each room was instrumented with two smoke detectors, one ionization detector and one photoelectric detector. The ionization detector was a Kidde, Model 0916 (Part Number 440375) and the photoelectric detector was a Kidde, Model PE9 (Part Number 440378).[**] Detector operation was monitored and recorded by connecting the speaker signal to the data acquisition system.

The detectors were installed on the interior wall with the centerline of the detectors 22.9 cm (9 in.) below the ceiling. The photoelectric detector was 20.3 cm (8 in.) inward from the edge of the archway and the ionization detector was 35.6 cm (14 in.) from the edge.

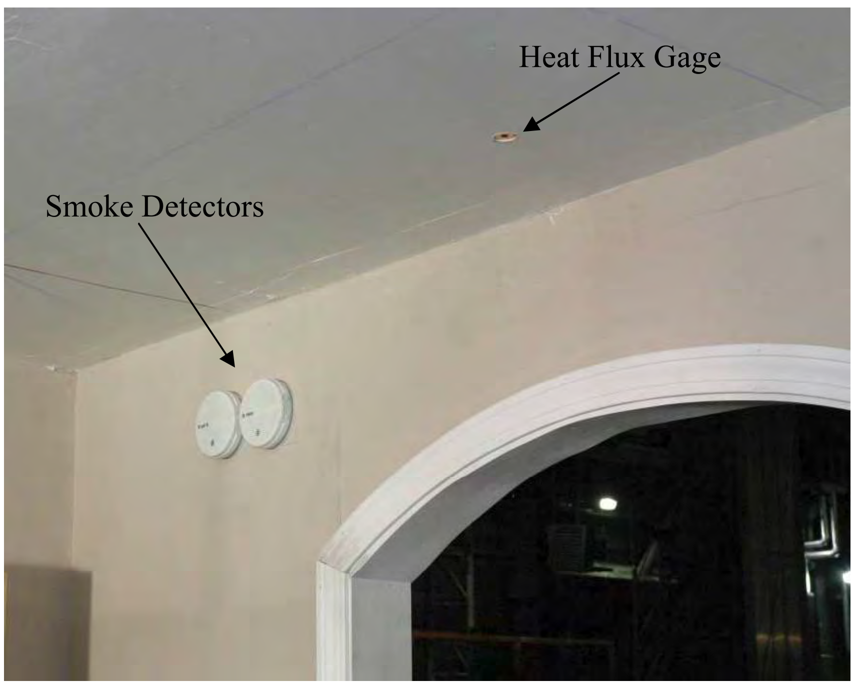


Figure 17: Smoke detector and ceiling heat flux gage locations.

2.4.6 Water Collection System

A special water collection system was constructed to collect the portion of the water exiting the living room via the archway. The system generally consisted of a stainless steel collection pan fastened to the base of the archway. Two sump pumps were located within the pan to transfer

[**] FM Approved units were not used for these tests since battery operated residential detectors were required and FM Approvals does not approve these types of detectors.

the water to a 1040 L (275 gal.) intermediate bulk container (IBC). Depending on the volume of water flowing through the archway, either a ⅓ HP Goulds model SP035M or 1/16 HP Simer model 2310-03 sump pump was turned on to keep the collection pan from overflowing. Each test used a new IBC, and the stainless steel collection pan was scrubbed and triple rinsed with distilled water between tests to ensure there was no cross contamination. The collection pan was also covered in plastic wrap until immediately before the start of each test.

For the non-sprinklered test this system consisted of a 1.85 m long x 0.3 m wide x 0.36 m tall (6 ft. 1 in. x 1 ft. x 1 ft. 2 in.) stainless steel pan connected to the IBC with plastic tubing. However, the heat output from the fire exiting the archway was sufficient to damage the pumps and burn the plastic tubing. This resulted in an unknown amount of contamination to the collected water. Consequently, the collection system was redesigned to minimize the heat flux to the pumping system for the sprinklered test and the demonstration test (referred to as non-sprinklered test (b)). The revisions to the system included increasing the length of the collection pan to 2.46 m (8 ft. 1 in.) and moving the pumps to the pan edge away from the archway, Figure 18. Additional revisions to the system for non-sprinklered test (b) included changing all tubing to stainless steel and surrounding the pumps with a stainless steel baffle, Figure 19.

Figure 18: Revised water collection pan setup for sprinklered test.

Figure 19: Baffled water collection pan setup for non-sprinklered test (b).

2.4.7 Water Quality Analysis

The services of Woodard and Curran were retained to evaluate the quality of the wastewater generated in each test and to determine the potential environmental impacts on groundwater and surface water. Analysis of the water samples included general chemistry parameters, heavy metals, cyanide, volatile organic compounds, and semi-volatile organic compounds. The complete list of analysis and appropriate test methods is provided in Table 11. Full details of the water analysis are reported in Reference 38.

Table 11: Wastewater Analysis Taken from Reference 38

Analysis	Test Method
Volatile Organic Compounds (VOCs)	USEPA 624
Semi-Volatile Organic Compounds (SVOCs)	USEPA 625
pH	USEPA 150.1
Chemical Oxygen Demand – COD	SM 5220
Specific Conductance	SM 2510
Ammonia Nitrogen	SM 4500
Nitrate Nitrogen	SM 4500
Total Cyanide	SM 4500
Total Suspended and Dissolved Solids	SM 2540
Total Organic Carbon (TOC)	SM 5310
Total Phosphorous	SM-4500P-E(M)
Total and Dissolved Priority Pollutant 13 Metals*	USEPA 6010B/7470

*Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc.

2.4.8 Solid Waste Analysis

The services of Woodard and Curran were retained to evaluate the solid waste generated in each test to determine if the debris exhibited the hazardous waste characteristics of toxicity. Samples of ash and/or charred materials were collected after each test and analyzed per the United States Environmental Protection Agency's (USEPA) Toxicity Characteristic Leaching Procedure (TCLP), Method 1311. Details of the solid waste analysis are reported in Reference 38.

2.4.9 Video and Photography Details

Each test was documented via video and still photography. Video documentation consisted of five cameras in total: two cameras viewing inside the living room (Panasonic Color CCTV, Model # WV-CP504) and three cameras, including a standard definition (Sony DSR-PD170) and two high definition (Sony HVR-Z1U), positioned around the exterior of the room. The standard definition camera was positioned to view the east wall of the room, while the two high definition cameras were positioned to look at the north-west and south-west corners of the room. The cameras viewing the interior of the room were installed in the west and north walls. The camera positions relative to the room are shown in Figure 20. In addition to the video images, still photography was taken before, during, and after each test, via two digital 35-mm cameras.

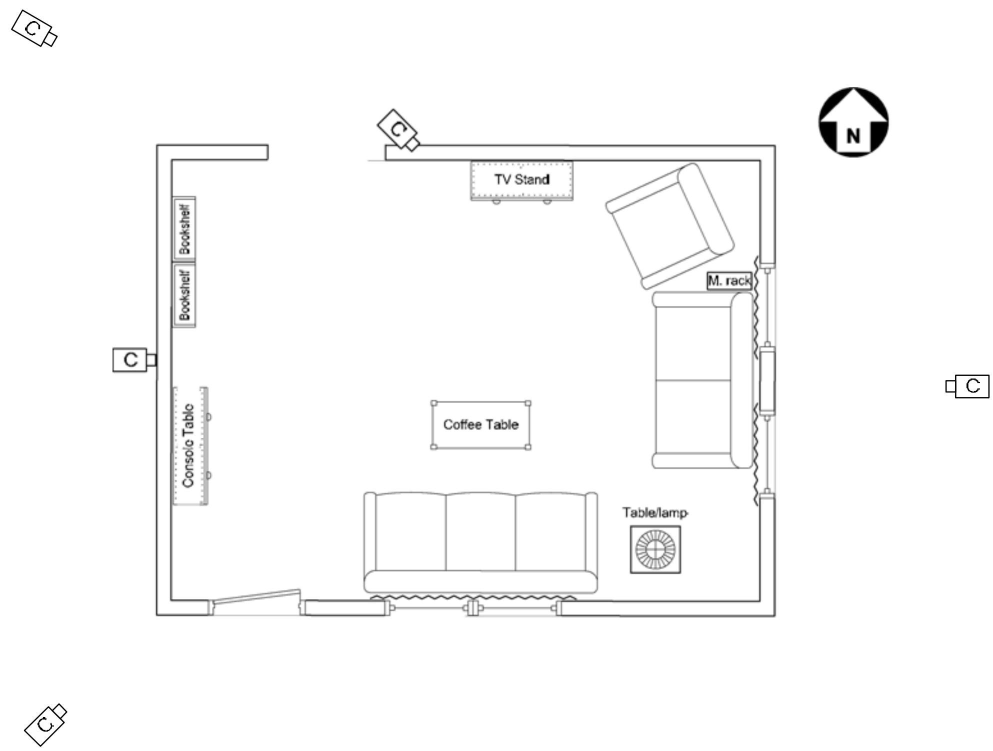


Figure 20: Video camera positions relative to the room.

3 EXPERIMENTAL RESULTS

3.1 FIRE TEST CHRONOLOGIES

On September 17, 2009, the first fully instrumented, non-sprinklered test was conducted. The comparison burn, a fully instrumented sprinklered test was conducted on October 1, 2009; in addition, a second non-sprinklered test was conducted as a demonstration test for the visitors present on that day. The test setup and conditions for the demonstration test were identical to the previous two tests. Very limited data was collected during the demonstration test and it is not included in the main analysis. The fire test chronologies for the two fully instrumented tests are provided in Table 12.

Table 12: Fire Test Chronologies

Event	Sprinklered Test (min:s)	Non-Sprinklered Test (min:s)
Ignition	0	0
Smoke Detector Activation (Ionization)	0:25	0:25
Flames Reach the Ceiling 2.4 m (8 ft.)	0:35	1:55
Sprinkler Activation	0:44	---
Smoke Detector Activation (Photoelectric)	1:10	0:33
Window 1 Breaks	---	4:00
Window 2 Breaks	---	4:42
Flames Extend Out of Archway	---	4:48
Window 4 Breaks	---	5:12
Window 3 Breaks	---	5:32
Flames Exit Around Exterior Door Seam	---	5:42
Window in Exterior Door Falls Out	---	6:18
Fire Service Pries Open Door	10:30	---
Fire Service Applies Hose Stream	10:38	10:30
Fire Service Enters Room	10:58	11:42
Fire Out	13:40	24:44

Note: Windows are numbered as East Wall, North (#1), East Wall, South (#2), South Wall, East (#3), and South Wall, West (#4).

In the non-sprinklered test, fire spread from the magazine rack to the curtains and loveseat and was noticeably slower compared to the sprinklered test, as seen in the time for the flames to reach the ceiling. This longer incipient period is reflected in the ceiling thermocouple measurements reported in Section 3.5; however, the slower fire development does not impact any of the final results and conclusions. It should be noted that in the demonstration test, non-sprinklered (b), the fire development from ignition until 44 seconds was very similar to the sprinklered test. The difference between the two non-sprinklered tests reflects the inherent variability of large-scale fires.

3.2 SPECIES MEASUREMENTS WITHIN THE DUCT

A limited number of species was measured by both FM Global and APCC within the 20-MW exhaust duct. The time resolved concentrations of carbon monoxide, carbon dioxide, and unburned hydrocarbons are presented for the non-sprinklered and sprinklered tests in Figure 21 and Figure 22, respectively. In Figure 21 and Figure 22 the FM Global data are one-second samples and the APCC data are 30-second grab samples.

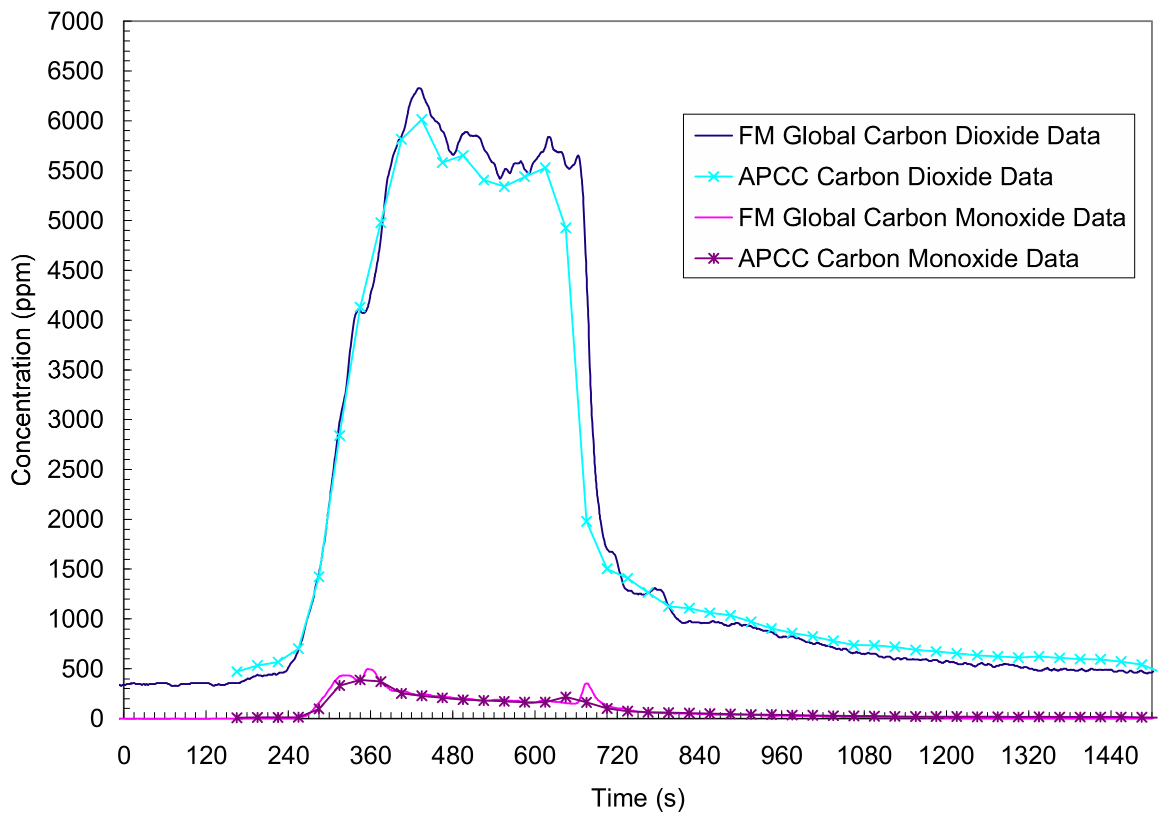


Figure 21: Duct concentrations of CO_2 and CO for the non-sprinklered test.

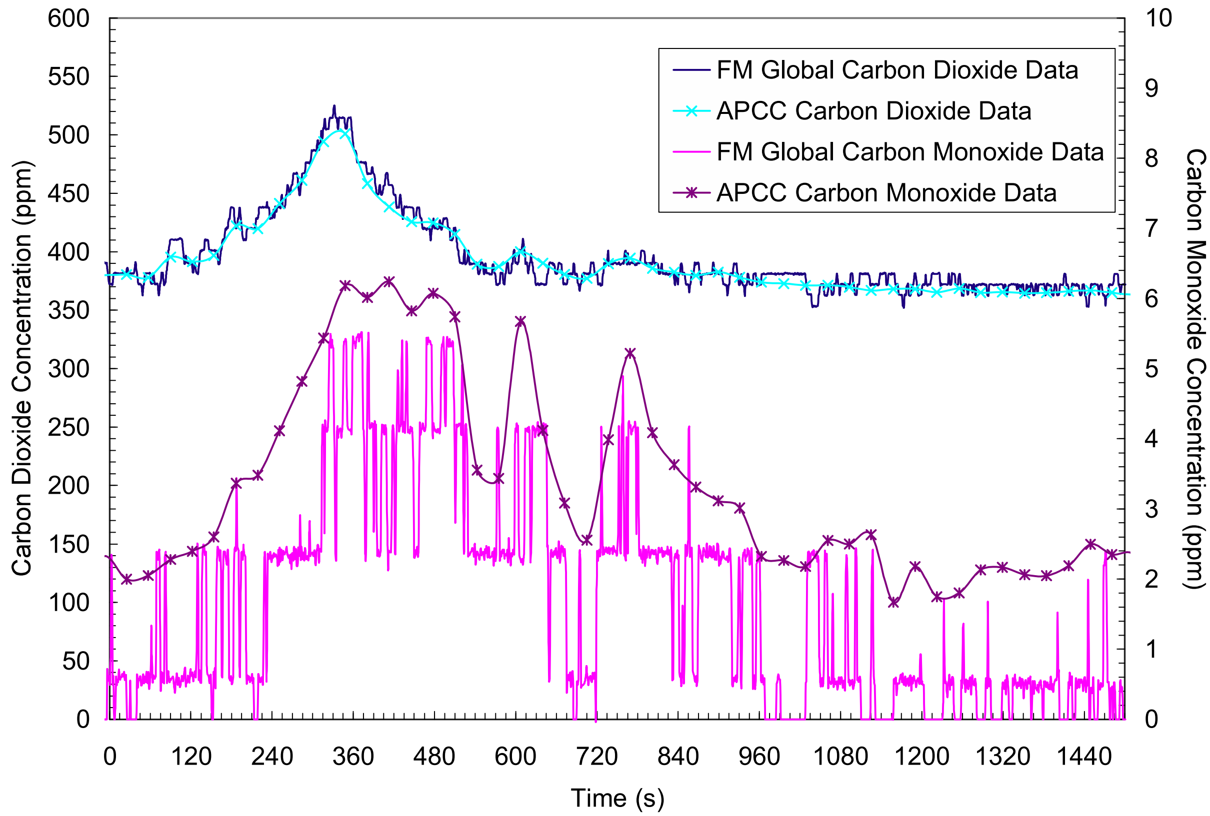


Figure 22: Duct concentrations of CO_2 and CO for the sprinklered test.

Excellent agreement is seen between the two independent data sets. The slight deviation between the FM Global data and the APCC data for the carbon monoxide levels in the sprinklered test is attributed to the very low concentrations, i.e., less than 7 ppm, and the dynamic range of the FM Global analyzer. In the following sections, the FM Global data are used to calculate the heat release rate and the total energy generated during each test, and the APCC data are used to evaluate the environmental impact.

3.3 HEAT RELEASE RATE AND TOTAL ENERGY

The chemical heat release rate (HRR) of each fire was calculated from calorimetry techniques based on carbon monoxide and carbon dioxide generation. The total chemical energy released during each fire was determined by integrating the time-resolved heat release rate data.

The chemical heat release rates as a function of time for the sprinklered and non-sprinklered tests are shown in Figure 23; the peak heat release rates were 300 kW and 13,200 kW respectively. The total energy released in the non-sprinklered test was 5,169 MJ, 76 times greater than that of the sprinklered test, which was 68 MJ. The calculated total energy released as a function of time is shown in Figure 24.

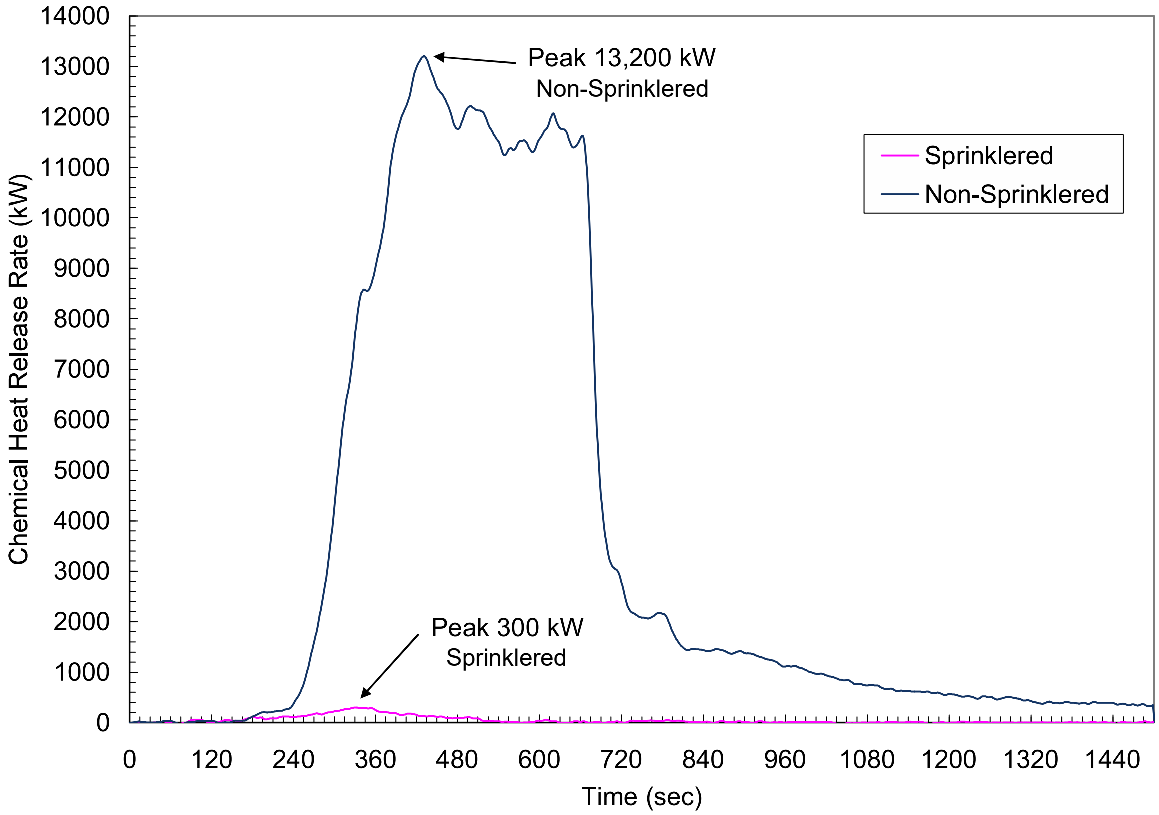


Figure 23: Chemical heat release rate as a function of time for the sprinklered and non-sprinklered tests.

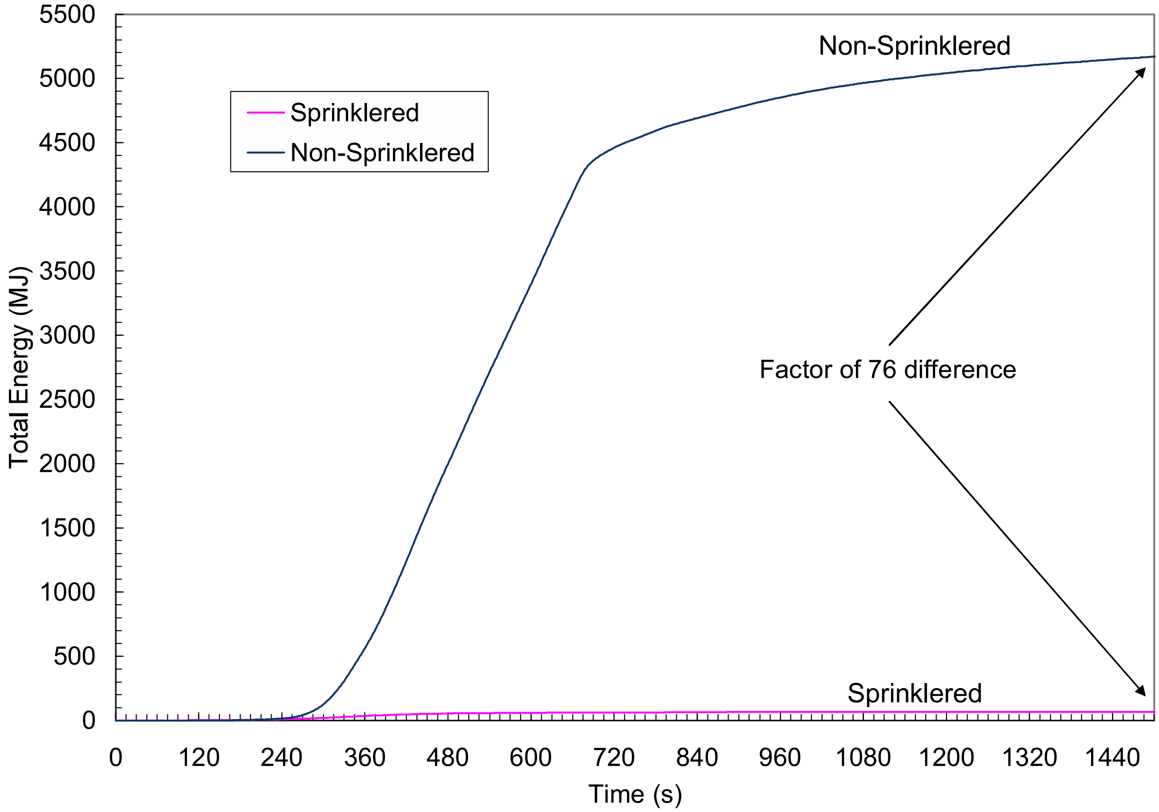


Figure 24: Total chemical energy as a function of time for the sprinklered and non-sprinklered tests.

3.4 ROOM GAS MEASUREMENTS

Gas measurements including the generated carbon dioxide, carbon monoxide, and total hydrocarbons, and the depleted oxygen levels within the rooms were monitored at a 1.5 m (5 ft.) elevation in the center of the room as described in Section 2.4.2. The generated species are plotted as a function of time in Figure 25 and Figure 26, for the non-sprinklered and sprinklered tests respectively.

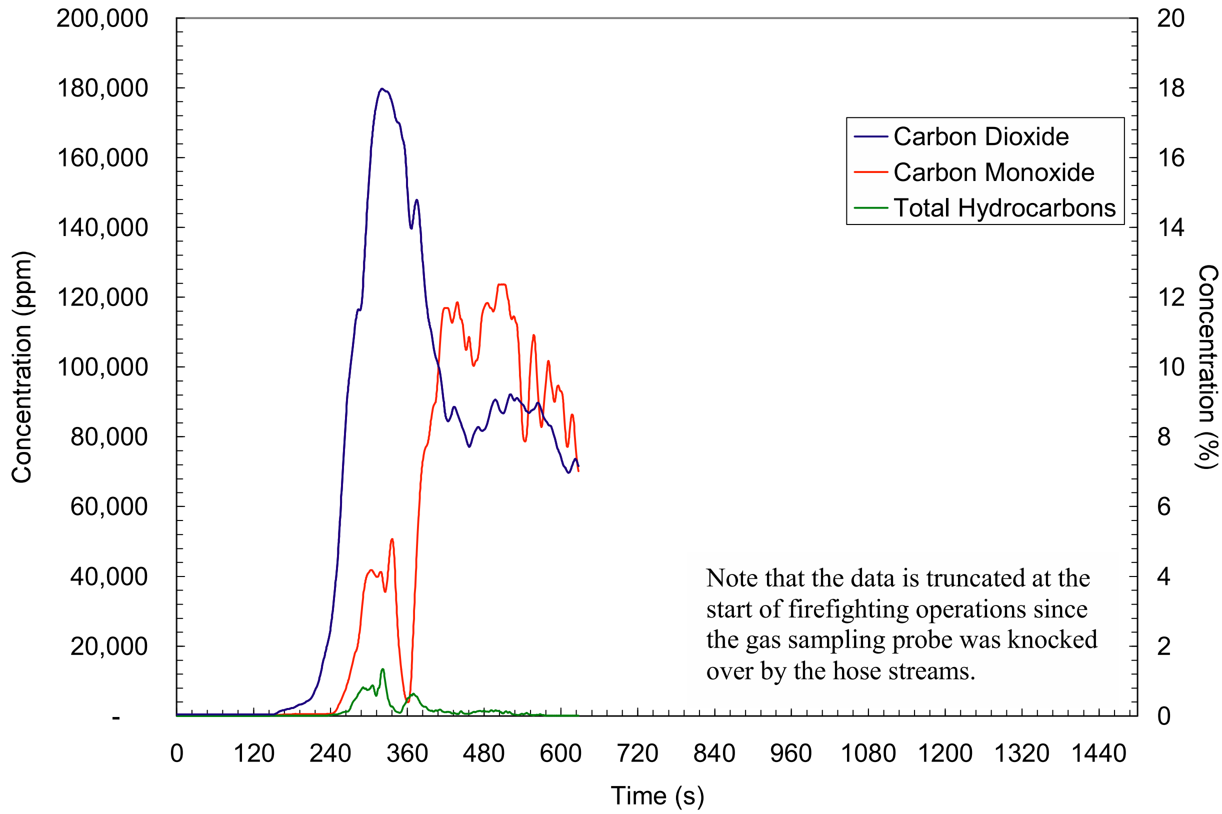


Figure 25: Carbon dioxide, carbon monoxide, and unburned hydrocarbon concentrations as a function of time within the room for the non-sprinklered test.

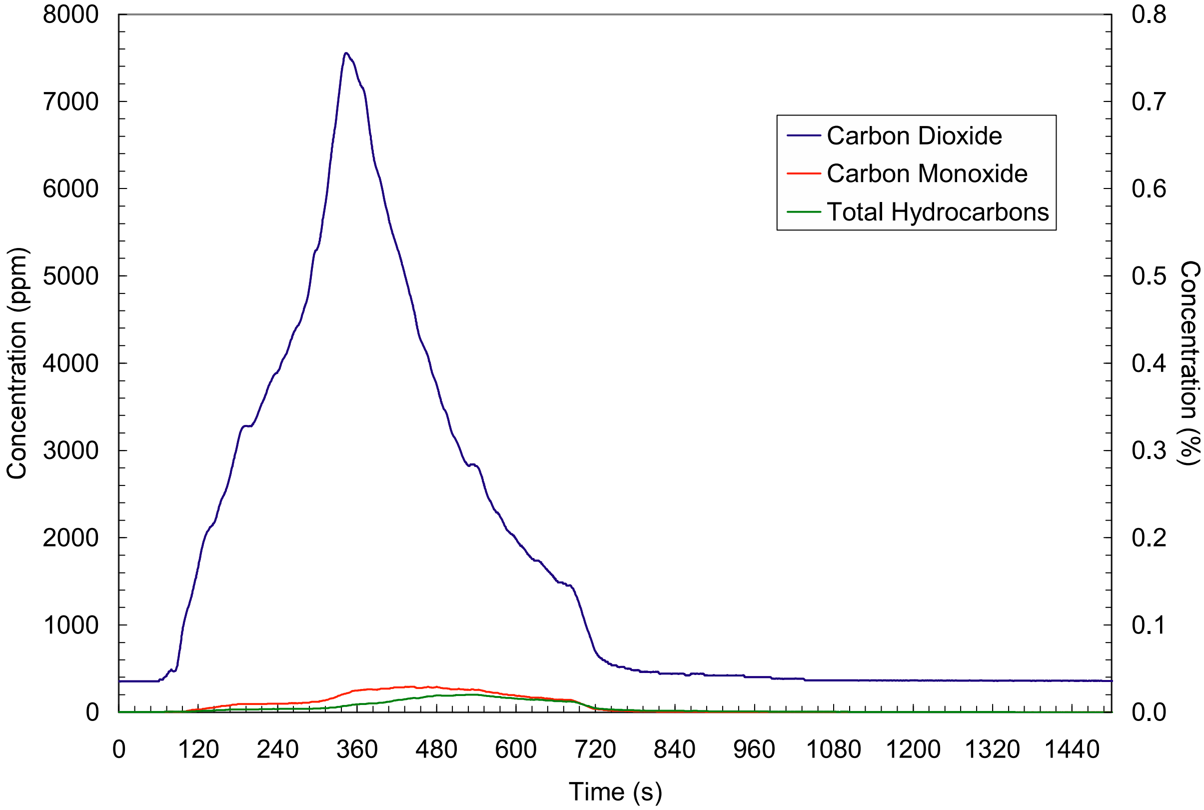


Figure 26: Carbon dioxide, carbon monoxide, and unburned hydrocarbon concentrations as a function of time within the room for the sprinklered test.

It should be noted that the maximum calibrated gas analyzer range for the carbon monoxide, in the non-sprinklered test, was 100,000 ppm (10%); measured concentrations above the maximum range should be viewed with caution. Furthermore, in the non-sprinklered test, at some point after the initiation of firefighting activities the gas sampling probe was knocked over by the hose streams; therefore, all of the data is truncated at the initiation of firefighting activities for this test.

Significantly higher levels of carbon dioxide, carbon monoxide, and total hydrocarbons were measured in the non-sprinklered test than in the sprinklered test. Maximum carbon monoxide levels differed by a factor of 420, while maximum carbon dioxide and total hydrocarbons levels differed by a factor of 24 and 67 respectively.

The oxygen concentrations as a function of time for the sprinklered and non-sprinklered tests are plotted in Figure 27. In the sprinklered test the oxygen level did not decrease below 18.8%; however, in the non-sprinklered test the oxygen level decreased to zero.

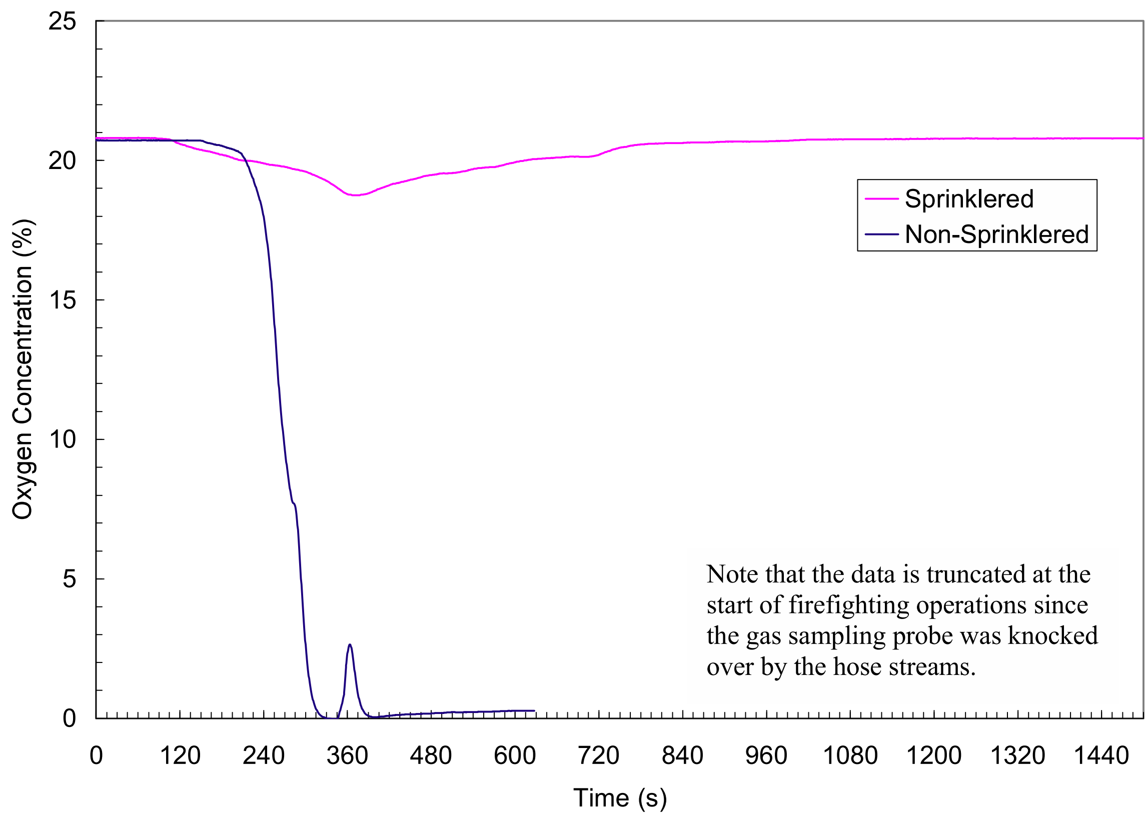


Figure 27: Oxygen concentrations as a function of time within the room for the sprinklered and non-sprinklered tests.

3.5 CEILING TEMPERATURES

Thermocouple measurements near the ceiling were taken at 13 locations as described in Section 2.4.3. The time resolved temperature measurements for the non-sprinklered and sprinklered tests are plotted in Figure 28 and Figure 29 respectively. In the non-sprinklered test a temperature rise across the ceiling is observed at approximately 120 s. The thermocouple reading directly over ignition, i.e., Tclg10NE, reached 530°C (986°F) as the flames spread up the curtain and reached the ceiling. The decrease in temperatures observed at 150 s is attributed to the curtain burning and falling to the floor, thus momentarily decreasing the flame height. As the fire developed and spread, the temperatures near the ceiling rose rapidly and thermocouple readings in excess of 900°C (1650°F) were recorded throughout the room up to the initiation of firefighting activities at 630 s. The maximum readings at several locations approached the upper calibrated limit of a Type K thermocouple, i.e., 1250°C (2282°F) and should be viewed with caution.

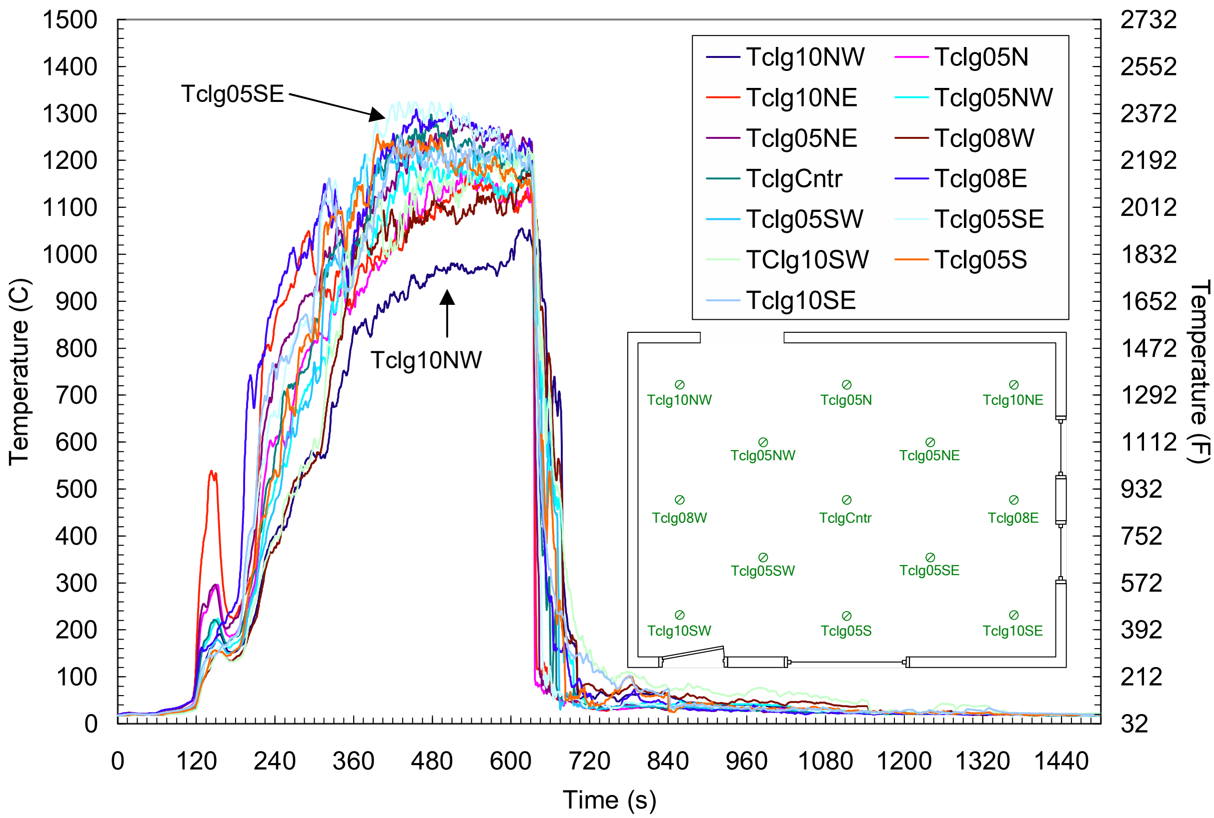


Figure 28: Near-ceiling thermocouple measurements for the non-sprinklered test.

In the sprinklered test, fire propagation from the magazine rack to the curtain and loveseat was more rapid and is reflected in the rapid temperature rise recorded directly over ignition. Upon sprinkler operation, at 44 seconds, the temperatures decrease and for the remaining duration of the test the temperatures near the ceiling do not exceed 260°C (500°F).

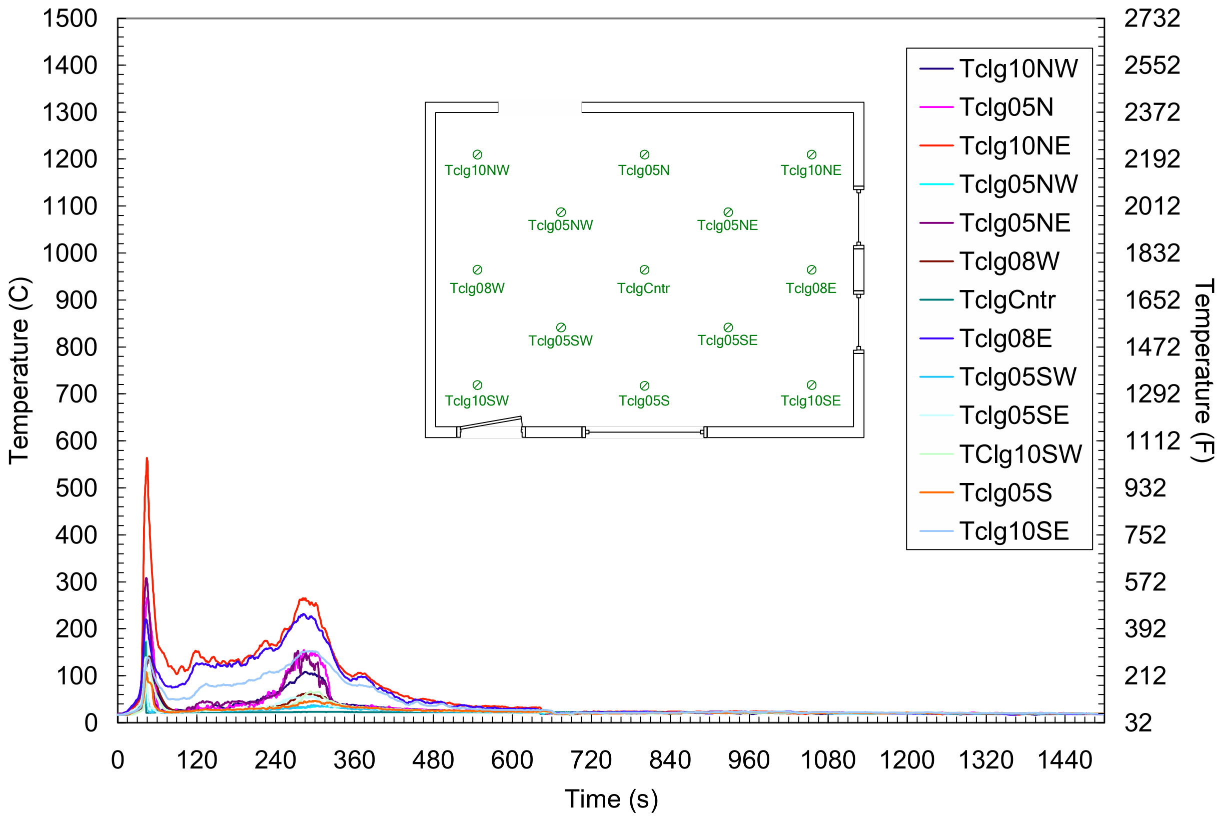


Figure 29: Near-ceiling thermocouple measurements for the sprinklered test.

3.6 FLASHOVER

Flashover is defined by the International Standards Organization as “the rapid transition to a state of total surface involvement in a fire of combustible material within an enclosure” [39]. Although not precise, the typical quantitative criteria for flashover are room temperatures between 500°C (932°F) and 600°C (1112°F), or radiation to the floor of the compartment from the gas layer between 15 and 20 kW/m^2 (1.3 to 1.8 BTU/ft^{2}s). A more subjective demarcation of flashover is the visual observation of flames external to the enclosure.

Using these criteria, the time to flashover in the non-sprinklered test was determined to be between 271 seconds and 327 seconds (see Figure 30). The embedded images in Figure 30 are of the archway taken at the two defining boundaries, i.e., ceiling temperature of 500°C (932°F) and a floor heat flux of 20 kW/m^2 (1.8 BTU/ft^{2}s). The dashed line indicates the visual observation of flames extending to the floor within the enclosure and extending out of the archway.

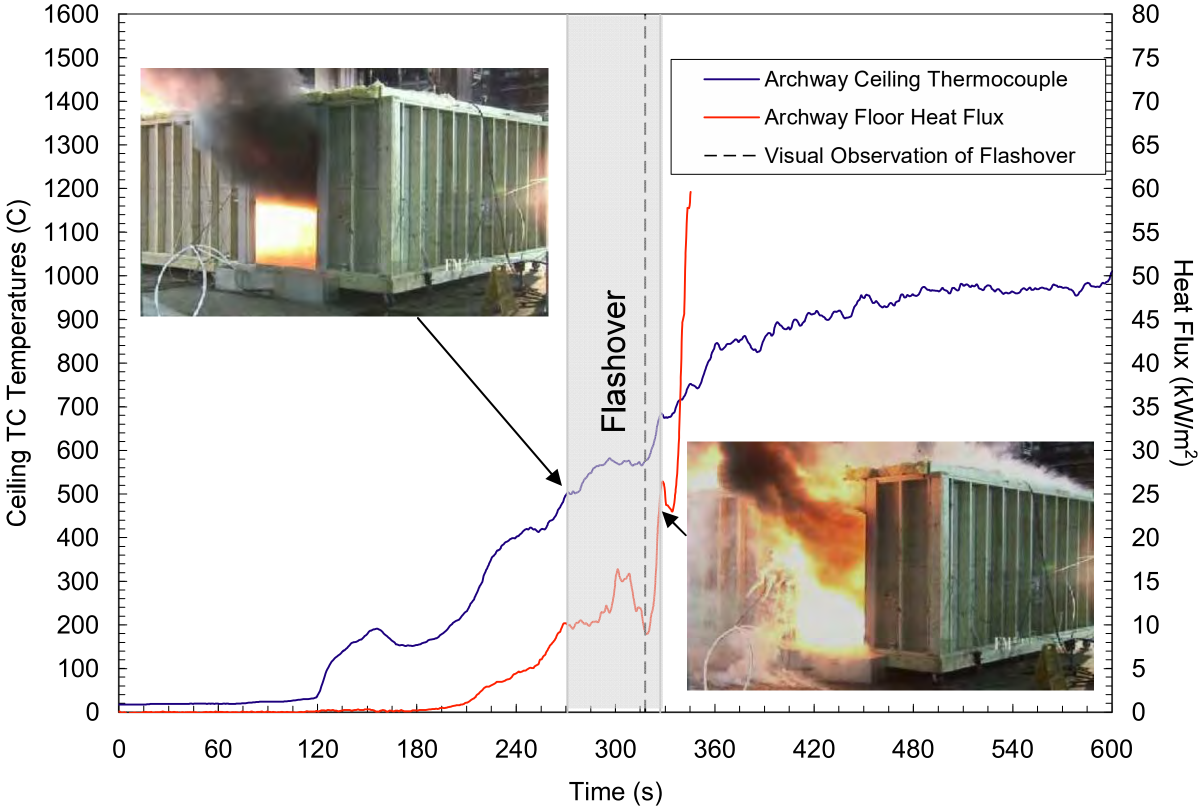


Figure 30: Flashover analysis of non-sprinklered test.

The occurrence of flashover prior to fire service response is an indication that the fire would have progressed to adjoining rooms, thus increasing the volume of materials consumed by the fire and the quantity of water required to extinguish the fire. In the sprinklered test the temperature near the ceiling at the archway did not exceed 136°C (277°F), the heat flux at the floor did not exceed 0.3 kW/m^2 (0.03 BTU/ft^{2}s), and no flames were observed exiting the enclosure. All of the data indicate that flashover did not occur in this case and the fire was contained completely to the room of origin.

3.7 WATER USAGE

As noted previously, the water sample from the first non-sprinklered test was potentially contaminated due to the melted plastic tubing and sump pumps within the water collection pan; therefore, water flow measurements and water samples for quality analysis were also taken during the demonstration test. Data from the demonstration test are labeled non-sprinklered (b). It should be noted that a more aggressive firefighting approach was also implemented in the demonstration test to better represent typical fire service response.

The volume of water discharged as a function of time in each of the three tests is plotted in Figure 31 and the results are tabulated in Table 13.

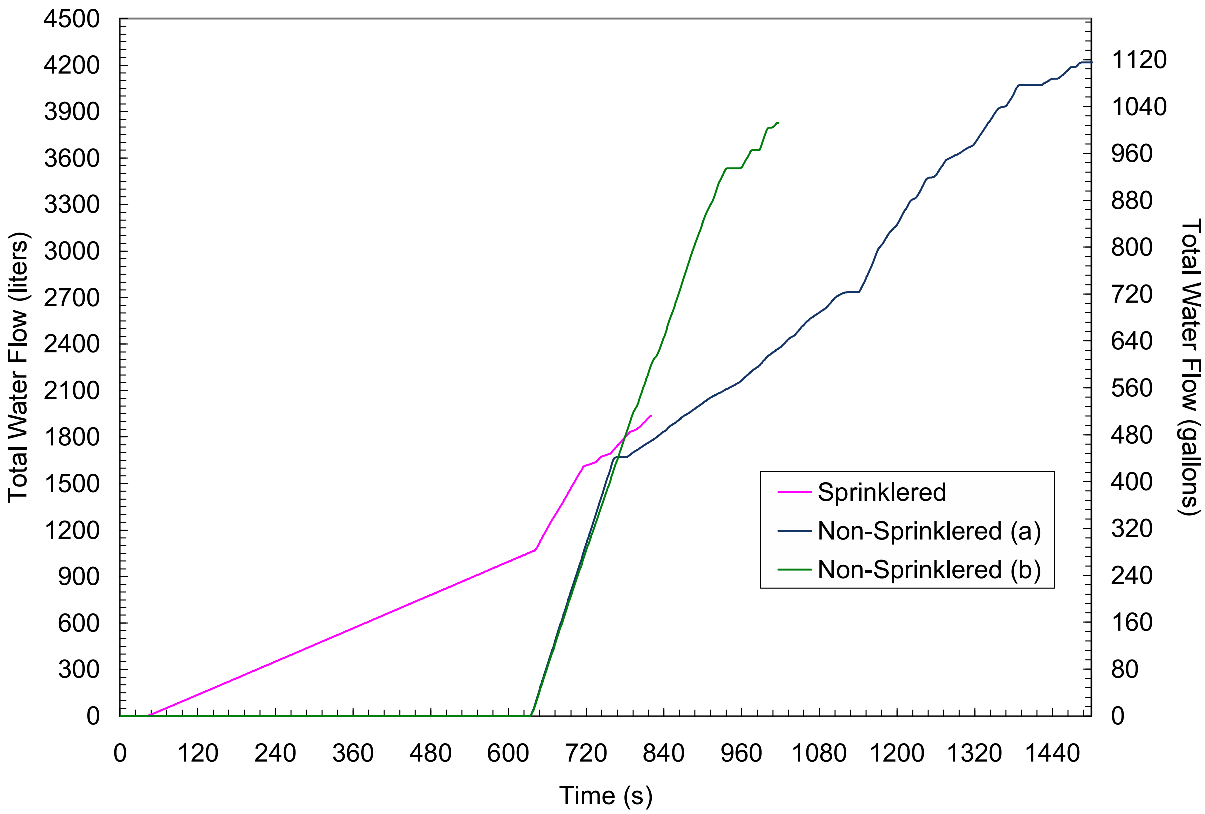


Figure 31: Total volume of water used as a function of time.

Comparing the water usage between non-sprinklered test (a) and (b), the difference in the total quantity of water discharged was not significant, i.e., ~379 L (100 gal.); however, the more aggressive firefighting tactic resulted in extinguishment of the fire 7 minutes and 46 seconds faster. Taking the lower water discharge volume as the representative volume of water for the non-sprinklered tests and comparing it to the total combined sprinkler and hose stream volume, for the sprinklered test, it is seen that 50% less water was used in the sprinklered test compared to the non-sprinklered test. Furthermore, the fire with the sprinkler was extinguished 3 minutes and 17 seconds faster than the non-sprinklered fire. This comparison is conservative, i.e., expected values for the non-sprinklered case will be larger, for two reasons, 1) the time to extinguishment and the volume of water used with the more aggressive firefighting tactics was used for the calculations; and more importantly, 2) in the non-sprinklered tests the fire would have propagated to adjacent rooms, if not the entire house, requiring more time and water to extinguish the fire. Conversely, the fire was contained to the ignition area in the sprinklered room making the results independent of any additional rooms. Extrapolation of the water usage data to larger occupancies will be made in Section 4.2.

Table 13: Water Usage Results

	Sprinklered	Non-Sprinklered (a)	Non-Sprinklered (b)
Sprinkler [L (gal.)]	1393 (368)	0	0
Hose Stream [L (gal.)]	545 (144)	4221 (1115)	3835 (1013)
Total [L (gal.)]	1938 (512)	4221 (1115)	3835 (1013)
Time to Extinguishment [s]	820	1484	1017

3.8 AIR EMISSION RESULTS

The following table, labeled Table 14, has been extracted directly from Reference 38. In the original report the table is labeled *Table 3-1: Controlled Burn Air Emissions* and the results are reported in pounds.[††] In addition to the mass of each species, the ratio between the non-sprinklered and sprinklered values is reported for each species. Of the 123 species analyzed, only 76 were detected in either the sprinklered or non-sprinklered test. There were 24 species detected at ratios in excess of 10:1, of which 11 were detected at ratios in excess of 50:1, and of those six were detected at ratios in excess of 100:1. Four species, NH_3, 1,2,3-trichloropropane, carbon tetrachloride, and o(rtho)-xylene, were detected in the non-sprinklered test but not in the sprinklered test. Similarly, four species, ethanol, hydrogen chloride (HCl), isopropyl alcohol (IPA), and bromoform, were detected in the sprinklered test but not the non-sprinklered test. The data indicate that "The total emissions from the Sprinkler controlled burn were lower than the emissions from the No Sprinkler controlled burn" [38].

[††] Note: Woodard and Curran used the terms "No Sprinkler" for the non-sprinklered test, and "Sprinkler" for the sprinklered test.

Table 14: Controlled Burn Air Emissions (Table 3-1 extracted from Reference 38)

Criteria Pollutants	Emissions (lbs/burn) 17 September No Sprinkler	1 October Sprinkler	Ratio of Emissions, No Sprinkler vs. Sprinkler
CO	26.42	0.23	113
NO_2	0.14	0.14	1
SO_2	0.48	0.20	2.4
Total VOC - THC (as CH_4)	3.77	0.02	184
Particulate	17.76	1.39	13
Greenhouse Gases	**Emissions (lbs/burn) 17 September No Sprinkler**	**1 October Sprinkler**	**Ratio of Emissions, No Sprinkler vs. Sprinkler**
CO_2	793.95	12.98	61
Methane	1.80	0.01	130
Nitrous Oxide (N_2O)	0.17	0.02	7
Metals	**Emissions (lbs/burn) 17 September No Sprinkler**	**1 October Sprinkler**	**Ratio of Emissions, No Sprinkler vs. Sprinkler**
Antimony (Sb)	0.017	0.00056	30
Arsenic (As)	0.00056	0.00023	2.5
Barium (Ba)	0.012	0.012	1
Beryllium (Be)	0.0014	0.000056	25
Cadmium (Cd)	0.0014	0.00012	12
Total chromium (Cr)	0.050	0.015	3.3
Copper (Cu)	0.016	0.0091	1.8
Mercury (Hg)	0.0082	0.0048	1.7
Lead (Pb)	0.013	0.0087	1.5
Manganese (Mn)	0.081	0.010	8.3
Nickel (Ni)	0.043	0.0095	4.6
Phosphorous (P)	0.012	0.0084	1.5
Selenium (Se)	0.012	0.00063	19
Silver (Ag)	0.00052	0.00026	2
Thallium (Tl)	0.00070	0.00028	2.5
Zinc (Zn	0.147	0.018	8.4

Table 14: Controlled Burn Air Emissions (Table 3-1 extracted from Reference 38) (cont'd)

Air Toxics and Other Pollutants	Emissions (lbs/burn)		Ratio of Emissions, No Sprinkler vs. Sprinkler
	17 September No Sprinkler	1 October Sprinkler	
Acetaldehyde	0.32	0.0016	200
Acrolein	0.21	0.35	0.6
Benzene	0.69	2.06	0.3
Ethanol	0	1.44	0
Ethylene	0.51	0.012	43
Formaldehyde	0.15	0.0092	17
Hydrogen Fluoride (HF)	0.0026	0.0045	0.6
Hydrogen Chloride (HCl)	0	0.016	0
Isopropyl Alcohol (IPA)	0	0.35	0
Methanol	0.20	0.037	5.5
NH_3	0.0026	0	---
NO	0.91	0.021	44
Toluene	0.58	0.084	6.9
Hydrogen Cyanide (HCN)	0.07	0.013	5.4
1,1,1-Trichloroethane	0.46	0.56	0.8
Bromoform	0	0.0011	0
Carbon Disulfide	25.15	0.037	678
Chloroform	0.046	0.012	3.8
Methyl Ethyl Ketone (MEK)	3.52	0.053	67
Iodo-methane	1.042	0.077	14
1,2,3-Trichloropropane	28.31	0	---
Carbon Tetrachloride	0.13	0	---
m(eta)-Xylene	0.057	0.016	3.5
o(rtho)-Xylene	2.97	0	---
p(ara)-Xylene	7.22	0.90	8
Total Xylenes	10.24	0.91	11
Methyl Isobutyl Ketone (MIBK)	3.16	0.032	98

Table 14: Controlled Burn Air Emissions (Table 3-1 extracted from Reference 38) (cont'd)

Semi-Volatile Organic Air Toxics	Emissions (lbs/burn) 17 September No Sprinkler	Emissions (lbs/burn) 1 October Sprinkler	Ratio of Emissions, No Sprinkler vs. Sprinkler
1,2,4-Trichlorobenzene	0	0	---
1,2-Dichlorobenzene	0	0	---
1,3-Dichlorobenzene	0	0	---
1,4-Dichlorobenzene	0	0	---
1-Chloronaphthalene	0	0	---
1-Methylnaphthalene	0.0056	0.0017	3.3
2,4,5-Trichlorophenol	0	0	---
2,4,6-Trichlorophenol	0	0	---
2,4-Dichlorophenol	0	0	---
2,4-Dimethylphenol	0	0	---
2,4-Dinitrophenol	0	0	---
2,4-Dinitrotoluene	0	0	---
2,6-Dinitrotoluene	0	0	---
2-Chloronaphthalene	0	0	---
2-Chlorophenol	0	0	---
2-Methylnaphthalene	0.0065	0.0011	5.7
2-Methylphenol	0.0095	0.0017	5.5
2-Nitroaniline	0	0	---
2-Nitrophenol	0	0	---
3 & 4-methylphenol	0.015	0.0020	7.6
3,3'-Dichlorobenzidine	0	0	---
3-Nitroaniline	0	0	---
4,6-Dinitro-2-methylphenol	0	0	---
4-Bromophenyl phenyl ether	0	0	---
4-Chloro-3-Methylphenol	0	0	---
4-Chloroaniline	0	0	---
4-Chlorophenyl phenyl ether	0	0	---
4-Nitroaniline	0	0	---

Table 14: Controlled Burn Air Emissions (Table 3-1 extracted from Reference 38) (cont'd)

Semi-Volatile Organic Air Toxics (con't)	Emissions (lbs/burn)		Ratio of Emissions, No Sprinkler vs. Sprinkler
	17 September No Sprinkler	1 October Sprinkler	
4-Nitrophenol	0	0	---
Acenaphthene	0	0	---
Acenaphthylene	0.021	0.00029	75
Aniline	0	0	---
Anthracene	0.0032	0.00023	14
Benzidine	0	0	---
Benzo(a)anthracene	0.0017	0.00023	7.4
Benzo(a)pyrene	0.0018	0.00029	6.1
Benzo(b)fluoranthene	0.0029	0.00023	13
Benzo(g,h,i)perylene	0.0021	0.00023	9
Benzo(k)fluoranthene	0.00088	0.00029	3.1
Benzoic Acid	0.15	0.0011	130
Benzyl Alcohol	0.0011	0.00029	3.7
Benzyl butyl phthalate	0.00026	0.0044	0.1
Biphenyl	0.013	0.0011	12
Bis(2-chloroethoxy)methane	0	0	---
Bis(2-chloroethyl)ether	0	0	---
Bis(2-chloroisopropyl)ether	0	0	---
Bis(2-ethylhexyl)phthalate	0.15	0.061	2.5
Carbazole	0	0	---
Chrysene	0.0013	0.00023	5.5
Dibenz(a,h)anthracene	0.00042	0.00023	1.8
Dibenzofuran	0	0	---
Diethyl phthalate	0	0	---
Dimethyl phthalate	0	0	---
Di-N-butyl phthalate	0	0	---
Di-N-octyl phthalate	0	0	---
Fluoranthene	0.0085	0.00061	14
Fluorene	0.0035	0.00023	15
Hexachlorobenzene	0	0	---
Hexachlorobutadiene	0	0	---
Hexachlorocyclopentadiene	0	0	---
Hexachloroethane	0	0	---
Indeno(1,2,3-cd)pyrene	0.0019	0.00029	6.7
Isophorone	0	0	---
Naphthalene	0.092	0.0012	78
Nitrobenzene	0	0	---
N-Nitrosodimethylamine	0	0	---
N-Nitroso-di-n-propylamine	0	0	---

Table 14: Controlled Burn Air Emissions (Table 3-1 extracted from Reference 38) (cont'd)

Semi-Volatile Organic Air Toxics (con't)	Emissions (lbs/burn) 17 September No Sprinkler	1 October Sprinkler	Ratio of Emissions, No Sprinkler vs. Sprinkler
N-Nitrosodiphenylamine	0	0	---
Pentachlorophenol	0	0	---
Phenanthrene	0.024	0.00055	44
Phenol	0.075	0.00085	88
Pyrene	0.0067	0.00029	23

Note: Carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) are greenhouse gases that were measured during the controlled burns. A result of zero indicates that the constituent was either not detected or controlled burn test results were below the detection limit of the analysis. A dash (---) indicates that ratio was not calculated, because a constituent was not detected in the analysis.

3.9 WATER QUALITY RESULTS

The following results and discussion related to the wastewater analysis have been extracted directly from Reference 38. The section and table numbering of the original report have been maintained. The water analysis includes water samples from each of the fire tests. In addition, since FM Global uses a closed-loop recycled water system for firefighting purposes, samples of the recycled water on each day were also analyzed to establish a baseline.

4.2.1 Analytical Results

As discussed, one composite wastewater sample was collected from each controlled burn (i.e., with and without sprinkler) immediately following fire response activities. Samples were analyzed for general chemistry parameters, dissolved and total metals, VOCs, and SVOCs. Additionally, one recycled water sample was collected per controlled burn and analyzed for the same suite of parameters. Analytical results for all constituents detected at least once in wastewater samples are summarized in Table 4-2a and 4-2b. Recycled fire fighting water sample results are also reported on these tables. The laboratory analytical reports for these samples are provided in Appendix B. As discussed, there were potential sample contamination issues associated with the September 17, 2009 sampling event for the No sprinkler controlled burn. However, for comparative purposes, the analytical results for this wastewater sample and recycled water samples collected on this date are presented on Table 4-2a.

The values presented in the analytical results table show either a detected concentration, or a "non-detect" concentration, indicated by a qualifier of "U". The "U"-qualified value is the reporting limit (RL), which is the lowest concentration that an analytical instrument can accurately measure, within specified limits of precision and accuracy. The constituent may potentially be present at a level below the RL, but the instrument is not able to detect it at a concentration lower than the RL. Note that RLs are, in part, dependent on sample-specific *characteristics, such as the level of contaminant present or the sample dilution required for analysis, and thus, the RL for one analyte in one sample may vary considerably from the RL reported for the same constituent in another sample.*

Because various constituents were detected in the recycled fire fighting water samples, the tables below provide adjusted concentrations of constituents in each wastewater sample. This adjusted, or net, concentration represents the difference between the detected level of a constituent in wastewater and the corresponding detected level in the recycled water sample. Non-detect results were not included in calculation of the adjusted concentration. A positive net value indicates that the concentration of constituent in the wastewater sample was greater than that of the recycled water sample; conversely, a negative value indicates that the concentration in the recycled water sample was greater than that of the wastewater sample.

Table 4-2a: Summary of Analytical Results – Wastewater Samples, September 17, 2009

		September 17, 2009 Sampling Event				
LOCATION		**RW - 1**		**WW-1**		**WW-1**
		Recycled Water		**No Sprinkler**		**No Sprinkler**
SAMPLING DATE		**9/17/2009**		**9/17/2009**		**9/17/2009**
	Units	Result	Qual	Result	Qual	**Net Result***
General Chemistry						
pH (H)	SU	7.8		11.6		3.8
Specific Conductance	umhos/cm	2,100		5,100		3,000
Solids, Total Dissolved	ug/l	1,200,000		4,000,000		2,800,000
Solids, Total Suspended	ug/l	5,000	U	2,000,000		2,000,000
Cyanide, Total	ug/l	5	U	96		96
Nitrogen, Ammonia	ug/l	75	U	7,200		7,200
Nitrogen, Nitrate	ug/l	100	U	1,900		1,900
Phosphorus, Total	ug/l	19		337		318
Chemical Oxygen Demand	ug/l	220,000		850,000		630,000
Total Organic Carbon	ug/l	71,000		240,000		169,000
Volatile Organic Compounds						
Chloroform	ug/l	150		160		10
Benzene	ug/l	50	U	50	U	ND
Styrene	ug/l	50	U	50	U	ND
Acetone	ug/l	5,900		6,400		500
Semivolatile Organic Compounds						
Phenol	ug/l	7	U	230		230
2-Methylphenol	ug/l	6	U	100		100
3-Methylphenol/ 4-Methylphenol	ug/l	6	U	200		200
Benzoic Acid	ug/l	86		1,300		1,214
Total Metals						
Antimony, Total	ug/l	50	U	208		208
Arsenic, Total	ug/l	5	U	5	U	ND
Chromium, Total	ug/l	10	U	10	U	ND
Copper, Total	ug/l	45		35		-10
Lead, Total	ug/l	2	U	12		12
Mercury, Total	ug/l	0.2	U	1.3		1.3
Silver, Total	ug/l	0.8	U	0.8	U	ND
Zinc, Total	ug/l	82		188		106
Dissolved Metals						
Antimony, Dissolved	ug/l	50	U	210		210
Copper, Dissolved	ug/l	10	U	10	U	ND
Mercury, Dissolved	ug/l	0.2	U	1.5		1.5
Zinc, Dissolved	ug/l	50	U	50	U	ND

U = Constituent not detected at laboratory reporting limit
ug/L = micrograms per liter
SU = standard units
umhos/cm = micromhos per centimeter
Free CN- = Cyanide (CN-) criteria are available for free, or bioavailable, cyanide. Wastewater results are reported for total cyanide. Total cyanide concentrations are not necessarily indicative of free cyanide concentrations.

*Wastewater concentrations were corrected to account for the contribution of contamination from the recycled firefighting water used to extinguish the test burns. The net result shown above is the difference between the measured level of a constituent in the test burn sample and the corresponding recycled water sample.
Non-detect (ND) results were not included in calculating the difference (i.e., these results were assumed equivalent to zero).
A negative result indicates that the test burn sample level was lower than the recycled water concentration.

Table 4-2b: Summary of Analytical Results – Wastewater Samples, October 1, 2009

LOCATION		October 1, 2009 Sampling Event							
		RW-1		WW-1		WW-1	WW-2		WW-2
		Recycled Water		Sprinkler		Sprinkler	No Sprinkler		No Sprinkler
SAMPLING DATE		10/1/2009		10/1/2009		10/1/2009	10/1/2009		10/1/2009
	Units	Result	Qual	Result	Qual	Net Result*	Result	Qual	Net Result*
General Chemistry									
pH (H)	SU	8.1		7.9		-0.2	12.1		4
Specific Conductance	umhos/cm	2,200		2,300		100	7,300		5,100
Solids, Total Dissolved	ug/l	1,200,000		1,300,000		100,000	5,500,000		4,300,000
Solids, Total Suspended	ug/l	5,000	U	36,000		36,000	640,000		640,000
Cyanide, Total	ug/l	5	U	639		639	55		55
Nitrogen, Ammonia	ug/l	75	U	1,470		1,470	4,850		4,850
Nitrogen, Nitrate	ug/l	100	U	130		130	440		440
Phosphorus, Total	ug/l	16		500		484	401		385
Chemical Oxygen Demand	ug/l	160,000		420,000		260,000	810,000		650,000
Total Organic Carbon	ug/l	54,000		110,000		56,000	190,000		136,000
Volatile Organic Compounds									
Chloroform	ug/l	290		84		-206	82		-208
Benzene	ug/l	100	U	62		62	50	U	ND
Styrene	ug/l	100	U	50	U	ND	63		63
Acetone	ug/l	13,000		11,000		-2,000	8,000		-5,000
Semivolatile Organic Compounds									
Phenol	ug/l	6.8	U	280	U	ND	370		370
2-Methylphenol	ug/l	5.8	U	240	U	ND	180		180
3-Methylphenol/ 4-Methylphenol	ug/l	5.8	U	240	U	ND	290		290
Benzoic Acid	ug/l	80		2,000	U	ND	960	U	ND
Total Metals									
Antimony, Total	ug/l	50	U	50	U	ND	272		272
Arsenic, Total	ug/l	5	U	5	U	ND	7		7
Chromium, Total	ug/l	10	U	10	U	ND	10		10
Copper, Total	ug/l	40		61		21	46		6
Lead, Total	ug/l	2	U	2		2	18		18
Mercury, Total	ug/l	0.2	U	2.5		2.5	0.8		0.8
Silver, Total	ug/l	0.8	U	0.8	U	ND	1.8		1.8
Zinc, Total	ug/l	165		337		172	350		185
Dissolved Metals									
Antimony, Dissolved	ug/l	50	U	50	U	ND	150		150
Copper, Dissolved	ug/l	10	U	30		30	10	U	ND
Mercury, Dissolved	ug/l	0.2	U	1.1		1.1	0.6		0.6
Zinc, Dissolved	ug/l	128		182		54	50	U	ND

U = Constituent not detected at laboratory reporting limit
ug/L = micrograms per liter
SU = standard units
umhos/cm = micromhos per centimeter
Free CN- = Cyanide (CN-) criteria are available for free, or bioavailable, cyanide. Wastewater results are reported for total cyanide. Total cyanide concentrations are not necessarily indicative of free cyanide concentrations.

*Wastewater concentrations were corrected to account for the contribution of contamination from the recycled firefighting water used to extinguish the test burns. The net result shown above is the difference between the measured level of a constituent in the test burn sample and the corresponding recycled water sample.
Non-detect (ND) results were not included in calculating the difference (i.e., these results were assumed equivalent to zero).
A negative result indicates that the test burn sample level was lower than the recycled water concentration.

4.2.1.2 Pollutant Concentrations in Wastewater

Recycled Water Samples: Analytical results for both of the recycled water samples indicate that total copper, total zinc, two VOCs (acetone and chloroform), and benzoic acid, a SVOC, are present at a level above the laboratory reporting limits. In general, the types of constituents detected in both September 17 and October 1 samples were similar, although concentrations of these constituents were variable. Of the metals, only zinc was detected in dissolved form, and only in the October 1, 2009 sample. General chemistry results showed that organic solids were also present in the water samples. These results indicate that a baseline level of chemical constituents is present in the recycled water system.

Sprinkler controlled burn: Acetone, benzene, and chloroform were detected in the sample obtained from the Sprinkler controlled burn, WW-1, on October 1, 2009. Both chloroform and acetone levels in the Sprinkler controlled burn sample were lower than those of the recycled water sample collected on the same sample date. No SVOCs were detected in the Sprinkler sample; however, reporting limits for several of the constituents were elevated in this sample compared to those in the recycled water sample (due to the high concentrations of several analytes present in the sample), thereby potentially "masking" the presence of these constituents. Total and dissolved copper, mercury, and zinc were detected in sample WW-1; lead was detected only in total form in this sample.

No Sprinkler controlled burn: Similar types of constituents were detected in the samples obtained from the No Sprinkler controlled burn (samples WW-1, on September 17, 2009 and WW-2, on October 1, 2009). Chloroform, styrene, acetone, and several phenolic compounds were detected; both acetone and chloroform levels were lower than those detected in the recycled water sample. Heavy metals, including antimony, arsenic, chromium, lead, mercury, and silver, were also detected. Of the metals, only antimony and mercury were detected in dissolved form, and in both samples, implying that most of the detected metals are likely associated with suspended particulate matter.

During the October 1, 2009 event, both chloroform and acetone concentrations were highest in the recycled water sample compared to concentrations detected in the Sprinkler and No Sprinkler samples. Because both of these compounds are volatile, one would expect a higher degree of volatilization resulting from either controlled burn (because recycled fire fighting water is spread over a larger area and because the heat from the fire would increase volatilization), which may, in part, explain the difference in concentration for these contaminants.

Three SVOCs were detected in the No Sprinkler sample, whereas none was detected in the Sprinkler sample; however, the reporting limits for SVOCs in the Sprinkler sample were similar to or higher than those of the No Sprinkler sample. It is therefore unclear whether SVOCs in the Sprinkler sample are not actually present or are present but at levels below the reporting limits.

Relative to the recycled water samples, the Sprinkler and No Sprinkler samples contained higher levels of both total suspended and dissolved solids, organic carbon, and nutrients (nitrogen and phosphorous). In general, the No Sprinkler water samples contained the highest levels of solids and TOC, and a higher pH. This is expected, considering the high generation of ash resulting *from the No Sprinkler controlled burn compared to the Sprinkler controlled burn. Of all of the wastewater samples, the total cyanide concentration was highest in the October 1, 2009 Sprinkler sample. Cyanide gas can be generated from burning synthetic polymers in building materials and furnishings, as well as natural materials such as wood.*

Metals concentrations were variable between the Sprinkler and No-Sprinkler controlled burn samples, with no clear bias shown by either sample. In general, however, the differences in concentration between the two controlled burns were less than an order of magnitude. Of the eight metals analyzed (as total metals), six metals were detected in the No Sprinkler sample at concentrations higher than that of the Sprinkler sample. However, dissolved copper, mercury, and zinc concentrations were highest in the Sprinkler controlled burn. Dissolved antimony concentrations were highest in the No Sprinkler sample.

The pH of the composite wastewater samples from the two No Sprinkler controlled burns were 11.6 and 12.1 vs. pH of 7.9 for the wastewater sample from the Sprinkler controlled burn. Thus, the wastewater from the No Sprinkler controlled burns was approximately four orders of magnitude higher in alkalinity than the wastewater from the Sprinkler controlled burn. The discharge of any wastewater with pH values of higher than 10 would be a serious environmental concern. Wastewaters exhibiting pH values of greater than 9.0 would be exceeding the allowable discharge range of pH 5.5-9.0 required by most environmental regulatory agencies.

3.10 SOLID WASTE ANALYSIS

Solid waste from each of the tests, including non-sprinklered test (b) was analyzed as described in Section 2.4.8. The results of the analysis indicate that all three samples "would not be considered 'hazardous waste' under USEPA regulations". Furthermore, "the wastes are not anticipated to significantly leach once landfilled" [38].

4 DISCUSSION

In the following sections, the reduction in the environmental impact due to the use of automatic fire sprinklers in a fire will be discussed. Quantification of the environmental impact will be based on analysis of greenhouse gases, water usage, potential environmental impacts of wastewater runoff, fire damage, and solid waste material disposed in landfills. In addition, the benefits of automatic fire sprinklers from a life safety perspective will be presented.

4.1 IMPACT ON GREENHOUSE GASES

This section discusses the impact of sprinkler protection on the generation of greenhouse gases. The measured greenhouse gases reported in Section 3.8 can be converted to an equivalent mass of carbon dioxide:

$$CO_{2,equivalent} = GWP_{gas} \cdot m_{gas} \qquad (9)$$

Where:

$CO_{2,equivalent}$ - equivalent mass of carbon dioxide for a gas

m_{gas} - mass of the greenhouse gas

GWP_{gas} - global warming potential of the gas

The global warming potentials (GWP) "are a measure of the relative radiative effect of a given substance compared to another, integrated over a chosen time horizon. [40]" A common time horizon used by regulators is 100 years.

The global warming potential, measured masses of greenhouse gases, and calculated equivalent carbon dioxide levels are listed in Table 15. The equivalent mass of CO_2 generated in the non-sprinklered test was 404.4 kg (890.7 lb.) versus 8.7 kg (19.2 lb.) generated in the sprinklered test. This indicates that in the event of a fire, the use of sprinklers can reduce the greenhouse gas emissions by 97.8%. It should be noted that this is a conservative value, i.e., the expected values will be larger, since in the non-sprinklered test the fire would have propagated to adjacent rooms, if not the entire house, before firefighting intervention commenced.

Table 15: Equivalent Carbon Dioxide Values for Measured Greenhouse Gases

Gas	GWP*	Measured Mass		Equivalent CO_2	
		(Non-Sprinklered) kg (lb.)	(Sprinklered) kg (lb.)	(Non-Sprinklered) kg (lb.)	(Sprinklered) kg (lb.)
CO_2	1	360.1 (794)	5.9 (13.0)	360.1 (794)	5.9 (13.0)
CH_4	25	0.82 (1.8)	0.004 (0.019)	20.5 (45.2)	0.1 (0.22)
N_2O	298	0.08 (0.17)	0.009 (0.02)	23.8 (52.5)	2.7 (6.0)
			Total	**404.4 (890.7)**	**8.7 (19.2)**

* Based on a 100-year time interval

These results can be extrapolated to estimate the total greenhouse gas production resulting for all residential fires within the U.S. between 1999 and 2008. As discussed previously in Sections 1.2.3 and 1.2.4, the average size of a single-family home during that time period was 164 m^2 (1,765 ft^2) and the estimated average damage, per NFPA statistics, was 14%. Furthermore, data from NFPA indicate that the total number of residential fires in one- and two-family homes (including manufactured homes) between 1999 and 2008 was 2,943,500. Assuming a direct proportionality between the greenhouse gas emissions and the area of the room, it is estimated that 14.5 kg/m^2 (3.0 lbs/ft^2) of equivalent carbon dioxide was generated. Based on these values, the total amount of greenhouse gases generated between 1999 and 2008, as a result of residential fires, was 979,950,020 kg (2,160,419,982 lb.) If sprinklers had been used, the total mass of greenhouse gases, over the 10-year period, would have been reduced by 97.8% to 21,558,900 kg (47,529,240 lb.) On a yearly basis the values are reduced by a factor of 10.

As a reference, the EPA reports that "In the United States, approximately 4 metric tons of carbon dioxide (CO_2) equivalent (almost 9,000 pounds) per person per year (about 17% of total U.S. emissions) are emitted from people's homes. The three main sources of greenhouse gas emissions from homes are electricity use, heating and waste."

4.2 WATER USE EXTRAPOLATION

In this section, the quantity of water needed to extinguish a fire in structures larger than the one used in this study will be estimated. The key assumption in this analysis is that the quantity of water needed to extinguish the fire is directly proportional to the area of the room. It is reported in Section 3.7 that the quantity of water used in non-sprinklered test (b) was 3,835 L (1,013 gal.). Based on the area of the room used in this study the quantity of water per unit area needed to extinguish the fire without a sprinkler was 138 L/m^2 (3.4 gal/ft^2).

Assuming various percentages of damage to a typical sized residence, the projected quantity of water required by firefighters can be determined and the percent reduction achieved by using a sprinkler can be estimated. The experimental data reported in Section 3.7 and the estimates in Table 16 indicate that, in the event of a fire, for an average sized home of 164 m^2 (1,765 ft^2) using sprinklers can reduce the water usage between 50% and 91%.

Table 16: Water Usage Estimates

Percentage Damaged	Area Damaged m^2 (ft^2)	Estimated Water Usage by Firefighters L (gal.)	Reduction Achieved by Using Sprinklers (%)
25	41 (441)	5,644 (1,491)	66
50	82 (883)	11,292 (2,983)	83
75	123 (1,324)	16,936 (4,474)	89
100	164 (1,765)	22,584 (5,966)	91

4.3 FIRE DAMAGE

The combustible loading within each living room consisted of the primary and secondary fuel items, decorative items, and ignition package comprising a combined mass of 309.8 kg (683.0 lb.). The carpet, carpet padding, and plastic window frames are also considered part of the combustible loading, adding an additional 130 kg (287 lb.) of combustible material. Therefore, the total mass of combustible material in each living room was 440 kg (970 lb.).

In the sprinklered test, the items that sustained fire damage included the recliner, loveseat, magazine rack, carpet, and carpet padding. The initial and final mass of each of these items is listed in Table 17. The final mass of the magazine rack, carpet, and carpet padding was not recorded; however, based on the post test images, it is assumed that 80% of the magazine rack was consumed in the fire, and a 457 mm x 457 mm (1.5 ft. by 1.5 ft.) area, or 0.75%, of carpet and carpet padding was damaged in the fire.

Table 17: Mass of Combustibles Consumed in Sprinklered Test

Item	Initial Weight kg (lb.)	Final Weight kg (lb.)	Mass Consumed kg (lb.)
Big Easy Recliner	44.5 (98.1)	40.8 (90)	3.7 (8.1)
Kick Back Loveseat	56.9 (125.5)	49.9 (110)	7.0 (15.4)
Carpet + Carpet Padding	94.0 (207)	93.3 (205.7)	0.7 (1.3)
Magazine Rack	1.7 (3.75)	0.34 (0.75)	1.4 (3.0)
Total	**197.1 (434.5)**	**184.3 (406.4)**	**12.8 (28.5)**

Based on the values listed in Table 17, and the initial weight of all the combustibles in the room, the fraction of material burned in the sprinklered test was 3.0%.

In the non-sprinklered test, following the fire extinguishment, none of the items within the room were recognizable and the final mass of individual items could not be determined directly. The mass of materials consumed is, therefore, estimated based on the total energy released and an assumption for the chemical heat of combustion. In Section 3.3, the total energy released from the fire was calculated to be 5,169 MJ. Using the chemical heat of combustion for pine, i.e., 12,400 kJ/kg, as the lower bound and that of flexible polyurethane foam, i.e., 19,000 kJ/kg, as the upper bound, it is calculated that the mass of material consumed in the fire was between 272 kg (600 lb.) and 417 kg (919 lb.), or 62% to 95% of the total room fuel load. For the fire scenario used in this study, in an actual home, the fire would likely have propagated to adjacent rooms increasing the mass of materials damaged.

The increased fire damage, in the non-sprinklered test, will have a direct impact on a building's sustainability via the embodied carbon associated with materials necessary for reconstruction. As stated previously, Norman *et al.* [24] estimated that the average equivalent annual embodied greenhouse gases per unit area for construction materials associated with residential dwellings is $7.4\ kg_{CO_2}/\left(m^2 - year\right)$. Estimates of the embodied carbon associated with furnishings, contents, and carpet are beyond the scope of this study.

4.4 POTENTIAL ENVIRONMENTAL IMPACTS OF WASTEWATER RUNOFF

The following results and discussion related to the wastewater analysis have been extracted directly from Reference 38. The section and table numbering of the original report have been maintained.

4.3 POTENTIAL ENVIRONMENTAL IMPACTS OF FIRE WATER RUNOFF

Fire water runoff carries with it numerous contaminants and solids that may enter soil, groundwater, or a waterbody and potentially pose a health risk or cause ecological harm. There are numerous examples of large industrial fires where fire fighting water runoff resulted in both short- and long-term devastating environmental impacts, such as fish kills [41]. However, even relatively small-scale fires have the potential to affect the local environment as a result of wastewater runoff‡‡*.*

During and after fire-fighting activities, there are several major pathways that the resultant fire wastewater can take to enter the environment:

- *Runoff can enter soil, where contaminants in the runoff may adsorb onto soil particles;*
- *Contaminants bound to soil may eventually leach into groundwater;*
- *Runoff may directly discharge into a nearby pond, wetland, or stream; and*
- *Runoff can enter a stormwater system and eventually discharge into a waterbody.*

Both human and ecological receptors may then contact contaminants adsorbed to soils, may ingest or contact contaminated groundwater or surface water, or may ingest contaminants that have accumulated in food items such as home-grown produce or fish. Pollutant loading to the environment will be directly influenced by the volume of water generated from fire fighting activities and associated wastewater runoff. By reducing the volume of fire wastewater, the potential hazard to the environment may be reduced.

To evaluate the difference in pollutant loading and associated environmental hazards between the Sprinkler and No Sprinkler controlled burns, wastewater results generated from the controlled burns conducted on October 1, 2009 were compared to two types of federal water quality standards: Maximum Contaminant Levels (MCLs) and National Recommended Water Quality Criteria (WQC). Although MCLs and WQC are not directly applicable to wastewater, these criteria can be used as tools to assess potential environmental impacts that may be associated with fire wastewater runoff.

MCLs (USEPA 2006) are criteria applicable to ground and surface waters and are relevant to all potable water supplies (both surface and ground) in the United States. MCLs are not available for each constituent detected in the wastewater samples; in such instances, wastewater

‡‡ Air and particulate emissions from fires are also significant pathways with respect to potential environment impacts; however, this section evaluates only the wastewater pathway. Air emissions from the controlled burn scenarios are discussed in Section 3 of this report.

data lacking MCLs were compared to USEPA Secondary Drinking Water Standards, Action Levels or Health Advisories, when available. These drinking water standards are generally designed to be protective of human health. Note that drinking water standards are not available for several of the detected organic constituents or general chemistry parameters. Drinking water standards are presented on Table 4-4.

WQC (USEPA 2009) are numeric limits on the amounts of chemicals that can be present in a river, lake, wetland, or stream and are designed to be protective of both human health and aquatic life. Altogether, there are six separate sets of WQC. Those protective of human health are applicable to waters that can be used as not only a source of potable water but also for fish or shellfish consumption. There are separate human health criteria for potable and non-potable waters. The "water + organism" WQC (for potable water supplies) are equivalent to or lower (i.e., more conservative) than the "organism only" WQC (for non-potable waters). Aquatic life WQC are available for fresh water and saltwater environments, as well as short- and long-term exposures. Of the aquatic life WQC, the Criterion Maximum Concentration (CMC) represents acute exposures in water, whereas the Criterion Continuous Concentration (CCC) represents chronic exposures. For a single fire event, CMCs are most relevant, since the discharge of fire wastewater to a waterway is expected to be a one-time event that occurs for a relatively short duration. Note that WQC are not available for the detected organic constituents and several of the general chemistry parameters. Water quality criteria are presented on Table 4-5.

For purposes of this evaluation, the net concentrations of constituents detected in the controlled burns conducted on October 1, 2009 were compared to these standards. As discussed, these standards are not applicable to wastewater, and this comparison is intended to be used only as a means to assess the relative impact to water quality of both types of controlled burns. The net concentrations in the wastewater represent a worst-case estimate of ground or surface water contamination. Under a more typical scenario, one would expect that only a portion of the total fire wastewater volume would percolate through the ground into an underlying aquifer or migrate overland and discharge into a waterbody. In all likelihood, the concentrations of pollutants in wastewater could be substantially reduced by the time the wastewater enters the receiving waterbody, or the volume of wastewater may never reach a waterbody.

Because there are a variety of environmental factors (such as soil type, volume of the receiving waterbody, depth to groundwater etc.) that could affect the extent of dilution of wastewater into either surface water or a groundwater aquifer, Woodard & Curran applied a generic ten-fold dilution factor to the net wastewater concentrations of constituents in order to estimate hypothetical surface or groundwater concentrations. This generic dilution factor represents the assumption that a ten-fold dilution of the levels of contaminants in wastewater would occur once the wastewater enters a receiving waterbody and is likely conservative for most situations where wastewater would percolate directly into the ground or discharge into a waterbody containing a relatively high volume of water. (Note that many states [e.g., Massachusetts, Connecticut] also use a generic 10-fold dilution factor to derive groundwater contaminant standards that are protective of groundwater migration to surface water bodies.) For smaller streams or wetlands, however, the ten-fold dilution factor may not necessarily be conservative. Estimated surface/groundwater concentrations were compared to drinking water standards and WQC, as shown on Tables 4-4 and 4-5, respectively.

Table 4-4: Comparison of Wastewater Results to USEPA Drinking Water Standards and Guidelines

Parameter	Units	Drinking Water Standard or Guideline		Analytical Results, 10/1/09			
				Sprinkler		No Sprinkler	
				WW-1	Diluted Concentration[1]	WW-2	Diluted Concentration[1]
		Value	Basis	Result	Estimated	Result	Estimated
General Chemistry							
pH	SU	6.5-8.5	SDWR	7.9	7.9	***12.1***	***12.1***
Specific Conductance	umhos/cm			100	10	5,100	510
Solids, Total Dissolved	ug/l	500,000	SDWR	100,000	10,000	***4,300,000***	430,000
Solids, Total Suspended	ug/l			36,000	3,600	640,000	64,000
Cyanide, Total	ug/l	200	MCL (free CN-)	***639***	63.9	55	5.5
Nitrogen, Ammonia	ug/l	30,000	Lifetime HA	1,470	147	4,850	485
Nitrogen, Nitrate	ug/l	10,000	MCL	130	13	440	44
Phosphorus, Total	ug/l			484	48.4	385	38.5
Chemical Oxygen Demand	ug/l			260,000	26,000	650,000	65,000
Total Organic Carbon	ug/l			56,000	5,600	136,000	13,600
Volatile Organic Compounds							
Benzene	ug/l	5	MCL	***62***	***6.2***	***50*** U	
Styrene	ug/l	100	MCL	50 U		63	6.3
Semivolatile Organic Compounds							
Phenol	ug/l	2,000	MCL	280 U		370	37
2-Methylphenol	ug/l			240 U		180	18
3-Methylphenol/ 4-Methylphenol	ug/l			240 U		290	29
Total Metals							
Antimony, Total	ug/l	6	MCL	***50*** U		***272***	***27.2***
Arsenic, Total	ug/l	10	MCL	5 U		7	0.7
Chromium, Total	ug/l	100	MCL	10 U		10	1
Copper, Total	ug/l	1,300	MCLG	21	2.1	6	0.6
Lead, Total	ug/l	15	Action Level	2	0.2	***18***	1.8
Mercury, Total	ug/l	2	MCL	***2.5***	0.25	0.8	0.08
Silver, Total	ug/l	100	SDWR	0.8 U		1.8	0.18
Zinc, Total	ug/l	5,000 / 2,000	SDWR/ Lifetime HA	172	17.2	185	18.5
Dissolved Metals							
Antimony, Dissolved	ug/l	6		***50*** U		***150***	***15***
Copper, Dissolved	ug/l	1,300	Action Level	30	3	10 U	
Mercury, Dissolved	ug/l	2		1.1	0.11	0.6	0.06
Zinc, Dissolved	ug/l	5,000	SDWR	54	5.4	50 U	

Notes:

U	= Constituent not detected at laboratory reporting limit	MCL	= Maximum Contaminant Level
ug/L	= micrograms per liter	MCLG	= Maximum Contaminant Level Goal
SU	= standard units	SDWR	= Safe Drinking Water Regulation
umhos/cm	= micromhos per centimeter	HA	= Health Advisory
Free CN-	The MCL is available for free cyanide. Results are available for total cyanide.	THM	= Total trihalomethanes (chloroform, bromoform, bromodichloromethane)

(1) Estimated surface or groundwater concentration based on wastewater analytical results, adjusted to account for baseline contamination from firefighting water. Estimated concentration assumes wastewater is diluted to one-tenth of the original concentration. pH level of sample was not adjusted.

Bold italicized font indicates that concentration or detection limit exceeds the drinking water standard or guideline.

(2) Results are presented for only the constituents detected at levels higher than those of the recycled firefighting water sample.

Table 4-5: Comparison of Wastewater Results to Federal Water Quality Criteria

Parameter	Units	National Recommended Water Quality Criteria – Aquatic Life Criteria – Freshwater CMC	Freshwater CCC	Saltwater CMC	Saltwater CCC	Human Health Criteria – Water + Organism	Organism Only	Analytical Results, 10/1/09 – Sprinkler – WW-1 Concentration Result	Sprinkler – Diluted Concentration[5] Estimated	No Sprinkler – WW-2 Concentration Result	No Sprinkler – Diluted Concentration[5] Estimated
General Chemistry											
pH	SU		6.5-9		6.5-8.5	5-9		7.9	7.9	***12.1***	***12.1***
Specific Conductance	umhos/cm							100	10	5,100	510
Solids, Total Dissolved	ug/l					250,000		***100,000***	10,000	***4,300,000***	***430,000***
Solids, Total Suspended	ug/l							36,000	3,600	640,000	64,000
Cyanide, Total [1]	ug/l	22	5.2	1	1	140	140	***639***	***63.9***	***55***	***5.5***
Nitrogen, Ammonia	ug/l		100[(4)]					***1,470***	***147***	***4,850***	**485**
Nitrogen, Nitrate	ug/l		100[(4)]			10,000		***130***	13	***440***	44
Phosphorus, Total	ug/l		8[(4)]					***484***	**48.4**	***385***	***38.5***
Chemical Oxygen Demand	ug/l							260,000	26,000	650,000	65,000
Total Organic Carbon	ug/l							56,000	5,600	136,000	13,600
Volatile Organic Compounds											
Benzene	ug/l					2.2	51	***62***	***6.2***	***50*** U	
Styrene	ug/l							50 U		63	6.3
Semivolatile Organic Compounds											
Phenol	ug/l					10,000	860,000	280 U		370	37
2-Methylphenol	ug/l							240 U		180	18
3-Methylphenol/ 4-Methylphenol	ug/l							240 U		290	29
Total Metals[2]											
Antimony, Total	ug/l					5.6	640	***50*** U		***272***	***27.2***
Arsenic, Total	ug/l	340	150	69	36	0.018	0.14	***5*** U		***7***	***0.7***
Chromium, Total[3]	ug/l	16	11	1,100	50			10 U		10	1
Copper, Total	ug/l	13	9	4.8	3.1	1,300		***21***	2.1	***6***	0.6
Lead, Total	ug/l	65	2.5	210	8.1			2	0.2	***18***	1.8
Mercury, Total	ug/l	1.4	0.77	1.8	0.94			***2.5***	0.25	***0.8***	0.08
Silver, Total	ug/l	3.2		1.9				0.8 U		1.8	0.18
Zinc, Total	ug/l	120	120	90	81	7,400	26,000	***172***	17.2	***185***	18.5
Dissolved Metals											
Antimony, Dissolved	ug/l					5.6	640	***50*** U		***150***	***15***
Copper, Dissolved	ug/l	13	9	4.8	3.1	1,300		***30***	3	***10*** U	
Mercury, Dissolved	ug/l	1.4	0.77	1.8	0.94			***1.1***	0.11	0.6	0.06
Zinc, Dissolved	ug/l	120	120	90	81	7,400	26,000	54	5.4	50 U	

Notes:

U	= Constituent not detected at laboratory reporting limit
ug/L	= micrograms per liter
SU	= standard units
umhos/cm	= micromhos per centimeter
CMC	= No CCC available. Value is the Criterion Maximum Concentration
Free CN-	= Cyanide (CN-) criteria are available for free, or bioavailable, cyanide. Wastewater results are reported for total cyanide. Total cyanide concentrations are not necessarily indicative of free cyanide concentrations.

(1) Value is for free (physiologically available) cyanide. Note that wastewater samples were analyzed for total cyanide.
(2) Aquatic life criteria are expressed in terms of dissolved metals. Many of the metals criteria are also dependent on water hardness and/or other chemical properties of the waterbody.
The values presented on this table are those reported in the EPA 2009 criteria document and have not been adjusted.
(3) Criteria are presented for hexavalent chromium, the more toxic form of chromium. Note that wastewater samples were analyzed for total chromium.
(4) EPA Ecoregional criteria. Values are the lowest ecoregional criteria for rivers, streams, lakes and reservoirs. Nitrate value is for total nitrogen.
(5) Estimated surface or groundwater concentration based on wastewater analytical results, adjusted to account for baseline contamination from firefighting water.
Estimated concentration assumes wastewater is diluted to one-tenth of the original concentration. pH level of sample was not adjusted.
Bold italicized font indicates that concentration or detection limit exceeds the drinking water standard or guideline.
(6) Results are presented for only the constituents detected at levels higher than those of the recycled firefighting water sample.

Comparison to Drinking Water Standards

For this evaluation, wastewater net concentrations based on the October 1, 2009 results were compared to Federal drinking water standards and guidelines (i.e., MCLs and Health Advisories; USEPA 2006), assuming that ground- or surface water at a site could be used as a potential source of potable water. Drinking water standards and guidelines are presented in Table 4-4.

Under a worst-case scenario, where all of the wastewater from a fire runs off or percolates into a potable water source and assuming that there is no decrease in the concentration of contaminants (i.e., the drinking water source would contain 100% of the initial concentration of a contaminant present in the wastewater), the resultant concentrations of numerous contaminants could exceed drinking water standards for both Sprinkler and No Sprinkler *controlled burns, suggesting that wastewater could potentially pose a health risk to users of an impacted water supply. Under a more realistic scenario, assuming that a 10-fold dilution of contaminant concentrations in wastewater would occur once wastewater enters a drinking water supply, fewer constituents exceed the MCLs. The following table summarizes the parameters and constituents that exceed MCLs for each controlled burn.*

Table 4-6: Constituents in Wastewater Exceeding Federal Drinking Water Standards

Sprinkler Controlled Burn	No Sprinkler Controlled Burn
Benzene	pH Antimony

This comparison indicates that different classes of pollutants in wastewater generated from a fire in a structure may potentially be present at levels exceeding Federal drinking water standards.

Comparison to Water Quality Criteria

Detected concentrations and diluted concentrations of constituents in each wastewater sample were compared to WQC, as shown on Table 4-5. Exceedances are summarized in the following table for each controlled burn.

Table 4-7: Constituents in Wastewater Exceeding Federal Water Quality Criteria

Sprinkler Controlled Burn	No Sprinkler Controlled Burn
Total cyanide Nitrogen (ammonia) Phosphorous Benzene	pH Total dissolved solids Total cyanide Nitrogen (ammonia) Phosphorous Antimony Arsenic

As indicated above, more constituents detected in the No Sprinkler controlled burn sample (in particular, heavy metals) exceed WQC compared to the Sprinkler controlled burn sample. Again, assuming that a 10-fold dilution of pollutant concentrations would occur once the wastewater entered a waterbody, several constituents remain at levels exceeding WQC in the No Sprinkler controlled burn, whereas fewer constituents under the Sprinkler controlled burn exceed WQC.

4.5 LANDFILL IMPACTS

In this section the environmental impact associated with disposing solid waste materials in a landfill is discussed[§§] in terms of total lifetime carbon dioxide emissions.

[§§] Evaluating the impact associated with alternative disposal such as recycling or energy recovery is beyond the scope of this project.

In the sprinklered test, only a small portion of the room furnishings was damaged. However, any fire damaged items would need to be replaced. The total mass of materials needing to be disposed of is 184.3 kg (406 lb.); the final mass of each of the items is listed in Table 17. Additional materials damaged due to smoke and water may need to be disposed of and replaced; however, assessment of this part of the damage would be very subjective and beyond the scope of this analysis.

In the non-sprinklered test, the mass of materials within the enclosure requiring disposal is assumed to be the remaining 5.3% to 38.2% of material, or 23.2 kg to 168 kg (51.1 lb. to 370.4 lb.), as discussed in Section 4.3. Although not included in this study, the extensive damage to the entire enclosure would require complete demolition increasing the landfill contribution.

Decomposition rates of furniture and furnishings in landfills, and the associated greenhouse gas emissions, are not readily available; however, estimates can be made based on data for wood and forest products. Micales and Skog [42] state that only "0-3% of the carbon from wood are ever emitted as landfill gas. The remaining carbon . . . remains in the landfill indefinitely." The methane yield for wood in a landfill is reported as 0.000 – 0.013 $kg_{CH_4}/kg_{dry\ wood}$. To determine the equivalent mass of CO_2 the value is multiplied by the GWP of methane. The resulting equivalent carbon dioxide generated by furniture and furnishings in landfills is 0.000 - 0.325 $kg_{CO_2}/kg_{dry\ wood}$.

The EPA reports that "as with other inorganic materials…there are zero landfill methane emissions, landfill carbon storage, or avoided utility emissions associated with landfilling carpet" [43]. In other words, carpet in landfills does not contribute to greenhouse gas emissions and can be omitted from this analysis.

The amounts of materials disposed of in a landfill from the sprinklered and non-sprinklered test, based on the analysis in Section 4.3, are listed in Table 18. For the sprinklered test the mass of materials is divided into carpet and furniture. Since the carpet does not contribute to the landfill emissions, the total equivalent carbon dioxide emission of 33.5 kg (74 lb.) is based solely on the quantity of wood products. For the non-sprinklered test, due to the excessive damage, the mass of materials could not be separated. As such, the total equivalent carbon dioxide emission of 7.5 - 54.6 kg (16.5 - 120.4 lb.) is based on the total mass of disposed materials.

Table 18: Mass and Carbon Dioxide Emissions from Damaged Materials in a Landfill

	Mass of Materials [kg (lb.)]		**Carbon Dioxide Emissions [kg (lb.)]**	
	Carpet	**Wood Products**	**Carpet**	**Wood Products**
Sprinklered	94.0 (207)	103.1 (227.3)	0	33.5 (74)
Non-Sprinklered	---	23.2 – 168 (51.1 - 370.4)	---	7.5 – 54.6 (16.5 – 120.4)

The values presented represent a conservative estimate of the impact of a non-sprinklered fire on landfill greenhouse gas emissions. As noted previously, there was extensive damage to the entire enclosure in the non-sprinklered test that would require complete demolition and add to the mass of material sent to a landfill. Furthermore, if additional rooms had been present, the fire would have propagated and additional materials would have required disposal in a landfill.

4.6 ROOM TENABILITY

Although not the main focus of this project, a brief analysis on the tenability within the sprinklered and non-sprinklered rooms will be provided in this section.

Fires generate a variety of toxic gases that have a synergistic physiological effect on humans; however, carbon monoxide inhalation is considered the key factor in fire fatalities. The physiological effects from carbon monoxide exposure range from headaches to death depending on the level of carbon monoxide exposure and the duration; some examples are provided in Table 19 [44]. In addition to the maximum concentrations, Reference 45 states that a time integrated exposure of 43,000 ppm-minutes will result in incapacitation, while 120,000 ppm-minutes is lethal.

Table 19: Physiological Effects of Carbon Monoxide Exposure and the Times Critical Levels Were Reached in the Sprinklered and Non-Sprinklered Tests

Level of CO (ppm)	Physiological Effects	Non-Sprinklered (s)	Sprinklered (s)
0	Normal, fresh air	0	0
100	Slight headache after 1-2 hours	157	179
200	Possible mild headache after 2-3 hours	167	334
400	Headache and nausea after 1-2 hours	238	NA
800	Headache, nausea, and dizziness after 45 minutes; collapse and possible unconsciousness after 2 hours	246	NA
1,000	Loss of consciousness after 1 hour	247	NA
1,600	Headache, nausea, and dizziness after 20 minutes	249	NA
3,200	Headache and dizziness after 5-10 minutes; unconsciousness after 30 minutes	254	NA
6,400	Headache and dizziness after 1-2 minutes; unconsciousness and danger of death after 10-15 minutes	261	NA
12,800	Immediate physiological effects; unconsciousness and danger of death after 1-3 minutes	272	NA

Elevated temperatures can also impact survivability. Purser states that “a victim exposed for more than a few minutes to high temperatures and heat fluxes (exceeding 120°C) in a fire is likely to suffer burns and die either during or immediately after exposure, due principally to hyperthermia” [46].

For the sake of this analysis, tenability within the rooms will be assessed based on the following three criteria measured at the 1.5 m (5 ft.) elevation within the center of the room:

- Maximum carbon monoxide level
- Time integrated carbon monoxide exposure
- Air temperature

The measured carbon monoxide levels at a 1.5 m (5 ft.) elevation in the center of the room are shown in Figure 32 and Figure 33, for the sprinklered and non-sprinklered rooms respectively.

In addition to the time resolved carbon monoxide concentrations, the integrated carbon monoxide is also plotted for each test.

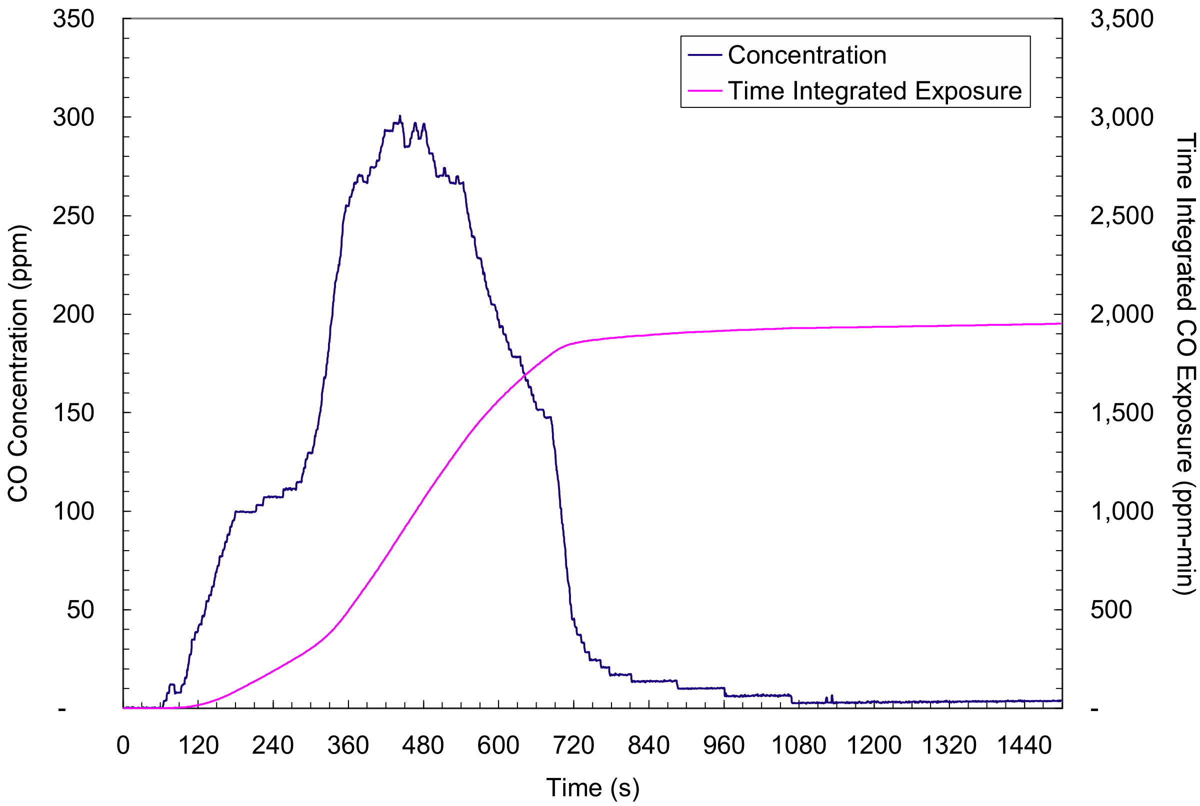


Figure 32: Carbon monoxide concentrations and integrated values as a function of time for the sprinklered test.

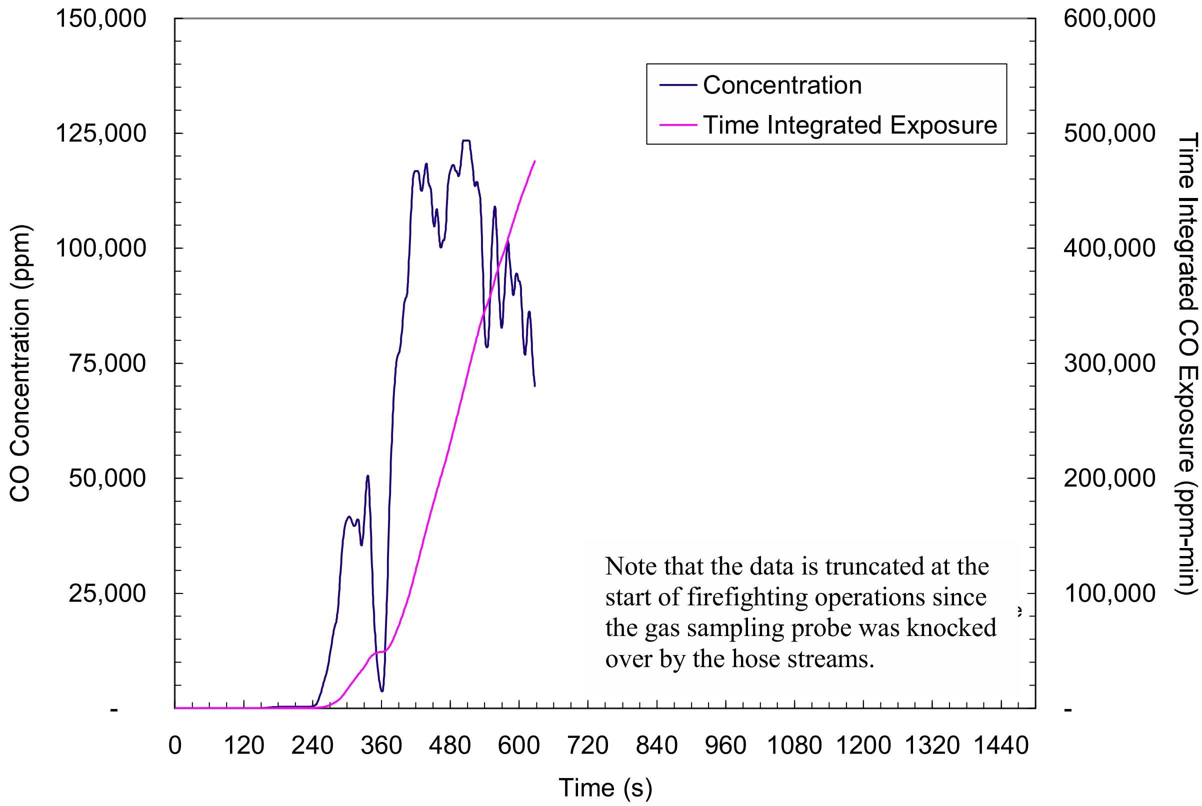


Figure 33: Carbon monoxide concentrations and integrated values as a function of time for the non-sprinklered test.

In the non-sprinklered test the maximum carbon monoxide concentration was in excess of 12% (120,000), an order of magnitude greater than that associated with immediate physiological effects and death. Conversely, in the sprinklered test the maximum carbon monoxide level was 300 ppm, which, based on the data in Table 19, would result in a headache and possibly nausea after one to three hours of exposure.

The integrated carbon monoxide levels in the sprinklered test did not reach either the incapacitation or lethal levels. The maximum value was 1,952 ppm-minutes, more than 20 times lower than the value associated with incapacitation. In the non-sprinklered test, the incapacitation level of 43,000 ppm-minutes was reached 339 seconds after ignition, while the lethal level of 120,000 ppm-minutes was reached 420 seconds after ignition.

The measured air temperatures at the 1.5 m (5 ft.) elevation in the center of the room as a function of time for the sprinklered and non-sprinklered tests are shown in Figure 34.

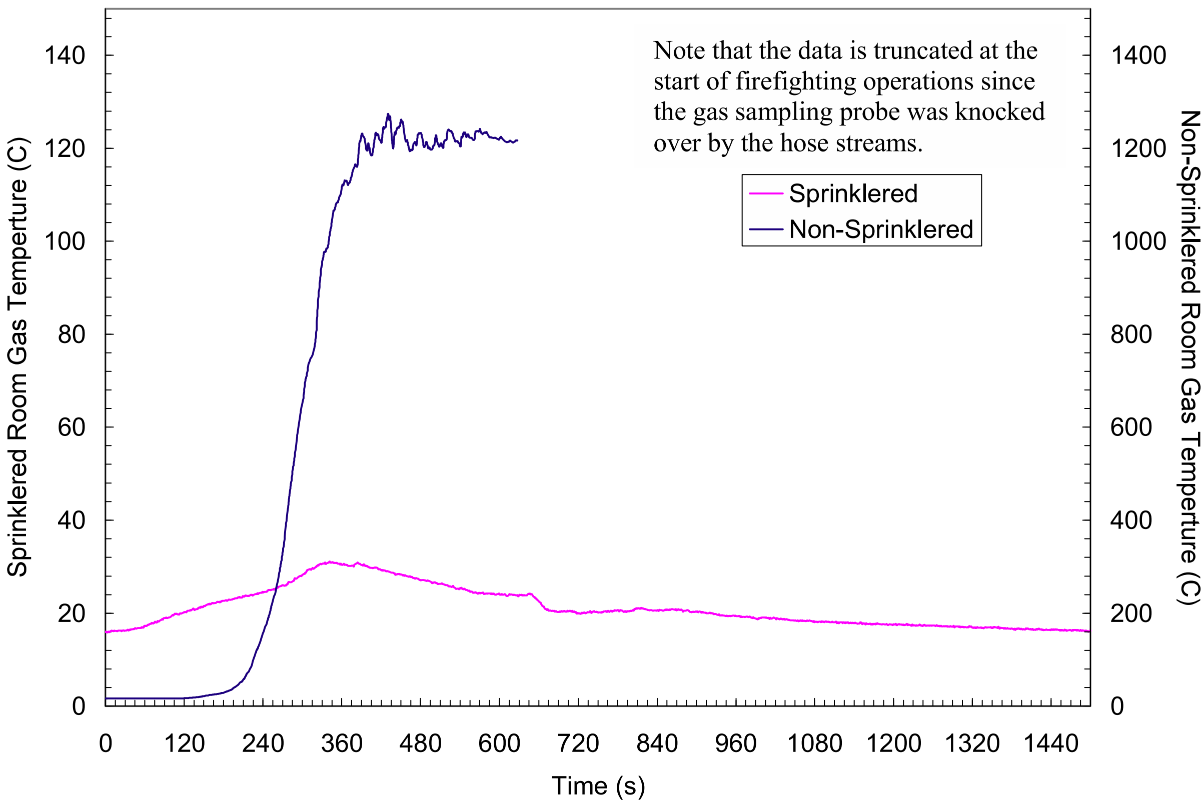


Figure 34: Air temperature as a function of time for the sprinklered and non-sprinklered test at 1.5 m (5 ft.) elevation within the center of the room.

In the non-sprinklered test the critical air temperature of 120°C (248°F) was reached at 230 seconds after ignition and reached a maximum level of 1274°C (2325°F). In the sprinklered test the maximum air temperature at the 1.5 m (5 ft.) elevation was 31°C (88°F).

The results clearly indicate that, in addition to the environmental benefits of using sprinklers, the use of sprinklers also results in maintaining safe, tenable conditions within the room.

5 CONCLUSIONS

The research presented in this report has demonstrated that automatic fire sprinklers protect the environment while further verifying that they reduce property damage and protect lives. The work included an analysis of the contribution of risk factors, such as fire, on the total lifecycle carbon emissions of a home and the reduction to that contribution achieved via the use of automatic fire sprinklers.

In support of the theoretical analysis, large-scale fire tests were conducted to quantify the reduction in the environmental impact via the use of sprinklers. Quantification of the environmental benefit achieved by using automatic fire sprinklers was based on comparisons of measurements between a sprinklered and non-sprinklered test and included total greenhouse gas production, quantity of water required to extinguish the fire, quality of water run-off, potential impact of wastewater runoff on groundwater and surface water, and mass of materials requiring disposal. Key conclusions from the experimental portion of the project are:

- In the event of a fire, the use of sprinklers reduces greenhouse gas emissions by 97.8%.
- In the event of a fire, the use of sprinklers reduces water usage between 50% and 91%.
- In the event of a fire, the use of sprinklers reduces fire damage.
- In the sprinklered test, flashover did not occur and the fire was contained to the room of origin.
- In the non-sprinklered test, flashover occurred prior to fire service intervention; therefore, additional materials would have been damaged, a greater mass of greenhouse gases would have been emitted, and additional materials would have been disposed of in a landfill.
- The total air emissions generated during the sprinklered test were significantly lower than the total air emissions generated during the non-sprinklered test.
- Of the 123 species of greenhouse gas and criteria pollutants, volatile and semi-volatile organic and inorganic compounds, heavy metals, and particulate matter analyzed, only 76 were detected in the air emissions in either the sprinklered or non-sprinklered tests.

- Of the 76 species detected, the ratio of non-sprinklered to sprinklered levels for 24 of the species was in excess of 10:1. Eleven were detected at a ratio in excess of 50:1, and of those six were detected at a ratio in excess of 100:1. The remaining species were detected at the same order of magnitude.
- Fewer persistent pollutants, such as heavy metals, and fewer solids were detected in the wastewater sample from the sprinklered test compared to those found in the non-sprinklered test.
- More constituents were detected in the non-sprinklered test that exceeded both federal drinking water standards and water quality standards than in the sprinklered test.
- The pH value of the non-sprinklered wastewater was between 11.6 and 12.1 versus the pH of 7.9 for the sprinklered test. Wastewater exhibiting pH values greater than 9.0 exceed the allowable discharge range of 5.5 to 9.0 required by environmental regulatory agencies. Wastewater exhibiting pH values greater than 10.0 represent a serious environmental concern.
- Wastewater generated from a fire in a structure not equipped with a sprinkler system may potentially have a greater impact on a water supply, due to the higher pollutant load that is carried with the wastewater stream.
- Analysis of the solid waste samples indicated that the ash/charred materials from neither the sprinklered nor the non-sprinklered test would be considered "hazardous waste," and that the wastes are not anticipated to significantly leach once landfilled.

6 REFERENCES

1 Kung, H.-C., Spaulding, R. D., Hill, E. E., and Symonds, A. P., “Field Evaluation of Residential Prototype Sprinkler – Los Angeles Fire Test Program,” Technical Report J.I. 0E0R3.RA(1), Factory Mutual Research Corporation, Norwood, MA, 1982.

2 Bill, Jr., R. G., Kung, H.-C., Anderson, S. K., and Ferron, R., “A New Test to Evaluate the Fire Performance of Residential Sprinklers,” *Fire Technology*, 38, 101-124, 2002.

3 Bill, Jr., R. G., Kung, H.-C., Brown, W. R., Hill, Jr., E. E., and Spaulding, R. D., “Predicting the Suppression Capability of Quick Response Sprinklers in a Light Hazard Scenario, Part 1: Fire Growth and Required Delivered Density Measurements,” *Journal of Fire Protection Engineering*, 3, 81-93, 1991.

4 NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes*, 1984 Edition, National Fire Protection Association, Quincy, MA.

5 FM Approvals Standard Class Number 2030, *Approval Standard for Residential Automatic Sprinklers for Fire Protection*, 1983 Edition, FM Approvals, Norwood, MA.

6 UL 1626, *Proposed First Edition of the Standard for Residential Sprinklers for Fire Protection Service*, 1986 Edition, Underwriters Laboratories, Northbrook, IL.

7 UL 1626, *Standard for Residential Sprinklers for Fire Protection Service*, 2008 Edition, Underwriters Laboratories, Northbrook, IL.

8 FM Approvals Standard Class Number 2030, *Approval Standard for Residential Automatic Sprinklers for Fire Protection*, 2009 Edition, FM Approvals, Norwood, MA.

9 NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes*, 2010 Edition, National Fire Protection Association, Quincy, MA.

10 FM Global Property Loss Prevention Data Sheet 2-5, *Installation Guidelines for Automatic Sprinklers in Residential Occupancies*, 2009 Edition, FM Global, Johnston, RI.

11 Madrzykowski, D., and Fleming, R. P., "Residential Sprinkler Systems," *Fire Protection Handbook*, 20th Edition, Vol. II, Section 16, Chapter 6, National Fire Protection Association, Quincy, MA, 2008.

12 U.S. Census Bureau, Current Housing Reports, Series H150/07, *American Housing Survey for the United States: 2007,* U.S. Government Printing Office, Washington, DC, 20401 (2008). http://www.census.gov/hhes/www/housing/ahs/ahs07/ahs07.html

13 Hall, Jr., J. R., "U.S. Experience with Sprinklers and Other Automatic Fire Extinguishment Equipment," NFPA Fire Analysis and Research Division, National Fire Protection Association, Quincy, MA, 2009.

14 Weatherby, S.,"Benefits of Residential Fire Sprinklers: Prince George's County 15-Year History with its Single-Family Residential Dwelling Fire Sprinkler Ordinance," Home Fire Sprinkler Coalition, August 2009.
http://www.firesprinklerinitiative.org/assets/files//PrinceGeorgesCountyReport.pdf

15 NFPA 1, *Fire Code*, 2006 Edition, National Fire Protection Association, Quincy, MA.

16 NFPA 101, *Life Safety Code*, 2006 Edition, National Fire Protection Association, Quincy, MA.

17 NFPA 5000, *Building Construction and Safety Code*, 2006 Edition, National Fire Protection Association, Quincy, MA.

18 Cade, G. B., "A Message from the U.S. Fire Administrator about Residential Sprinklers," United States Fire Administration, U.S. Dept. of Homeland Security, Emmetsburg, MD, March 28, 2008.

19 http://www.residentialfiresprinklers.com/blog/icc-approves-residential-fire-sprinklers-in-the-international-residential-code

20 Gritzo, L. A., Doerr, W., Bill, R., Ali, H., Nong, S., and Krasner, L., "The Influence of Risk Factors on Sustainable Development," FM Global, Johnston, RI, 2009. http://www.fmglobal.com/page.aspx?id=0401030,

21 U.S. Green Building Council, *Leadership in Energy and Environmental Design Brochure*, Washington, DC. http://www.usgbc.org

22 *U.S. EPA Climate Leaders Greenhouse Gas Inventory Protocol*, May 2005. http://www.epa.gov/statply/resourses/design.htlm

23 Brown, M., "The Residential Energy and Carbon Footprint of the 100 Larger U.S. Metropolitan Areas," Working Paper #39, Ivan Allen College, Georgia Tech, May 2008. http://smartech.gatech.edu/handle/1853/22228.

24 Norman, J., MacLean, H. L., and Kennedy, C. A., "Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions," *Journal of Urban Planning and Development*, Vol. 132, No. 1, March 2006.

25 U.S. Census Bureau, Current Housing Reports, Series H-150-99, *American Housing Survey National Tables: 1999,* U.S. Government Printing Office, Washington, DC.

http://www.census.gov/hhes/www/housing/ahs/ahs99/ahs99.html

26 U.S. Census Bureau, Current Housing Reports, Series H150/01, *American Housing Survey for the United States: 2001,* U.S. Government Printing Office, Washington, DC, 2002. http://www.census.gov/hhes/www/housing/ahs/ahs01_2000wts/ahs01_2000wts.html

27 U.S. Census Bureau, Current Housing Reports, Series H150/03, *American Housing Survey for the United States: 2003,* U.S. Government Printing Office, Washington, DC, 2004. http://www.census.gov/hhes/www/housing/ahs/ahs03/ahs03.html

28 U.S. Census Bureau, Current Housing Reports, Series H150/05, *American Housing Survey for the United States: 2005,* U.S. Government Printing Office, Washington, DC, 2006. http://www.census.gov/hhes/www/housing/ahs/ahs05/ahs05.html

29 "The U.S. Fire Problem," Fire Statistics, NFPA Fire Analysis and Research, National Fire Protection Association, Quincy, MA, 2009. http://www.nfpa.org/itemDetail.asp?categoryID=953&itemID=23858&URL=Research/Fire%20statistics/The%20U.S.%20fire%20problem

30 Davoodi, A., "Confinement of Fire," *Fire Protection Handbook*, 20th Edition, Vol. II, Section 18, Chapter 1, National Fire Protection Association, Quincy, MA, 2008.

31 Tewarson, A., "Generation of Heat and Chemical Compounds in Fires," *The SFPE Handbook of Fire Protection Engineering*, 3rd Edition, Section 3, Chapter 4, National Fire Protection Association, 2002, pg. 3-82 – 3-161.

32 http://chronicle.augusta.com/stories/2009/03/30/yrb_516386.shtml (accessed March 3, 2010)

33 NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*, 2010 Edition, National Fire Protection Association, Quincy, MA.

34 NFPA 1720, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments*," 2010 Edition, National Fire Protection Association, Quincy, MA.

35 Brady/Prentice Hall Health. Essentials of Fire Fighting and Fire Department Operations. 5th edition. Oklahoma State University: Fire Protection Publications, 2008.

36 ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories, 2005 Edition, International Standards Organization, Geneva, Switzerland.

37 Powell, J. H., "Test Burn Emissions Testing," Air Pollution Characterization and Control, LTD., Technical Report, December 2009.

38 "Air and Water Quality Impacts of Residential Fires from Controlled Burns," Woodard and Curran Technical Report prepared for FM Global, 222415, March 2010.

39 ISO/CD 13943, *Glossary of Fire Terms and Definitions*, 1996 Edition, International Standards Organization, Geneva, Switzerland.

40 Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, United Kingdom and New York, NY, USA, 2001.

41 Institute of Environmental Science and Research Limited (ESR), "The Ecotoxicity of Fire-Water Runoff. Part 1: Review of the Literature," New Zealand Fire Service Commission Research Report, No. 17, 2000.

42 Micales, J. A., and Skog, K. E., "The Decomposition of Forest Products in Landfills," *International Biodeterioration & Biodegradation*, Vol. 39, No. 2-3, 1997, pg. 145-158.

43 Environmental Protection Agency, "Background Document for Life-Cycle Greenhouse Gas Emission Factors for Carpet and Personal Computers," EPA530-R-03-018, November 21, 2003.

44 Black, A., "Carbon Monoxide Detection in Residential Occupancies," *Fire Protection Handbook*, 20th Edition, Vol. II, Section 14, Chapter 9, National Fire Protection Association, Quincy, MA, 2008.

45 Bill, R. G., and Kung, H.-C., "Evaluation of an Extended Coverage Sidewall Sprinkler and Smoke Detectors in a Hotel Occupancy," *Journal of Fire Protection Engineering*, Vol. 1, No. 3, 1989, pg. 77-98.

46 Purser, D. A., "Toxicity Assessment of Combustion Products," *The SFPE Handbook of Fire Protection Engineering*, 3rd Edition, Section 2, Chapter 6, National Fire Protection Association, 2002, pg. 2-83 – 2-171.

Questions regarding this report may be directed to FM Global at research@fmglobal.com.

P10062 Printed in USA (4/10)

In the United Kingdom:
FM Insurance Company Limited
1 Windsor Dials, Windsor, Berkshire, SL4 1RS
Regulated by the Financial Services Authority.

Proponents:
Rob Brooks, Rob Brooks and Associates, LLC, John Tokarczyk, Oregon Department of Forestry, Timm Locke, Oregon Forest Industries Council

Affiliation: Oregon Department of Forestry (www.oregon.gov/ODF),Oregon Forest Resources Institute (www.oregonforests.org)

Rob Brooks & Associates, LLC
Address: 1513 S Willow Lake Pl City: Eagle State: ID
Zip: 83616 Country: USA
Telephone: 208-880-4142 Fax: E-Mail: rob@rtbrooks.com

Oregon Department of Forestry
Address: 2600 State St City: Salem State: OR Zip: 97310 Country: USA
Telephone: 208-880-4142 Fax: E-Mail: John.A.Tokarczyk@oregon.gov

Oregon Forest Resources Institute
Address: 317 SW Sixth Ave., Suite 400 City: Portland State: OR
Zip: 97204 Country: USA
Telephone: 971-673-3191 Fax: E-Mail: locke@ofri.org

Current Language in 2015 NGBS:

606.2 Wood-based products. Wood or wood-based products are certified to the requirements of one of the following recognized product programs:
(a) American Forest Foundation's American Tree Farm System (ATFS)
(b) Canadian Standards Association's Sustainable Forest Management System Standards (CSA Z809)
(c) Forest Stewardship Council (FSC)
(d) Program for Endorsement of Forest Certification Systems (PEFC)
(e) Sustainable Forestry Initiative Program (SFI)
(f) National Wood Flooring Association's Responsible Procurement Program (RPP)
(g) other product programs mutually recognized by PEFC

Proposed Language for 2018 NGBS:

606.2 Wood-based products. Wood or wood-based products <u>shall be derived from a manufacturers' fiber procurement system that has been audited by an *approved agency* as compliant with the provisions of:</u>
<u>(a) ASTM D7612 as a responsible or certified source. Government or tribal forestlands whose water protection programs have been evaluated by an *approved agency* as compliant with the responsible source designation of ASTM D7612 are exempt from auditing in the manufacturers' fiber procurement system.</u>
~~are certified to the requirements of one of the following recognized product programs:~~
~~(a) American Forest Foundation's American Tree Farm System (ATFS)~~
~~(b) Canadian Standards Association's Sustainable Forest Management System Standards (CSA Z809)~~
~~(c) Forest Stewardship Council (FSC)~~
~~(d) Program for Endorsement of Forest Certification Systems (PEFC)~~
~~(e) Sustainable Forestry Initiative Program (SFI)~~
(b) ~~(f)~~ National Wood Flooring Association's Responsible Procurement Program (RPP)
~~(g) other product programs mutually recognized by PEFC~~

Similar changes are proposed to 12.1.(A).606.2

Reason and substantiation:

- This proposed change related to the acceptance of forest products is vital to the use of ICC-700 in states where forest product production is an important source of revenue, such as Oregon. Neighboring states, such as Washington, Idaho and California also rely upon forest product production and support the use of sustainable forestry and best management practices to maintain (among other objectives) water quality.

- The IgCC, USGBC Pilot Credit and the USDA BioPreferred Program currently recognize ASTM D7612 *responsible and certified sources*. The 2012 ICC-700 recognizes *responsible sources* through the SFI Fiber Sourcing program. Alternatively, SFI Chain of Custody is a *certified source*. (see attached table). All of the existing forest certification programs listing in ICC-700 are recognized by ASTM D7612.
- ASTM D7612 provides a means to specify sustainable forestry via the *certified sources* designation without the reference to proprietary standards such as SFI, FSC, ATFS, etc. The American National Standards Institute's (ANSI) Essential Requirements for Due Process, excludes specifying ecolabels—FSC, PEFC, SFI—that is, their brand name—because that would run afoul of ANSI's prohibition on the use of commercial terms. It says in part, "[t]he appearance that a standard endorses any particular products, services or companies must be avoided." Previously, there was no method to generically specify these ecolabels, but with the advent of the ASTM D7612, the generic reference is available, which should replace the proprietary ecolabel. The USGBC Pilot Credit recognizes this advantage and avoids comparison between proprietary systems to avoid improper commercial endorsement.
- ASTM D7612 provides a means to specify enforcement of best management practices by governmental agencies that have authority to protect water quality on both certified and non-certified forestlands via the *responsible source* designation. For Oregon, enforcement is achieved through the Oregon Forest Practices Act (OFPA), regardless of whether the forestland is certified to sustainable forestry standards, or not.
    - Enforcement is defined as having authority, staffing, budget, proof of citations and the ability to adapt the rules to improve the system. Oregon forestlands subject to the OFPA have been independently audited and found compliant to the *responsible source* designation by PFS Corporation.
    - The emphasis on water quality for government or tribal forestlands is due to the existing rules already in place tp protect forests (see https://cfpub.epa.gov/watertrain/moduleFrame.cfm?parent_object_id=1517
      The degree to which these rules are enforced by each state has been evaluation by the National Association of State Foresters http://www.stateforesters.org/state-forestry-agency-best-management-practices-protecting-water#sthash.7VDEx3y6.dpbs
      The three tiers of enforcement are non-regulatory, quasi-regulatory and regulatory in order of increasing compliance. ASTM D76712 recognizes those states having quasi-regulatory and regulatory compliance under the *responsible source* designation.
    - The strength of the *responsible sources* program is the ability to issue citations (fines) for noncompliance to water quality rules and to reward states/jurisdictions that fund enforcement. Citations are issued to operators on both certified and non-certified forests. In some states, such as Oregon, the OFPA rules extend beyond water quality. Oregon producers want recognition of their compliance to OFPA, but not at the same tier as *certified sources* to avoid market confusion that *responsible and certified sources* are equivalent.
    - Manufacturers are required to trace fiber procurement under both the *responsible* and *certified sources* designation. Further information can be provided to the ICC-700 committee upon request.
    - The strength of the *certified sources* program is to write rules that extend beyond issues related to water quality. When damage to the forest happens from non-compliance, *certified source* programs can de-certify clients, they cannot issue citations or stop-work orders to remediate damage.
    - Thus, the *responsible source* program is an important enforcement component (and partner) to a *certified* source program. It will provide recognition for those states who actively monitor, enforce and punish offenders not in compliance with the law. It encourages states to enforce their water quality rules through inspection, documentation and citation, which is complementary to the voluntary sustainable forestry standards, or *certified sources*. It supports the "boots on the ground", actively monitoring harvest operations on both public and private lands.
    - ASTM D7612 not only supports the expanded enforcement of existing water quality rules (aka best management practices), but also recognizes voluntary compliance to those sustainable forestry practices above and beyond state water quality rules.
- In Oregon, the OFPA applies to approximately 10 million acres; of which approximately 4 million acres are certified forests. If the *responsible source* designation were also applied to federal and tribal lands,

the designation would apply to approximately 30 million acres of forestland in Oregon. The fiscal implication of the *responsible source* designation is significant to the increased value of building products derived from private and public lands, which is why the state of Oregon is presenting this request. The *responsible source* designation provides states recognition of best management practice enforcement on public lands without the controversial decision and cost to convert to the *certified source* designation.

Further information about ASTM D7612 is found at https://www.astm.org/standardization-news/?q=features/green-greener-greenest-ma17.html.

USGBC RECOGNIZES ALL CERTIFICATION STANDARDS FOR LEED POINTS			
PROGRAM NAME	Legal (non-controversial) Compliant?	Responsible Sources Compliant?	Certified Sources Compliant? (CoC)
Sustainable Forestry Initiative (SFI)			
• Forest Management (via SFI CoC certificate)	Yes	Yes	Yes
• SFI Fiber Sourcing certificate	Yes	Yes	No
American Tree Farm System (ATFS)			
• Forest Management (via SFI CoC certificate)	Yes	Yes	Yes
Canadian Standards Association (CSA)			
• Forest Management (via SFI CoC certificate)	Yes	Yes	Yes
Programme for the Endorsement of Forest Certification (PEFC)			
• Forest Management (via PEFC chain of custody certificate)	Yes	Yes	Yes
• PEFC Due Diligence System	Yes	No	No
Forest Stewardship Council (FSC)			
• Forest Management (via FSC chain of custody certificate)	Yes	Yes	Yes
• FSC Controlled Wood certificate	Yes	No	No

(taken from: How to count your SFI products for a LEED Point, Sustainable Forestry Initiative)

LogID 6479

United States
Enivronmental Protection
Agency

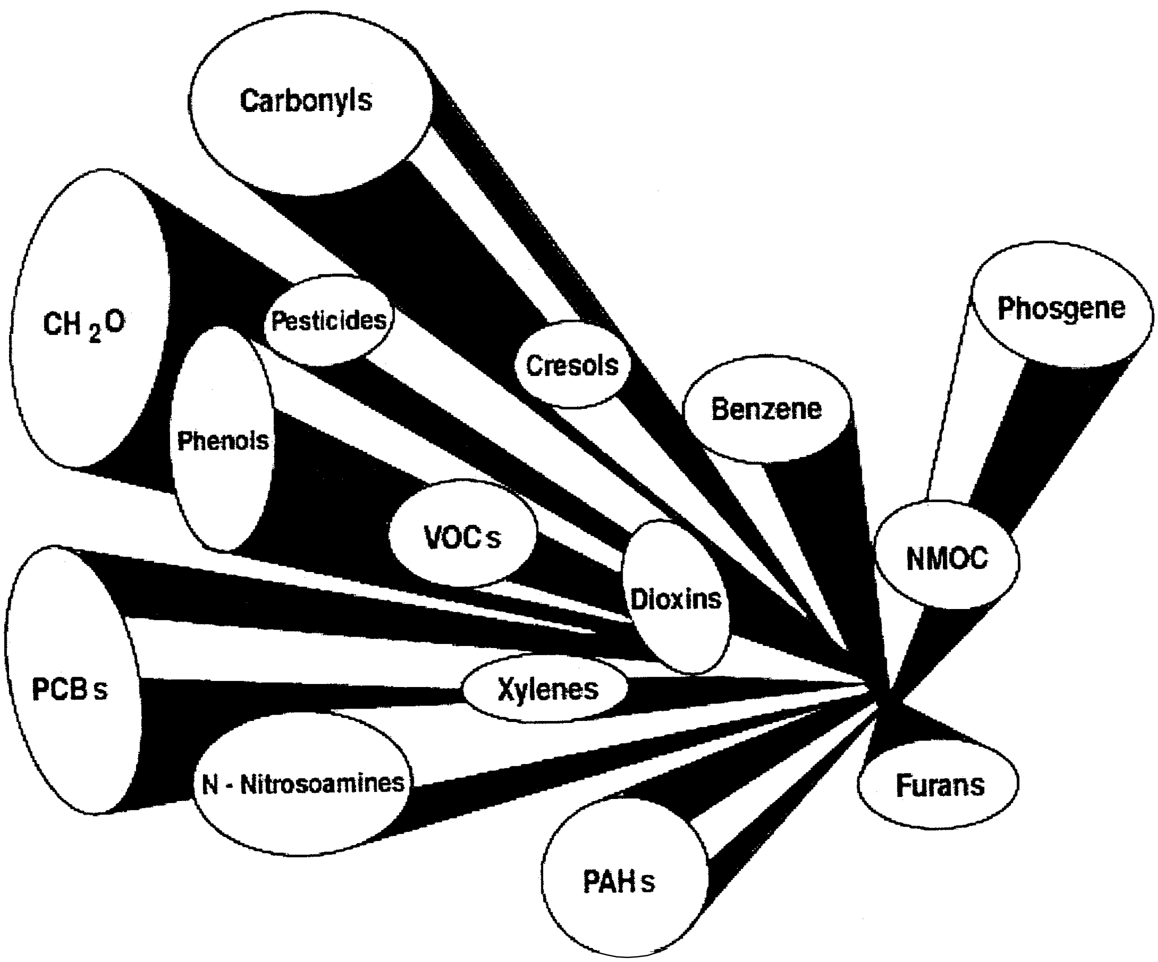
Center for Environmental
Research Information

EPA/625/R-96/010b
January 1999

Research and Development

EPA

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air - Second Edition



Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

U. S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Center for Environmental Research Information
Cincinnati, Ohio 45268

January 1999

Disclaimer

The information in this document has been compiled wholly or in part by the United States Environmental Protection Agency under contract No. 68-C3-0315, W.A. 3-10 to Eastern Research Group (ERG). The work was performed by Midwest Research Institute (MRI) under subcontract to ERG. It has been subjected to Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

It is further noted that the test methods compiled here are working compilations subject to on-going review and update. It is recommended that the reader refer to the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network web site at http://www.epa.gov/ttn/amtic/airtox.html to obtain the latest updates, corrections, and/or comments to these test methods.

FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

Measurement of organic pollutants in ambient air is often difficult, in part because of the variety of organic substances of potential concern, the variety of potential techniques for sampling and analysis, and the lack of standardized and documented methods. Consequently, NRMRL has developed a Second Edition of the *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air* to assist Federal, State, and local regulatory personnel in developing and maintaining necessary expertise and up-to-date monitoring technology for characterizing organic pollutants in the ambient air. The Compendium contains a set of 17 peer reviewed, standardized methods for the determination of volatile, semi-volatile, and selected toxic organic pollutants in the air. The 17 methods in the Second Edition have been compiled from the best elements of methods developed or used by various research or monitoring organizations and of which EPA has experience in use of the methodology during various field monitoring programs over the last several years. As with the previous Compendia of methods, these methods are provided only for consideration by the user for whatever potential applications for which they may be deemed appropriate. In particular, these methods are not intended to be associated with any specific regulatory monitoring purpose and are specifically offered with no endorsement for fitness or recommendation for any particular application.

This publication has been prepared in support of NRMRL's goal to provide technical support and information transfer. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

TABLE OF CONTENTS

		Page
Method TO-1:	Method for the Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Tenax® Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)	1-1 through 1-2
Method TO-2:	Method for the Determination of Volatile Organic Compounds (VOCs) in Ambient Air by Carbon Molecular Sieve Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)	2-1 through 2-2
Method TO-3:	Method for the Determination of Volatile Organic Compounds in Ambient Air Using Cryogenic Preconcentration Techniques and Gas Chromatography with Flame Ionization and Electron Capture Detection	3-1 through 3-2
Method TO-4A:	Determination of Pesticides and Polychlorinated Biphenyls in Ambient Air Using high Volume Polyurethane Foam (PUF) Sampling Followed by Gas Chromato-graphic/Multi-Detector Detection (GC/MD)	4A-1 through 4A-44
Method TO-5:	Determination of Aldehydes and Ketones in Ambient Air Using High Performance Liquid Chromatography (HPLC)	5-1 through 5-2
Method TO-6:	Determination of Phosgene in Ambient Air Using High Performance Liquid Chromatography (HPLC)	6-1 through 6-2
Method TO-7:	Method for the Determination of N-nitrosodimethylamine (NDMA) in Ambient Air Using Gas Chromatography	7-1 through 7-2
Method TO-8:	Method for the Determination of Phenol and Methylphenols (Cresols) in Ambient Air Using High Performance Liquid Chromatography	8-1 through 8-2
Method TO-9A:	Determination of Polychlorinated, Polybrominated And Brominated/Chlorinated Dibenzo-p-Dioxins And Dibenzofurans In Ambient Air	9A-1 through 9A-90

TABLE OF CONTENTS (continued)

		Page
Method TO-10A:	Determination Of Pesticides And Polychlorinated . . . . Biphenyls In Ambient Air Using Low Volume Polyurethane Foam (PUF) Sampling Followed By Gas Chromatographic/Multi-Detector Detention (GC/MD)	10A-1 through 10A-32
Method TO-11A:	Determination of Formaldehyde in Ambient Air Using . . . . Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC)	11A-1 through 11A-51
Method TO-12:	Method for the Determination of Non-methane Organic . . . . . . Compounds (NMOC) in Ambient Air Using Cryogenic Preconcentration and Direct Flame Ionization Detection (PDFID)	12-1 through 12-2
Method TO-13A:	Determination of Polycyclic Aromatic Hydrocarbons . . . . (PAHs) in Ambient Air Using Gas Chromatographic/Mass Spectrometry (GC/MS)	13A-1 through 13A-78
Method TO-14A:	Determination Of Volatile Organic Compounds (VOCs) . . . . . In Ambient Air Using Specially Prepared Canisters With Subsequent Analysis By Gas Chromatography	14A-1 through 14A-86
Method TO-15:	Determination of Volatile Organic Compounds (VOCs) . . . . . . In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography Mass Spectrometry (GC/MS)	15-1 through 15-62
Method TO-16:	Long-Path Open-Path Fourier Transform Infrared . . . . Monitoring Of Atmospheric Gases	16-1 through 16-40
Method TO-17:	Determination of Volatile Organic Compounds in . . . . Ambient Air Using Active Sampling Onto Sorbent Tubes	17-1 through 17-49

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-1

Method for the Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Tenax® Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)

Summary of Method

Compendium Method TO-1 involves drawing ambient air through a cartridge containing ~1-2 grams of Tenax®. Selected VOCs are trapped on the resin, while highly volatile organic compounds and most inorganic atmospheric constituents pass through the cartridge. The cartridge is then transferred to the laboratory and analyzed.

For analysis, the cartridge is placed in a heated chamber and purged with an inert gas, which transfers the VOCs from the cartridge onto a cold trap and subsequently onto the front of the GC column. The column is first held at low temperature (e.g., -70°C), then the column temperature is uniformly increased (temperature programmed). The components eluting from the column are identified and quantified by mass spectrometry. Component identification is normally accomplished using a library search routine on the basis of the GC retention time and mass spectral characteristics. Less sophisticated detectors (e.g., electron capture or flame ionization) may be used for certain applications, but their suitability for a given application must be verified by the user. Due to the complexity of ambient air samples, only high resolution (i.e., capillary) GC techniques are considered to be acceptable in this method.

Sources of Methodology

Method TO-1 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-1 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-2

Method for the Determination of Volatile Organic Compounds (VOCs) in Ambient Air by Carbon Molecular Sieve Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)

Summary of Method

Compendium Method TO-2 is similar to Compendium Method TO-1 except the adsorbent is a carbon molecular sieve (CMS) rather than Tenax®. The use of CMS allows some of the more volatile organics (i.e., vinyl chloride) to be captured and analyzed.

Method TO-2 is suitable for the determination of certain nonpolar VOCs having boiling points in the range of -15°C to 120°C. The analytical detection limit varies with the analyte. Detection limits of 0.01 to 1 ppbv are achievable using a 20-liter sample.

Sampling involves drawing ambient air through a cartridge containing ~0.4 g of a CMS adsorbent. Volatile organic compounds are captured on the adsorbent while major inorganic atmospheric constituents pass through (or are only partially retained). After sampling, the cartridge is returned to the laboratory for analysis. Prior to analysis the cartridge is purged with 2 to 3 liters of pure, dry air (in the same direction as sample flow) to remove adsorbed moisture.

Similar to Compendium Method TO-1, the cartridge is heated to 350° to 400°C, under helium purge, and the desorbed organic compounds are collected in a specially designed cryogenic trap. The collected organics are then flash evaporated onto a capillary column GC/MS system (held at -70°C). The individual components are identified and quantified during a temperature programmed chromatographic run.

Similar to Compendium Method TO-1, contamination of the CMS, breakthrough, and antifact formation are potential weaknesses of the methodology. Method TO-2 also involves a single analysis.

Sources of Methodology

Method TO-2 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-2 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-3

Method for the Determination of Volatile Organic Compounds in Ambient Air Using Cryogenic Preconcentration Techniques and Gas Chromatography with Flame Ionization and Electron Capture Detection

Summary of Method

Compendium Method TO-3 involves the *in situ* collection of VOCs having boiling points in the range of -10° to 200°C in a cryogenic trap constructed of copper tubing packed with glass beads. The collection trap is submerged in either liquid nitrogen or liquid argon. Liquid argon is highly recommended because of the safety hazard associated with liquid oxygen. With the sampling valve in the fill position, an air sample is admitted into the trap by a volume measuring apparatus. In the meantime, a GC column oven is cooled to a subambient temperature (-50°C) for sample analysis. Once sample collection is completed, the value is switched so that the carrier gas sweeps the VOCs in the trap onto the head of the cooled GC column. Simultaneously, the liquid cryogen is removed, and the trap is heated to assist the sample transfer process. The GC column is temperature programmed, and the component peaks eluting from the columns are identified and quantified using flame ionization and/or electron capture detection. Alternative detectors (e.g., photoionization) can be used as appropriate. An automated system incorporating these various operations as well as the data processing function is described in the method. Due to the complexity of ambient air samples, high resolution (capillary column) GC techniques are recommended. However, when highly selective detectors (such as the electron capture detector) are employed, packed column technology without cryogenic temperature programming can be effectively used in some cases.

Sources of Methodology

Method TO-3 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-3 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

EPA/625/R-96/010b

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-5

Determination of Aldehydes and Ketones in Ambient Air Using High Performance Liquid Chromatography (HPLC)

Summary of Method

Compendium Method TO-5 involves drawing ambient air through a midget impinger containing 10 mL of 2N HCl/0.05% 2,4-dinitrophenylhydrazine (DNPH reagent) and 10 mL of isooctane. Aldehydes and ketones readily form stable 2,4-dinitrophenylhydrazones (DNPH derivatives).

After sampling, the impinger solution is placed in a screw-capped vial having a Teflon®-lined cap and returned to the laboratory for analysis. The DNPH derivatives are recovered by removing the isooctane layer, extracting the aqueous layer with 10 mL of 70/30 hexane/methylene chloride, and combining the organic layers.

The combined organic layers are evaporated to dryness under a steam of nitrogen and the residue dissolved in methanol. The DNPH derivatives are determined using reversed phase HPLC with an ultraviolet (UV) adsorption detector operated at 370 nm.

Sources of Methodology

Method TO-5 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-5 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the “AMTIC, Air Toxics” section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-6

Determination of Phosgene in Ambient Air Using High Performance Liquid Chromatography (HPLC)

Summary of Method

Compendium Method TO-6 involves drawing an air sample through a midget impinger containing 10 mL of 2% aniline/toluene (2/98 by volume). Phosgene readily reacts with aniline to form carbanilide (1,3-diphenylurea), which is stable indefinitely. After sampling, the impinger contents are transferred to a screw-capped vial having a Teflon-lined cap and returned to the laboratory for analysis. The solution is taken to dryness by heating to 60°C on an aluminum heating block under a gentle stream of pure nitrogen gas. The residue is dissolved in 1 mL of acetonitrile. Carbanilide is determined in the acetonitrile solution using reverse-phase HPLC with an ultraviolet (UV) absorbance detector operating at 254 nm. Precision for phosgene spiked into a clean air stream is ±15-20% relative standard deviation. Recovery is quantitative within that precision, down to less than 3 ppbv.

Sources of Methodology

Method TO-6 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-6 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the “AMTIC, Air Toxics” section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-7

Method for the Determination of N-nitrosodimethylamine (NDMA) in Ambient Air Using Gas Chromatography

Summary of Method

Compendium Method TO-7 involves drawing ambient air through a Thermosorb/N adsorbent cartridge at a rate of approximately 2 L per minute for an appropriate period of time. Breakthrough has been shown not to be a problem with total sampling volumes of 300 L (i.e., 150 minutes at 2 L per minute) or less. The selection of Thermosorb/N adsorbent over Tenax® GC, was due, in part, to recent laboratory studies indicating artifact formation on Tenax® from the presence of oxides of nitrogen in the sample matrix.

After sampling, the cartridge is plugged and returned to the laboratory for analysis. In the laboratory, the cartridge is pre-eluted with 5 mL of methylene chloride (in the same direction as sample flow) to remove interferences. Residual methylene chloride is removed by purging the cartridge with air in the same direction. The cartridge is then eluted, in the reverse direction, with 2 mL of acetone. This eluate is collected in a screw-capped vial and refrigerated until analysis. NDMA is determined by GC/MS using a Carbowax 20M capillary column. NDMA is quantified from the response of the m/e 74 molecular ion using an external standard calibration method.

Sources of Methodology

Method TO-7 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-7 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the “AMTIC, Air Toxics” section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-8

Method for the Determination of Phenol and Methylphenols (Cresols) in Ambient Air Using High Performance Liquid Chromatography

Summary of Method

Compendium Method TO-8 involves drawing ambient air through two midget impingers, each containing 15 mL of 0.1 N NaOH. The phenols are trapped as phenolates. The impinger solutions are placed in a vial with a Teflon®-lined screw cap and returned to the laboratory for analysis. The solution is cooled in an ice bath and adjusted to a pH <4 by addition of 1 mL of 5% sulfuric acid (V/V). The sample is adjusted to a final volume of 25 mL with distilled water. The phenols are determined using reverse-phase HPLC with either ultraviolet (UV) absorption detection at 274 nm, electrochemical detection, or fluorescence detection. In general, the UV detection approach should be used for relatively clean samples.

Sources of Methodology

Method TO-8 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-8 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the “AMTIC, Air Toxics” section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-12

Method for the Determination of Non-Methane Organic Compounds (NMOC) in Ambient Air Using Cryogenic Preconcentration and Direct Flame Ionization Detection (PDFID)

Summary of Method

Compendium Method TO-12 combines a cryogenic concentration technique for trapping organics in the ambient air (similar to Compendium Method TO-3) coupled to a highly sensitive and simple flame ionization detector (FID) to determine non-speciated total NMOC concentrations in the ambient air.

In Compendium Method TO-12, a whole air sample is either extracted directly from the ambient air and analyzed on-site by the GC system or collected into a precleaned specially-treated canister and analyzed off-site.

The analysis requires drawing a fixed-volume portion of the extracted sample air, at a low flow rate, through a glass-bead filled trap that is cooled to approximately -186°C with liquid argon. The cryogenic trap simultaneously collects and concentrates the NMOC (either via condensation or adsorption) while allowing the methane, nitrogen, oxygen, etc. to pass through the trap without retention. The system is dynamically calibrated so that the volume of sample passing through the trap does not have to be quantitatively measured, but must be precisely repeatable between the calibration and the analytical phases.

After the fixed-volume air sample has been drawn through the trap, a helium carrier gas flow is diverted to pass through the trap, in the opposite direction to the sample flow, and into an FID. When the residual air and methane have been flushed from the trap and the FID baseline restabilizes, the cryogen is removed and the temperature of the trap is raised to approximately 90°C.

The NMOC previously collected in the trap revolatilize due to the increase in temperature and are carried into the FID, resulting in a response peak or peaks from the FID. The area of the peak or peaks is integrated, and the integrated value is translated to concentration units via a previously obtained calibration curve relating integrated peak areas with known concentrations of propane.

By convention, concentrations of NMOC are reported in units of parts per million carbon (ppmC), which, for a specific compound, is the concentration by volume (ppmv) multiplied by the number of carbon atoms in the compound.

Sources of Methodology

Method TO-12 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-12 is contained in the original supplement of *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989**. The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

> Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:
>
> **http://www.adobe.com/prodindex/acrobat/readstep.html**
>
> and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

United States
Environmental Protection
Agency

Center for Environmental
Research Information

Research and Development | EPA-625/SR-96/010b | January 1999

EPA **Project Summary**[1]

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air--Second Edition

This Project Summary is the announcement of the availability of the Second Edition of the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air. This Second Edition of the Compendium has been prepared to provide regional, state and local environmental regulatory agencies with step-by-step sampling and analysis procedures for the determination of selected toxic organic pollutants in ambient air. It is designed to assist those persons responsible for sampling and analysis of hazardous air pollutants (HAPs) in complying with the requirements of Title III of the Clean Air Act.

Determination of pollutants in ambient air is a complex task, primarily because of the wide variety of compounds of interest coupled with the lack of standardized sampling and analysis procedures. Many toxic organics can be sampled and analyzed by several techniques, often with different interferences and detection limitations. This revised Compendium presents a set of 17 methods in a standardized format with a variety of applicable sampling methods, as well as several analytical techniques, for specific classes of organic pollutants, as appropriate to the specific pollutant compound, its level, and potential interferences. Consequently, this treatment allows the user flexibility in selecting alternatives to complement his or her background and laboratory capability. These methods may be modified from time to time as advancements are made.

This Project Summary was developed jointly by the U. S. Environmental Protection Agency (EPA) Center for Environmental Research Information (CERI), National Risk Management Research Laboratory (NRMRL), Office of Research and Development (ORD), Cincinnati, OH and ORD's National Exposure Research Laboratory (NERL) at Research Triangle Park, NC to alert potential users of the availability of the updated Compendium that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Clean Air Act Amendments of 1990 (CAAA of 1990) have significantly increased the responsibilities of both federal and state agency programs for evaluating and maintaining air emissions compliance. In turn, this increased responsibility has generated a need for more

[1] *Written by: William T. "Jerry" Winberry, Jr., EnviroTech Solutions, 1502 Laughridge Drive, Cary, NC 27511, (919)-467-2785, email: jwinberry@mindspring.com.*

personnel trained to interpret, enforce, and respond to regulatory initiatives. Consequently, the Agency has restructured its technology transfer program to more effectively provide technical assistance in the form of publication of technical documents, presentations and workshops, and development of tools to assist Agency personnel in keeping their skills up-to-date so that they may efficiently cope with the many changes evolving in new programs, equipment, sampling and analytical methodology, and available enforcement tools.

Limited guidance has been available to state and local agencies or to other organizations concerned with the determination of toxic organic compounds in ambient air. As a result, state and local agencies and others responding to air pollution problems have had to develop their own monitoring strategies, including selection of monitoring methods, sampling plan design, and specific procedures for sampling, analysis, logistics, calibration and quality control. For the most part, these procedures were based on professional judgments rather than adherence to any documented uniform guidelines. Many governmental agencies and professional or research organizations have developed ambient air monitoring methods and procedures, mostly to respond to specialized needs. But these methods and procedures have, *in general,* been neither standardized nor readily available to other agencies involved with ambient air monitoring for organic hazardous air pollutants (HAPs).

To meet these needs, EPA's ORD, through CERI and NERL has supported technology transfer programs involving standardized, peer reviewed monitoring methods for regulatory and industrial personnel via publications of Compendia methods. Other recent or upcoming documents in this series are:

- *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air,* EPA 625/R-96/010a, January 1999. (This publication is scheduled for release during the first half of 1999).
- *Compendium of Methods for the Determination of Air Pollutants in Indoor Air,* EPA 600/4-90-010, April 1990.

These Compendia have historically assisted Federal, State, and local regulatory personnel in developing and maintaining necessary expertise and up-to-date technology involving sampling and analysis of both inorganic and organic HAPs. However, since the publication of these documents, new technology has been introduced to cope with the monitoring requirements identified in the Amendments, thus creating the need for updating many of the methods in the existing Organic Compendium.

The methods in the Second Edition have been compiled from the best elements of methods developed or used by various research or monitoring organizations. They are presented in a standardized format, and each one has been extensively reviewed by several technical experts having expertise in the methodology presented.

Structure of the Second Edition of the Compendium

This Second Edition has been prepared to provide regional, state and local environmental regulatory agencies, as well as other interested parties, with specific guidance on the determination of selected toxic organic compounds in ambient air. A visual guide to the organization of the Compendium for specific methods covering a variety of organic compounds is illustrated in Figure 1.

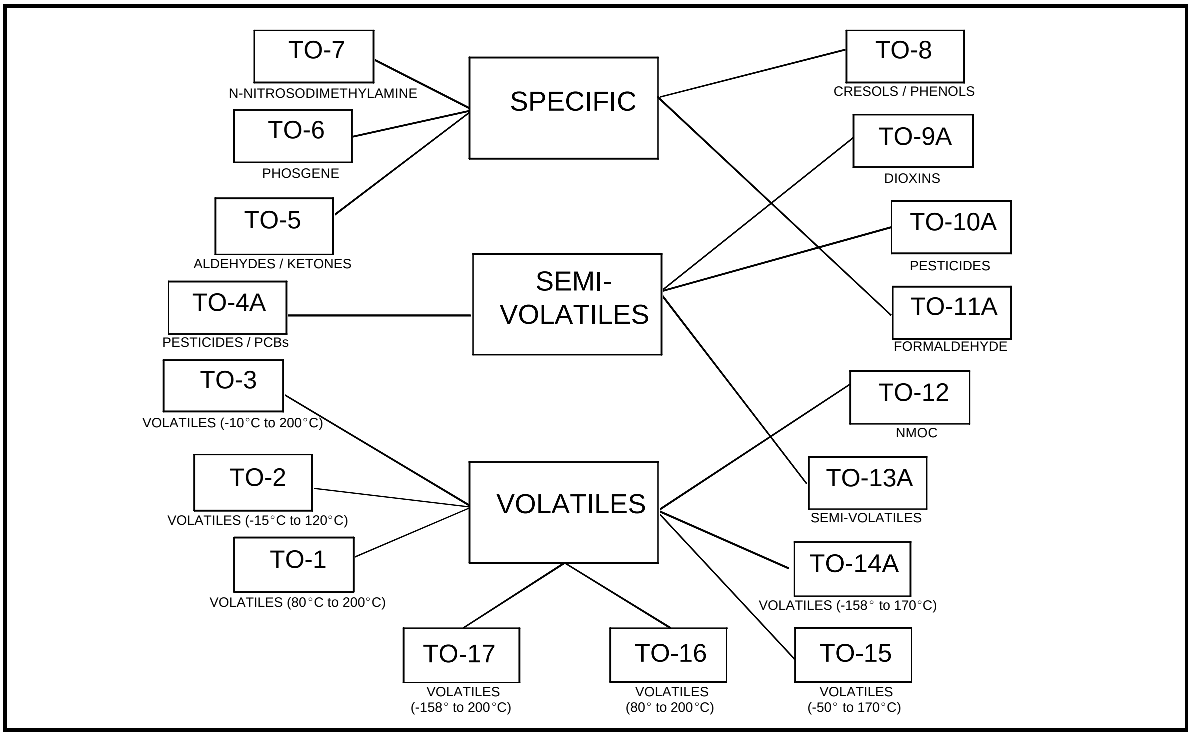


Figure 1. A visual guide to the organization of the Second Edition of the Organic Compendium.

Those methods assigned the "A" notation are methods which were published in the First Edition (Compendium Methods TO-1 through TO-14) of the Compendium and have now been updated due to technological advances in either the sampling or analysis methodology. In addition, three new methods (Compendium Methods TO-15 through TO-17) have been added to make the complete Second Edition of the Compendium. These methods were added due to their advanced technology application involving specially treated canisters (Compendium Method TO-15), long-path (open-path) fourier transform infrared spectroscopy (Compendium Method TO-16), and multibed sorbent techniques (Compendium Method TO-17). The methods which are neither new or modified are not reproduced in the Second Edition in order to save space. This decision was based on the fact that they are not as likely to be used as the revised or new methods.

A list of methods contained in the Second Edition of the Compendium is presented in Table 1. This listing provides a brief indication of the type of compounds to which the method is applicable, the type of sample collection device used, and the type of analytical methodology for which the sample collection system was designed for compatibility. Finally, a listing of the advantages and disadvantages of the methods in the Second Edition of the Compendium are documented in Table 2.

TABLE 1. LIST OF METHODS IN SECOND EDITION OF THE COMPENDIUM

Compendium Method No.	Type of Compounds Determined	Sample Collection Device	Analytical Methodology[1]
TO-1[2]	Volatile organic compounds	Tenax® solid sorbent	GC/MS
TO-2[2]	Volatile organic compounds	Molecular sieve sorbent	GC/MS
TO-3[2]	Volatile organic compounds	Cryotrap	GC/FID
TO-4A	Pesticides/PCBs	Polyurethane foam	GC/MD
TO-5[2]	Aldehydes/Ketones	Impinger	HPLC
TO-6[2]	Phosgene	Impinger	HPLC
TO-7[2]	Anilines	Adsorbent	GC/MS
TO-8[2]	Phenols	Impinger	HPLC
TO-9A	Dioxins	Polyurethane foam	HRGC/HRMS
TO-10A	Pesticides/PCBs	Polyurethane foam	GC/MD
TO-11A	Aldehydes/ketones	Adsorbent	HPLC
TO-12[2]	Non-methane organic compounds (NMOC)	Canister or on-line	FID
TO-13A	Polycyclic aromatic hydrocarbons	Polyurethane foam	GC/MS
TO-14A	Volatile organic compounds (nonpolar)	Specially-treated canister	GC/MS and GC/MD
TO-15	Volatile organic compounds (polar/nonpolar)	Specially-treated canister	GC/MS
TO-16	Volatile organic compounds	Open path monitoring	FTIR
TO-17	Volatile organic compounds	Single/multi-bed adsorbent	GC/MS, FID, etc.

[1] GC/MS = Gas chromatography/mass spectrometry.
GC/FID = Gas chromatography/flame ionization detector.
HPLC = High performance liquid chromatography.
GC/MD = Gas chromatography/multi-detector.
GC/IT = Gas chromatography/ion trap detector.
FTIR = Fourier transform infrared spectroscopy.
HRGC/HRMS = High resolution gas chromatography/high resolution mass spectrometry.

[2] Methods denoted by "2" have not been changed since their publication in the First Edition of the Compendium, so the full content of these methods is not repeated in this Second Edition. Therefore, the full content of these methods must be obtained from the original Compendium (EPA 600/4-89-017).

TABLE 2. COMPENDIUM METHODS CHARACTERISTICS

Method Desig.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-1 (See also Methods TO-14A, TO-15, and TO-17)	VOCs (80° to 200°C) [e.g., benzene, toluene, xylenes]	**TENAX-GC ADSORPTION AND GC/MS OR GC/FID ANALYSIS** Ambient air is drawn through organic polymer sorbent where certain compounds are trapped. The cartridge is transferred to the laboratory, thermally desorbed and analyzed using GC/MS or GC/FID.	0.01-100 ppbv	• Good data base. • Large volume of air can be sampled. • Water vapor is not collected. • Wide variety of compounds collected. • Low detection limits. • Standard procedures available. • Practical for field use.	• Highly volatile compounds and certain polar compounds are not collected. • Rigorous clean-up of adsorbent required. • No possibility of multiple analysis. • Low breakthrough volumes for some compounds. • Desorption of some compounds difficult. • Structural isomers are the most common interferences. • Contamination of adsorbent and blank contaminants may be a problem. • Artifact formation.
TO-2 (See also Methods TO-14A, TO-15, and TO-17)	Highly volatile VOCs (-15° to +120°C) [e.g., vinyl chloride, chloroform, chlorobenzene]	**CARBON MOLECULAR SIEVE ADSORPTION AND GC/MS OR GC/FID ANALYSIS** Selected volatile organic compounds are captured on carbon molecular sieve adsorbents. Compounds are thermally desorbed and analyzed by GC/MS or GC/FID techniques.	0.1-200 ppbv	• Trace levels of volatile organic compounds are collected and concentrated on sorbent material. • Efficient collection of polar compounds. • Wide range of application. • Highly volatile compounds are adsorbed. • Easy to use in field.	• Some trace levels of organic species are difficult to recover from the sorbent. • Structural isomers are common interferences. • Water is collected and can de-activate adsorption sites. • Thermal desorption of some compounds may be difficult.
TO-3 (See also Methods TO-14A, TO-15, and TO-17)	VOCs nonpolar (-10° to +200°C) [e.g., vinyl chloride, methylene chloride, acrylonitrile]	**CRYOGENIC PRECONCENTRATION AND GC/FID/ECD ANALYSIS** Vapor phase organics are condensed in a cryogenic trap. Carrier gas transfers the condensed sample to a GC column. Adsorbed compounds are eluted from the GC column and measured by FID or ECD.	0.1-200 ppbv	• Collects wide variety of volatile organic compounds. • Standard procedures are available. • Contaminants common to adsorbent materials are avoided. • Low blanks. • Consistent recoveries. • Large data base.	• Moisture levels in air can cause freezing problems with cryogenic trap. • Difficult to use in field. • Expensive. • Integrated sampling is difficult. • Compounds with similar retention times will interfere.
TO-4 (See also Method TO-10A)	Pesticides/PCBs [e.g., PCBs, 4,4-DDE, DDT, DDD]	**HIGH VOL FILTER AND PUF ADSORBENT FOLLOWED BY GC/FID/ECD OR GC/MS DETECTION** Pesticides/PCBs trap on filter and PUF adsorbent trap. Trap returned to lab, solvent extracted and analyzed by GC/FID/ECD or GC/MS.	0.2pg/m^3 - 200 ng/m^3	• Low detection limits. • Effective for broad range of pesticides/PCBs • PUF reusable. • Low blanks. • Excellent collection and retention efficiencies for common pesticides and PCBs.	• Breakdown of PUF adsorbent may occur with polar extraction solvents. • Contamination of glassware may limit detection limits. • Loss of some semi-volatile organics during storage. • Extraneous organics may interfere. • Difficulty in identifying individual pesticides and PCBs if using ECD.

TABLE 2. (CONTINUED)

Method Desig.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-5 (See also Method TO-11A)	Aldehydes and ketones [e.g., formaldehyde, acetaldehyde, acrolein]	**DNPH LIQUID IMPINGER AND HPLC/UV ANALYSIS** Air sample is drawn through dinitrophenylhydrazine (DNPH) impinger solution using a low volume pump. The solution is analyzed using HPLC with a UV detector.	1-50 ppbv	• Specific for aldehydes and ketones. • Good stability for derivative compounds formed in the impingers. • Low detection limits.	• Sensitivity limited by reagent purity. • Potential for evaporation of liquid over long term sampling. • Isomeric aldehydes and ketones may be unresolved by the HPLC system.
TO-6	Phosgene	**ANILINE/TOLUENE LIQUID IMPINGER AND HPLC/UV ANALYSIS** Ambient air is drawn through a midget impinger containing 10 mL of 2/98 aniline/toluene (v/v). The phosgene reacts with aniline to form 1,3-diphenylurea and is analyzed using reverse-phase HPLC with a UV absorbance detector operating at 254 nm.	1-50 ppbv	• Good specificity. • Good stability for derivative compounds formed in the impingers. • Low detection limits.	• Chloroformates and acidic materials may interfere. • Contamination of aniline reagents may be a source of interference. • Use of midget impingers in field application may not be practical.
TO-7	N-Nitroso dimethylamine	**THERMOSORB/N CARTRIDGE WITH GC/MS ANALYSIS** Ambient air is drawn through a cartridge containing Thermosorb/N adsorbent to trap N-nitrosodimethylamine. The cartridge is returned to the lab and eluted with 5 mL of dichloromethane. The cartridge is then eluted in reverse direction with 2 mL of acetone. The N-nitrosodimethylamine is then determined by GC/MS.	1-50 ppbv	• Good specificity. • Good stability for derivative compounds formed on the cartridge. • Low detection limit for n-nitrosodimethylamine. • Placement of sorbent as first component in sample train minimizes contamination. • Sampling system portable and lightweight.	• Compounds with similar GC retention times and detectable MS ions may interfere. • Specificity is a limiting factor if looking for other organic amines.
TO-8	Cresol/phenol	**SODIUM HYDROXIDE LIQUID IMPINGER AND HPLC/UV DETECTION** Ambient air is drawn through two midget impingers. Phenols are trapped as phenolates in NaOH solution which is returned to the lab and analyzed by HPLC.	1-250 ppb	• 4,6-dinitro-2-methylphenol specific to class of compounds. • Good stability. • Detects non-volatile as well as volatile phenol compounds.	• Compounds having the same HPLC retention times will interfere with this method. • Phenolic compounds of interest may be oxidized during sampling. • Limited sensitivity.

TABLE 2. (CONTINUED)

Method Desig.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-9A	Dioxin/Furan/PCBs	**PUF ADSORBENT CARTRIDGE AND HRGC/ HRMS ANALYSIS** Ambient air is drawn through a glass fiber filter and a polyurethane foam (PUF) adsorbent cartridge by means of a high volume sampler. The filter and PUF cartridge are returned to the laboratory and extracted using toluene. The extract is concentrated using the Kuderna-Danish technique, diluted with hexane, and cleaned up using column chromatography. The cleaned extract is then analyzed by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS).	0.25-5000 pg/m^3	• Cartridge is reusable. • Excellent detection limits. • Easy to preclean and extract. • Excellent collection and retention efficiencies. • Broad database. • Proven methodology.	• Analytical interferences may occur from PCBs, methoxybiphenyls, chlorinated hydroxydiphenylethers, naphthalenes, DDE, and DDT with similar retention times and mass fractions. • Inaccurate measurement Ds/Fs are retained on particulate matter and may chemically change during sampling and storage. • Analytical equipment required (HRGC/HRMS) is expensive and not readily available. • Operator skill level important. • Complex preparation and analysis process. • Can't separate particles from gaseous phase.
TO-10A	Pesticides [e.g., heptachlor, chlordane, dieldrin, aldrin]	**PUF ADSORBENT CARTRIDGE AND GC/ECD/PID/FID ANALYSIS** A low-volume sample (1-5 L/min) is pulled through a polyurethane foam (PUF) plug to trap organochlorine pesticides. After sampling, the plug is returned to the laboratory, extracted and analyzed by GC coupled to multi-detectors (ECD, PID, FID, etc.).	1-100 ng/m^3	• Easy field use. • Proven methodology. • Easy to clean. • Effective for broad range of compounds. • Portability. • Good retention of compounds.	• ECD and other detectors (except the MS) are subject to responses from a variety of compounds other than target analytes. • PCBs, dioxins and furans may interfere. • Certain organochlorine pesticides (e.g., chlordane) are complex mixtures and can make accurate quantitation difficult. • May not be sensitive enough for all target analytes in ambient air.

TABLE 2. (CONTINUED)

Method Desig.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-11A	Formaldehyde (other aldehydes/ ketones) [e.g., formaldehyde, acetaldehyde, acrolein]	**<u>DNPH-CARTRIDGE AND HPLC/UV DETECTION</u>** An ambient air sample is drawn through a commercially-coated DNPH cartridge at a rate of 500-1200 mL/minute. The cartridges are returned to the laboratory in screw-cap glass vials. The cartridges are then removed from the vials and washed with acetonitrile by gravity feed elution. The eluate is diluted volumetrically and an aliquot is removed for determination of the DNPH-formaldehyde derivative by isocratic reverse phase HPLC with UV detection at 350 nm.	0.5-100 ppbv	• Placement of sorbent as first element in the sampling train minimizes contamination. • Large database. • Proven technology. • Sampling system is portable and light weight.	• Isometric aldehydes and ketones and other compounds with the same HPLC retention time as formaldehyde may interfere. • Carbonyls on the DNPH cartridge may degade if an ozone denuder is not employed. • Liquid water captured on the DNPH cartridge during sampling may interfere. • O_3 and UV light deteriorates trapped carbonyls on cartridge.
TO-12	NMOC (non-methane organic compounds)	**<u>CANISTER SAMPLING--CRYOGENIC PRECONCEN-TRATION AND FID DETECTION</u>** Ambient air is drawn into a cryogenic trap where the non-methane organic compounds (NMOCs) are concentrated. The trap is heated to move the NMOCs to the FID. Concentration of NMOCs is determined by integrating under the broad peak. Water correction is necessary.	0.1-200 ppmvC	• Standard procedures are available. • Contaminants common to adsorbent materials are avoided. • Low blanks. • Consistent recoveries. • Large data base. • Good sensitivity. • Useful for screening areas or samples. • Analysis much faster than GC.	• Moisture levels in air can cause freezing problems. • Non-speciated measurement. • Precision is limited.

TABLE 2. (CONTINUED)

Method Desig.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-13A	PAHs [e.g., benzo(a)pyrene, naphthalene, fluorene]	**<u>PUF OR XAD-2 ADSORBENT CARTRIDGE AND GC/MS ANALYSIS</u>** Ambient air is drawn through a glass fiber filter and a polyurethane foam (PUF) or XAD-2 adsorbent cartridge by means of a high volume sampler. The filter and PUF cartridge are extracted using 10% diethyl ether. The extract is concentrated using Kuderna-Danish technique, diluted, and cleaned up using column chromatography. The cleaned extract is then analyzed by gas chromatography/mass spectrometry (GC/MS).	0.5-500 ng/m^3	• Allows for sample dilution if concentration is too high during analysis. • Repeated analysis is possible. • High-volume sampling provides for lower detection limits. • Filter and PUF are low cost.	• Method has interferences due to contamination of solvents, reagents, glassware, and sampling hardware. • Coeluting contaminants may cause interference with target analytes. • Heat, ozone, NO_2, and ultraviolet light may cause sample degradation.
TO-14A	VOCs (non-polar) [e.g., toluene, benzene, chlorobenzene]	**<u>SPECIALLY-PREPARED CANISTER AND GC/FID/ECD OR GC/MS DETECTION</u>** Whole air samples are collected in an evacuated stainless steel canister. VOCs are concentrated in the laboratory with cryogen trap. VOCs are revolatilized, separated on a GC column, and passed to one or more detectors for identification and quantitation.	0.2-25 ppbv	• Best method for broad speciation of unknown trace volatile organics. • Simple sampling approach. • Good QA/QC database. • Proven field and analytical technology.	• Limited to non-polar compounds due to use of permeation type dryer. • Sample components may be adsorbed or decompose through interaction with container walls. • Water condensation at high humidity may be a problem at high concentrations (ppm). • Complex equipment preparation required. • Expensive analytical equipment.
TO-15	VOCs (polar/non-polar) [e.g., methanol, benzene, xylene, nitrobenzene]	**<u>SPECIALLY-PREPARED CANISTER AND GC/MS ANALYSIS</u>** Whole air samples are collected in a specially-prepared canister. VOCs are concentrated on a solid sorent trap or other arrangement, refocused on a second trap, separated on a GC column, and passed to an MS detector for identification and quantification.	0.2-25 ppbv	• Incorporates a multisorbent/ dry purge technique or equivalent for water management thereby addressing a more extensive set of compounds. • Establishes method performance criteria for acceptance of data. • Provides enhanced provisions for quality control. • Unique water management approach allows analysis for polar VOCs.	• Expensive analytical equipment. • Operator skill level important.

TABLE 2. (CONTINUED)

Method Desig.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-16	VOCs (polar/non-polar) [e.g., alcohols, ketones, benzene, toluene, o-xylene, chlorobenzene]	**FTIR OPEN PATH SPECTRO-SCOPY** VOCs are monitored using real-time long-path open-path fourier transform infrared spectroscopy (FTIR).	25-500 ppbv	• Open path analysis maintains integrity of samples. • Multi-gas analysis saves money and time. • Path-integrated pollutant concentration measurement minimizes possible sample contamination, and provides real-time pollutant concentration.. • Applicability for special survey monitoring. • Monitoring at inaccessible areas possible using open-path FTIR.	• High level of operator skill level required. • Requires spectra interpretation. • Limited spectra library available. • Higher detection limits than most alternatives. • Must be skilled in computer operation. • Substantial limitations from ambient CO_2 and humidity levels associated with spectral analysis.
TO-17	VOCs (polar/non-polar) [e.g., alcohols, ketones, benzene, toluene, o-xylene, chlorobenzene]	**MULTI-BED ADSORBENT TUBE FOLLOWED BY GC/MS** Ambient air is drawn through a multi-bed sorbent tube where VOCs are trapped. The cartridge is returned to the laboratory, thermally desorbed and analyzed by GC/MS or other methods.	0.2-25 ppbv	• Placement of the sorbent as the first element minimizes contamination from other sample train components. • Large selection of sorbents to match with target analyte list. • Includes polar VOCs. • Better water management using hydrophobic sorbents than Compendium Method TO-14A. • Large database, proven technology. • Size and cost advantages in sampling equipment.	• Distributed volume pairs required for quality assurance. • Rigorous clean-up of sorbent required. • No possibility of multiple analysis. • Must purchase thermal desorption unit for analysis. • Desorption of some VOCs is difficult. • Contamination of adsorbent can be a problem.

[1]Number in parenthesis is the boiling point range of the organics applicable to that Compendium Method.

The following is a brief overview of important technical changes/additions that have been made to those methods which have been updated or added to comprise the Second Edition of the Organic Compendium.

Compendium Method TO-4A
(Pesticides/PCBs)

- Incorporates an extensive update of quality assurance (QA) requirements involving the sampling mechanism.
- Allows a multi-detector approach for quantifying analytes on the target compound list (TCL).
- Establishes method performance criteria for acceptance of data, allowing the use of alternative but equivalent sampling and analytical equipment.
- Provides specific procedures for sample clean-up, employing solid phase extraction using silica, alumina or florisil.
- A detailed discussion associated with method performance criteria involving surrogate recoveries, laboratory method blanks, GC column performance and minimum detection limits is provided.

Compendium Method TO-9A
(Dioxins/Furans)

- Includes guidance associated with the use of benzene or toluene as the extraction solvent.
- Provides extensive guidance associated with field operation and quality assurance checks involving the high-volume sampler.
- Presents extracted ion current profiles (EICP) for selected dioxins and furans.
- Discusses method performance criteria involving surrogate recoveries, laboratory method blanks, GC column performance, laboratory control spikes, matrix spikes, and minimum detection limits determination.
- Provides specific procedures for sample clean-up employing solid phase extraction using silica, alumina, and carbon adsorbents.

Compendium Method TO-10A
(Pesticides/PCBs)

- Provides guidance on determining sampling efficiency (SE), retention efficiency (RE), and dynamic retention efficiency (RE_d).
- Recommends specific detectors for common pesticides and PCBs.
- Gives construction specifications for both PUF and PUF/XAD-2 adsorbent cartridges.
- Includes recent laboratory evaluation of sampling efficiencies for organochlorine pesticides, PCBs, ureas, triazines and pyethrins.
- Describes generator used in determining sampling efficiencies.

Compendium Method TO-11A
(Formaldehyde)

- Includes new material from EPA's Technical Assistance Document (TAD) on enhanced ozone monitoring.
- Adds design and construction specifications for an ozone denuder and scrubber.
- Reviews commercially-prepared low pressure drop adsorbent cartridges.
- Discusses sampler design for sequential sampling and heated inlet.

- Provides guidance on sorbent selection (C_{18} vs. silica gel).
- Illustrates the application of ozone denuder or scrubber to the field sampling system.
- Updates of HPLC procedures for column alternatives to quantitate up to 14 carbonyl compounds.

Compendium Method TO-13A
(Semi-volatiles)

- Incorporates an extensive update of quality assurance (QA) requirements involving sampling mechanism.
- Allows only gas chromatography/mass spectrometry (GC/MS) approach specified for quantifying analytes on the target compound list (TCL).
- Establishes method performance criteria for acceptance of data, allowing the use of alternative but equivalent sampling and analytical equipment.
- Provides specific procedures for sample clean-up, employing solid phase extraction.
- Provides detailed discussion of method performance evaluation (PE) standard and recoveries, laboratory method blanks, GC column performance and minimum detection limits requirements.

Compendium Method TO-14A
(VOCs - non-polar)

- Excludes alternative "water management" technique in lieu of permeation dryers.
- Expands canister requirements to include specially-prepared canisters.
- Provides for gas chromatography coupled to an ion trap detector.

Compendium Method TO-15
(VOCs - polar/non-polar)

- Addresses a more extensive set of compounds (the VOCs mentioned in Title III of the CAAA of 1990).
- The analytical methodology emphasizes GC/MS as the means to identify and quantitate target compounds.
- Establishes method performance criteria for acceptance of data, allowing the use of alternate but equivalent sampling and analytical equipment.
- Uses a multisorbent/dry purge technique or equivalent for water management.

Compendium Method TO-16
(VOCs - polar/non-polar)

- Describes the use of an FT-IR system to measure pollutants using a long, open air path.
- Provides measurement of the path-average atmospheric concentrations of various organic gases.
- Methodology discussed in Compendium Method TO-16 provides the following advantages for field application:
  - -- The integrity of the sample is assured, since no sampling actually occurs.
  - -- Multi-gas analysis is possible with a single field spectrum.
  - -- Path-integrated pollutant concentrations are obtained.
  - -- Spatial survey monitoring of industrial facilities is possible if scanning optics are used.

-- Coadding of spectra to improve detection capabilities is easily performed.
-- Rapid temporal scanning of line-of-site or multiple lines-of-sight is possible.
-- Monitoring of otherwise inaccessible areas is possible.

Compendium Method TO-17
(VOCs - polar/non-polar)

- The use of solid adsorbents in multisorbent tubes for concentrating VOCs from the ambient air is presented as part of EPA's program for methods development of automated gas chromatographs.
- Uses sorbent tubes with single or multisorbent packings.
- Compendium Method TO-17, collection of VOCs in ambient air samples by passage through solid sorbent packings, provides numerous advantages, including:

-- The small size and light weight of the sorbent packing and attendant equipment allows for field application.
-- The placement of the sorbent packing as the first element (with the possible exception of a filter or chemical scrubber for ozone) in the sampling train reduces the possibility of contamination from upstream elements.
-- The availability of a large selection of sorbents enables matching sorbents with a target set of compounds, including polar VOC.
-- The method provides for the possibility of water management using a combination of hydrophobic sorbents (to cause water breakthrough while sampling), dry gas purge of water from the sorbent after sampling, and splitting of the sample during analysis.
-- Technology is based on a large amount of literature associated with the use of sorbent sampling and thermal desorption for monitoring of workplace air, particularly from the Health and Safety Executive in the United Kingdom.

Ordering Information

The First Edition of the Compendium was published over a period of four years in four separate EPA documents. They are:

- Original Compendium (Methods TO-1 through TO-5), EPA 600/4-84-041, April 1984.
- First Supplement (Methods TO-6 through TO-9), EPA 600/4-87-006, September 1986.
- Second Supplement (Methods TO-10 through TO-14), EPA 600/4-89-018, June 1988.
- Full Compendium (Methods TO-1 through TO-14), EPA 600/4-89-017, June 1988.

Please Note: The Second Edition of the Compendium does not contain Methods TO-1, 2, 3, 5, 6, 7, 8, and 12. These methods, which were not updated because there were no significant technological advances made in them, can be found in their entirety in the First Edition only. The Second Edition contains only: a) the updated methods (methods assigned with an "A" in Table 1 from the First Edition which includes Compendium Methods TO-4A, TO-9A, TO-10A, TO-11A, TO-13A, and TO-14A); and b) the three new methods, Compendium Methods TO-15, TO-16, and TO-17.

These documents, including the Second Edition, may be purchased in hard copy from:

National Technical Information Service (NTIS)
5285 Port Royal Road, Springfield, VA 22161
Telephone: 703-487-4650; FAX: 703-321-8547
E-mail:Info @ NTIS.FEDWORLD.GOV
INTERNET: http://www.ntis.gov.

U.S. EPA: Office of Air Quality Planning and Standards (OAQPS)

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the “AMTIC, Air Toxics” section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-17 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

U.S. EPA: Office of Research and Development (ORD),
Center for Environmental Research Information (CERI)

New technology transfer documents may be ordered on-line through the CERI Technology Transfer web site - “http://www.epa.gov/ttbnrmrl/”. Once the web site has been accessed, click on the publication list and follow the menu-driven ordering instructions.

Acknowledgements

The Second Edition of the **Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air** (EPA/625/R-96/010b) was prepared under Contract No. 68-C3-0315, WA No. 3-10, by Midwest Research Institute (MRI), as a subcontractor to Eastern Research Group, Inc. (ERG), and under the sponsorship of the EPA. Justice A. Manning, John O. Burckle, Scott Hedges, Center for Environmental Research Information, and Frank F. McElroy, National Exposure Research Laboratory , all in EPA’s Office of Research and Development, were responsible for overseeing the preparation of the Second Edition of the Compendium. Invaluable support was also provided by the following members of the Compendium Workgroup:

John O. Burckle, U.S. EPA, ORD, NRMRL, Cincinnati, OH
James L. Cheney, U.S. Army Corps of Engineers, Omaha, NB
Michael Davis, U.S. EPA, Region 7, Kansas City, KS
Joseph B. Elkins Jr., U.S. EPA, OAQPS, Research Triangle Park, NC
Robert G. Lewis, U.S. EPA, ORD, NERL, Research Triangle Park, NC
William A. McClenny, U.S. EPA, ORD, NERL, Research Triangle Park, NC
Heidi Schultz, ERG, Lexington, MA
William T. "Jerry" Winberry, Jr., EnviroTech Solutions, Cary, NC

U.S. Department of Housing and Urban Development
Office of Community Planning and Development

LogID 6476

Noise Notebook

Chapter 4
Supplement

Sound Transmission Class Guidance

Table of Contents

Title	Page
Introduction	1
What is Sound	1
Sound Reduction in Structures	1
Elimination	2
Absorption	2
Sound Barriers	2
Design	3
Weather and Sound	3
STC Ratings for Wall, Floor and Window Materials and Assemblies	3
Appendix A STC Ratings	A-1
Walls	A-1
Exterior	A-1
Interior	A-9
Wooden Studs	A-9
Metal Studs	A-14
Floors	A-16
Wood	A-16
Concrete	A-21
Windows	A-24
Doors	A-27
Exterior	A-27
Interior	A-29
Appendix B References	B-1

Sound Transmission Class Guidance

Introduction

The Noise Guidebook, pages 33-37, provides an elementary discussion of STC, provides some STC ratings for common building materials and limited exterior and interior wall construction configurations, and describes a method to determine composite STC value of a wall containing a window or door. This update provides for an understanding of STC and provides an expanded material and construction classification for both internal and external building materials and typical construction patterns.

The intent of this chapter is not to endorse anyone building manufacturer or product over another but to keep HUD Environmental staff and other interested persons advised on the STC values of current building materials and practices which can be applied to HUD supported housing activities. Additional subsections on specific types of building materials, construction techniques and STC values will be periodically added.

As stated in the Noise Guidebook, "STC is used as a measure of a material's ability to reduce sound," and effectively mitigate any adverse noise levels that could impede a person's use of a residential or commercial structure. The higher the STC value, the greater the sound attenuation and presumably the quieter the structure's interior. In addition to STC, another interior building measuring technique to evaluate sound impact or absorption between floors is the Impact Isolation Class (IIC). Both techniques will be fully discussed after a brief explanation of the following basic principals related to sound.

What Is Sound

Sound is indicated in two ways: frequency and intensity. Frequency, the high or low pitch of sound, is expressed as the number of vibrations or cycles per second. One vibration or cycle per second is a hertz (Hz). For example on a piano the middle C note has a frequency of 262 Hz and the total range of a piano has a frequency of 27 Hz to 4186 Hz, well within the 16 to 20,000 Hz range of the human ear. The sound created by the piano is heard by the human ear by air pressure created by vibration. The greater the pressure, the greater the loudness or intensity of the sound heard by the human ear. Loudness is expressed in decibels (dB). The decibel is one-tenth of a "Bel," a unit named for Alexander Graham Bell. Since the ear is more sensitive to sound in the middle range of frequencies, loudness (intensity) is determined at a frequency of 1,000 Hz. On the decibel scale, 0 dB indicates a level of sound at 1,000 Hz, a sound just barely audible to person with normal unimpaired hearing.

The A-weighted scale of a sound meter is designed to adjust the sensitivity of a sound meter to sounds of different frequencies that closely approximate how the human ear might respond to moderate sound levels in the 1,000 to 4,000 Hz range. The A-weighted sound level is used extensively for measuring community and transportation noises.

The Sound Transmission Class (STC), measured in decibels, is used to measure building material's ability to absorb sound. The STC can be used to measure sound absorption for both external building walls and internal walls in single and multifamily structures. The STC is measured by positioning a representative sample of the building material midway in an acoustical chamber, dividing the chamber in half or into two rooms. One section of the chamber contains the sound source and the other section the sound receiving equipment. The test procedure calls for a steady sound in the source room and measuring the sound level in both the source and receiving rooms. Differences in sound levels in the rooms determines the transmission loss characteristics of the material tested. For example, if a generated sound level of 80 dB is measured in the source room and 30 dB is measured in the adjacent receiving room, the tested material has a sound reduction intensity (STC) of 5OdB.

The Impact Isolation Class (IIC), measured in decibels, is the classification system used to determine sound *impact* from floor to ceiling in a structure. The IIC is not to be used to measure airborne sound penetration or absorption in walls. The IIC numerical rating efficiency increases with improved impact isolation performance of the floor and its component sub flooring and materials. The rating scale values are generally equivalent to the airborne sound transmission loss. The impact of steps or vibrations on a floor and the reverberation of that noise in the room below is dependent upon the type, density and thickness of the floor and ceiling material, its absorption material, and quality of construction. A separate section on common floor materials and construction patterns to illustrate both the STC and IIC ratings is included.

Sound Reduction In Structures

Four general techniques for controlling noise in single-family and multifamily structures are:

1. Elimination of the cause or source of the noise,
2. Employ materials which absorb sound rather than reflect noise,

3. Use sound barriers in building layout to prevent sound from being transmitted from one adjoining area into another, and
4. Use design considerations to mask or absorb the noise.

A description of each technique and its applicability follows.

1. ELIMINATION:
The elimination of a noise source may be impractical or impossible to achieve, whether emanating from within or outside the structure. Examples include the operation of mechanical equipment within the dwelling unit, excessive corridor noise, air conditioning/heating system, elevators, exhaust fans, and outdoor transportation sounds such as automotive traffic, aircraft overflights, and commercial or industrial activities. Some noise reduction could be achieved through sound reduction or absorption techniques, but total elimination of these sounds may be impossible.

2. ABSORPTION:
Sound absorption control is the reduction of sound emanating from a source within a room. The extent of control depends upon the efficiency of the room's surfaces in absorbing rather than reflecting sound waves. A surface, which could theoretically absorb 100% of the sound would have a sound absorption coefficient of 1.0. A surface absorbing 35% of the sound would have a coefficient of 0.35. The effectiveness of wall construction as a means of sound absorption is tested in a similar manner as that of STC. If a generated sound level of 80 dB is observed in one room and 30 dB is measured in an adjacent room, the reduction in sound absorption for the intervening wall is 50 dB. In choosing the type of construction material for interior walls to absorb sound transmission, porosity and density of the material should be considered. Resistance to sound transmission increases with unit weight and decreases with porosity. For example, unpainted, open textured concrete block exhibits improved resistance to sound passage after sealing the surface with plaster or paint. The sealing of the pores result in a reduction in the sound absorption of the block. In multifamily structures using concrete block partitions to separate public areas such as stairwells and corridors from adjacent living areas, sound transmission reduction is achieved through plastering or painting the surface of the residential unit or living area on the opposite side of the partition. The sound is absorbed by the concrete masonry's unpainted side and its transmission is prevented into the residential unit or living area by the plaster or paint on the other side.

However, all of the design elements that are employed to control sound can be nullified through poor or improper construction practices. Sound leakage will occur through any opening in a wall. An improperly fitted door or window is a prime source of sound leakage, as well as openings around ducts, pipes and electrical outlets which are improperly fitted or sealed.

3. SOUND BARRIERS:
Prudent building layout can be effective in controlling noise in single-family and multifamily housing. Sound waves can be prevented from being transmitted from one adjoining area to another. Closets, stairways and corridors can be used as buffers against airborne sound transmission between apartments or bedrooms. Concrete blocks or solid partitions can be employed to separate boiler rooms, air conditioning units, work areas or noisy public areas such as stairwells, corridors or lobbies from adjacent living areas. Partitions designed to absorb sound on one side and to retain sound absorption on the other can effectively block or reduce sound transmission into living areas intended for quiet use. The barrier should have a high sound absorption coefficient on one side and an equally high sound retention coefficient on the reverse side to effective. For example, unpainted porous concrete block would have a high sound absorption coefficient and a high noise retention coefficient on the reverse side if the porous surface in the living unit was effectively sealed by plaster or paint. Similarly, noise originators such as cloths washing machines, central heaters, and other noisy major appliances can be placed in a basement or utility rooms that are physically isolated from other living areas by walls or floors to absorb or block the emitted sounds.

4. DESIGN:
Design factors is the last major element to consider in controlling noise in single-family and multifamily structures. Design considerations offer the most infinite prospects for controlling noise due to the numerous types of building designs. For example, adjacent apartments can be arranged to have quiet areas (bedrooms or living rooms) abut and have noisy areas (kitchens and bathrooms) next to similar noisy areas. Apartment door openings into the same hallway can be staggered to reduce sound penetration into the unit directly across the hall. Since sound travels in a straight line, some of the sound from one doorway would be absorbed or diffused into the wall building material of the unit directly across the hall.

Windows should be placed as far away as possible from common walls. The closer the windows are to each other, the more sound will pass from one apartment to another. Medicine cabinets in opposite bathroom partitions should be offset. Cabinets placed back-to-back will transmit almost as much noise as an opening. Heating/cooling ducts are like speaking tubes, carrying noise from one room to another. Techniques should be employed to trap or splinter sound or have turns in the ducts to reduce noise transference.

Noise producing equipment should be kept as far as possible from living areas and especially the bedrooms. Flexible connectors should be used to couple mechanical equipment to pipes and ducts. Pipes and ducts should not be firmly connected to parts of a building that could serve as sounding boards but be supported by resilient connections to solid supports. Where pipes and ducts pass through walls and floors, they should be isolated by gaskets. The acoustical integrity of a building or a building section with an otherwise adequate STC rating can be significantly reduced by a small hole or crack in the exterior wall or any other path that allows sound to bypass the exterior or interior walls and flow into other areas of the structure.

Weather and Sound

Air will attenuate noise at high frequencies usually from 1,000 Hz upwards. Sound absorption by air changes with wind speed, temperature and humidity. For example, wind blowing at slower speeds near the ground surface than at higher elevations will produce a bending of the sound upwards, resulting in less noise at ground level. Temperature gradients have a similar effect because the velocity of sound increases with the higher temperatures. If the temperature is higher near the ground than in the upper layers (usually the case during the day), the sound waves higher above the ground will travel slower and the sound will be bent upwards resulting in quieter conditions at ground level. The reverse is true at night, the temperature is lower near the ground, sound will bend towards the ground, increasing noise at the ground level. Wind and temperature- gradient effects can also account for the occasional freak reception of sounds over long distances, especially train whistles. The sound has been bent upwards by a temperature or wind gradient and after traveling some way at high level is bent down again by a reverse gradient.

Weather conditions can produce substantial variations of as much as +- 10 dB. For example, fog causes an increase in the absorption in the air. A moderately dense fog, visibility 150 feet, gives extra attenuation of 1 to 3 dB per 300 feet, depending on frequency. Similarly, snow forms an absorbent layer on the ground, which affects ground reflection, thereby reducing the sound level.

Weather can also be a significant source of noise in a structure. Common irritants are wind and rain. Wind whistling around a building, into ventilation grilles, screens or past other external architectural or artistic features can result in disturbing noise. Similarly, the impact of rain on lightweight roofing, gutters or skylights can produce high internal noise levels.

STC Ratings for Wall, Floor and Window Materials and Assemblies

Appendix A illustrates sound transmission class ratings for wall, floor, window and door assemblies. The data used in this section is compiled from laboratory reports and various technical and trade literature publications received by this Office. Each item has an assigned STC rating, an accompanying sketch and a brief description of its composition or assembly. In addition, where possible, an Impact Isolation Class (IIC) rating has been assigned to floors to determine sound impact from floor to ceiling. Appendix A is a guide designed to aid HUD Housing and Environmental personal in determining STC values for most common housing construction practices and materials used in residential construction. The STC information can be used to supplement acoustical measurements by providing approximate interior noise levels for existing or proposed dwellings located in high noise areas by deducting the STC value from the exterior noise level. The data could also be used to advise HUD clients in determining and achieving compliance with the noise criteria stated in 24 CFR Part 51 B through the use of common construction materials and techniques to achieve noise attenuation for new construction and rehabilitation.

The appendix is divided into the following subsections:

1. WALLS
    - Exterior
    - Interior
2. FLOORS
    - Wood
    - Concrete
3. WINDOWS
4. DOORS
    - Exterior
    - Interior

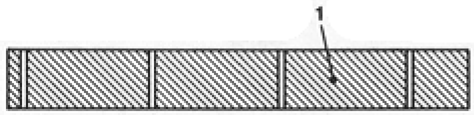
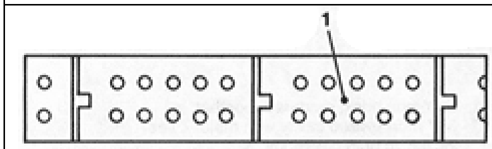
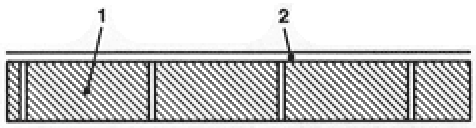
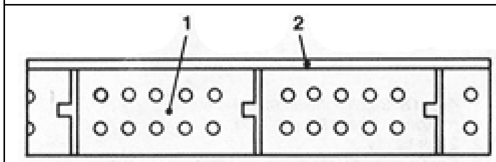
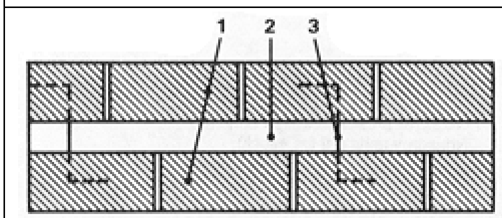
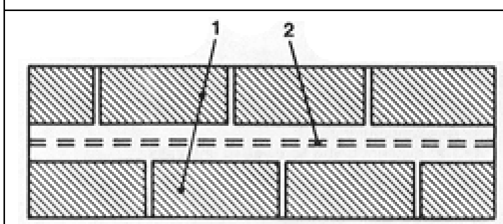
A bibliography of the reports, manufacturer's catalogs, technical papers, testing laboratories and other publications used in compiling this data is listed in the Appendix B.

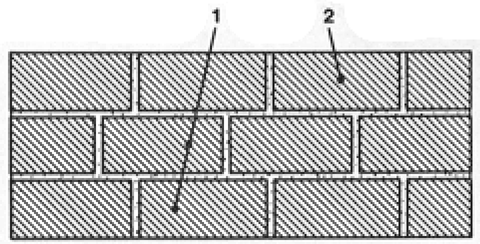
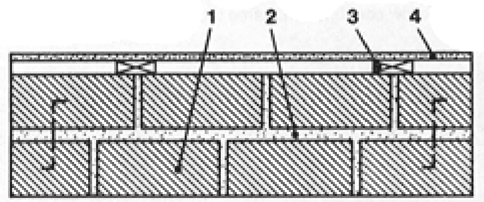
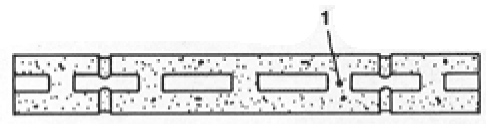
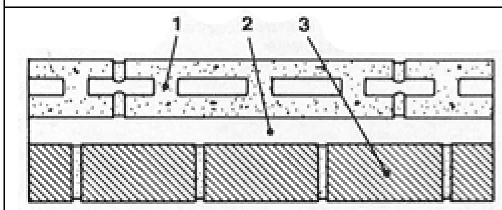
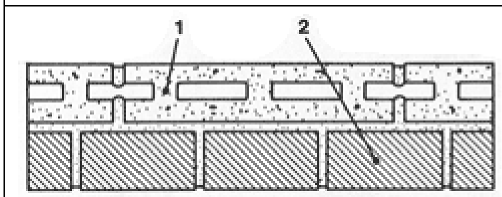
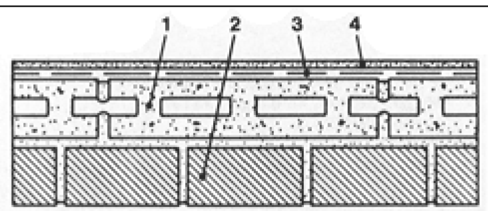
Appendix A STC Ratings

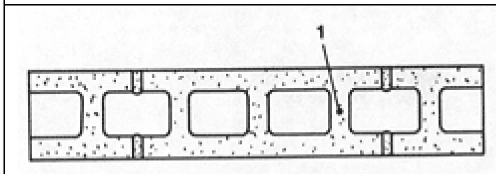
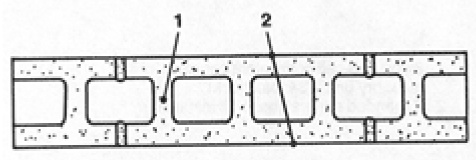
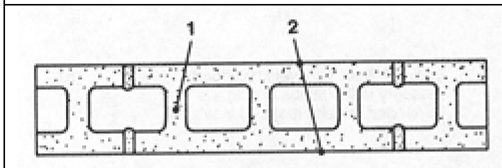
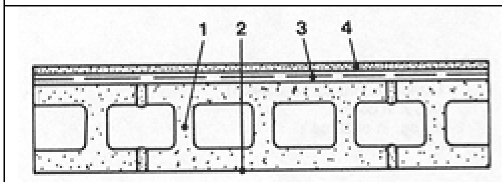
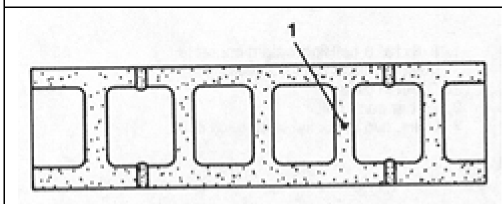
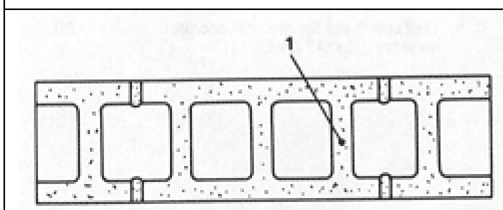
Appendix A

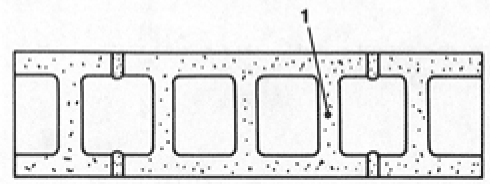
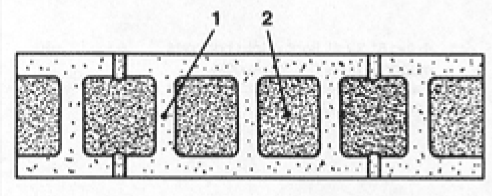
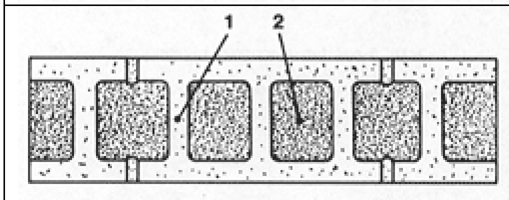
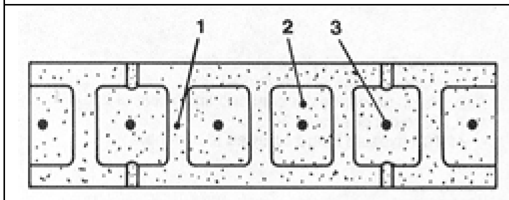
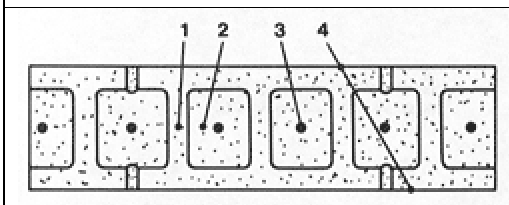
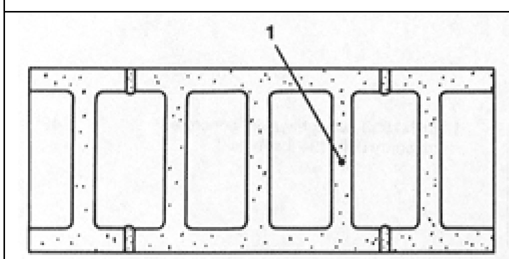
STC Ratings

Walls: Exterior

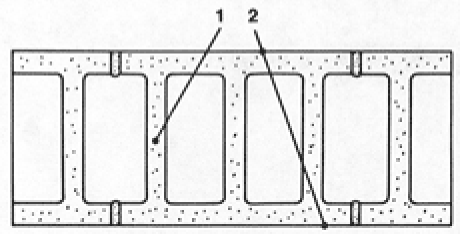
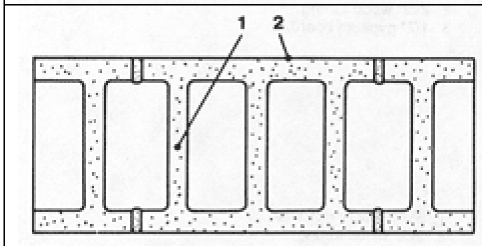
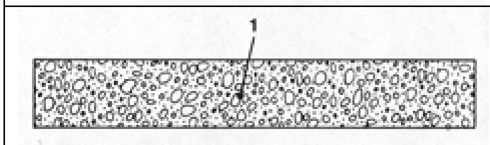
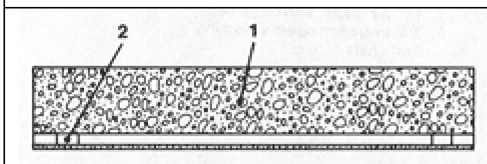
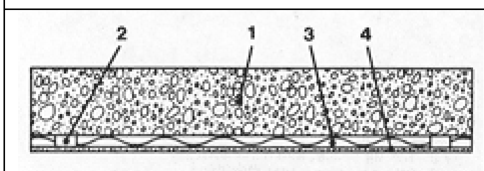
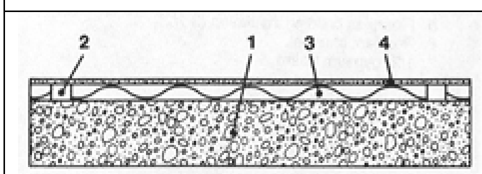
Sketch	Brief Description	STC
	1. 4” face brick, mortared together.	45
	1. Hollow core brick, mortared together.	51
	1. Common brick, mortared together. 2. ½” gypsum/sand plaster.	50
	1. Hollow core brick, mortared together. 2. ½” gypsum/sand plaster.	53
	1. Face brick, mortared together. 2. 2” air space. 3. Metal ties.	50
	1. Brick, mortared together. 2. 2 ¼” cavity filled with concrete grout and #6 bars vertically 48”o.c. and #5 bars horizontally 30”o.c.	59

Sketch	Brief Description	STC
	1. Common brick, mortared together. 2. Face brick, mortared together.	59
	1. Common brick, mortared together. 2. ¾" mortar-filled cavity with metal Z ties 24"o.c. in both directions. 3. 1x3" furring strips 16"o.c. and nailed vertically into mortar joints 12"o.c. 4. ½" gypsum board nailed 8"o.c. along edges and 12"o.c. in field.	53
	1. 4x8x16" 3-cell lightweight concrete masonry units (17 lbs./block).	40
	1. 4x8x18" 3-cell lightweight concrete masonry units (19 lbs./block). 2. 2" air cavity. 3. Common brick, mortared together.	54
	1. 4x8x18" 3-cell lightweight concrete masonry units (19 lbs./block). 2. Common brick, mortared together. (brick headers after every second course of block to tie the withes together).	51
	1. 4x8x18" 3-cell lightweight concrete masonry units (19 lbs./block). 2. Common brick, mortared together. 3. Resilient channels. 4. ½" gypsum board screwed to channels.	56

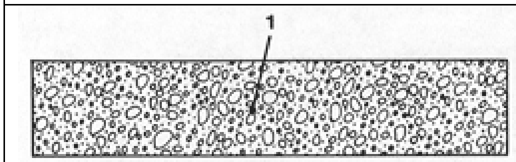
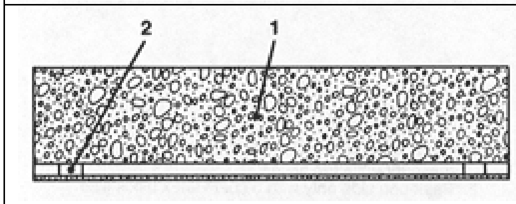
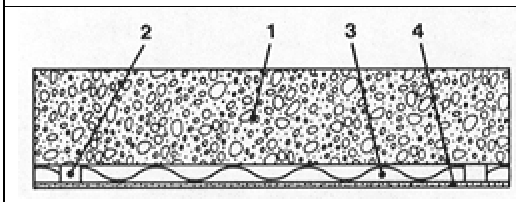
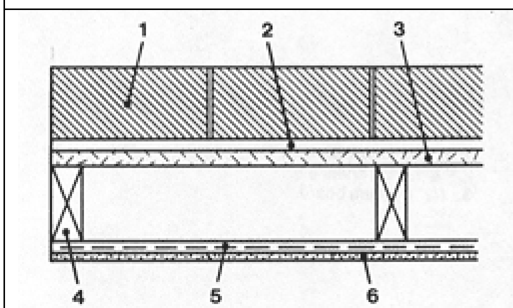
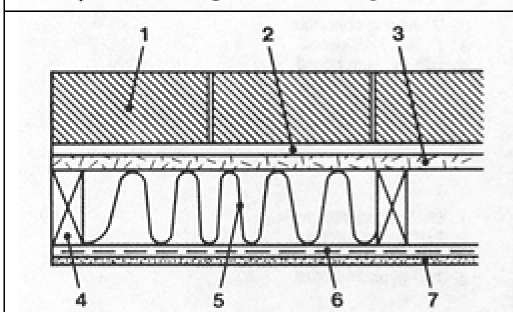
Sketch	Brief Description	STC
	1. 6x8x16” 3-cell lightweight concrete masonry units (21 lbs./block).	44
	1. 6x8x16” 3-cell lightweight concrete masonry units (21 lbs./block). 2. Paint both sides with primer-sealer coat and finish coat of latex.	46
	1. 6x8x18” 3-cell dense concrete masonry units (36 lbs./block). 2. Paint both sides with primer-sealer coat and finish coat of latex.	48
	1. 6x8x16” 3-cell lightweight concrete masonry units (21 lbs./block). 2. Paint, primer-sealer coat and finish coat of latex. 3. Resilient channels, 24”o.c. 4. ½” gypsum board screwed to channels.	53
	1. 8x8x16” 3-cell lightweight concrete masonry units (28 lbs./block).	45
	1. 8x8x18” 3-cell lightweight concrete masonry units (34 lbs./block).	49

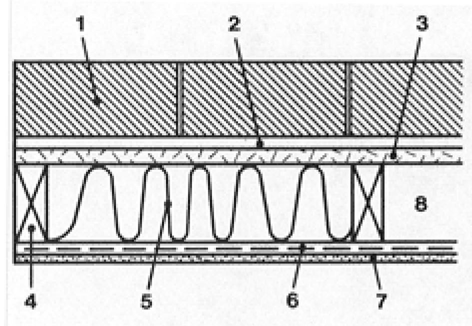
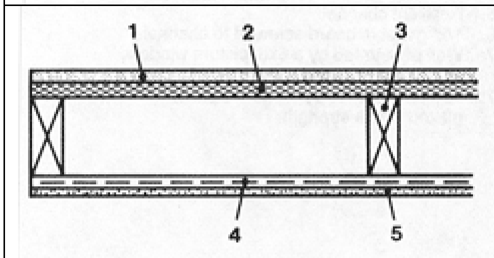
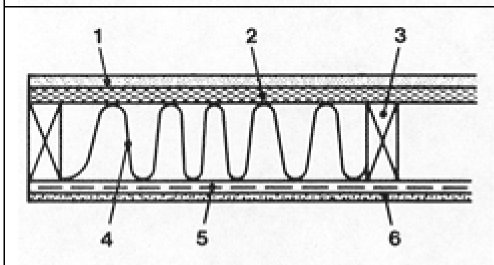
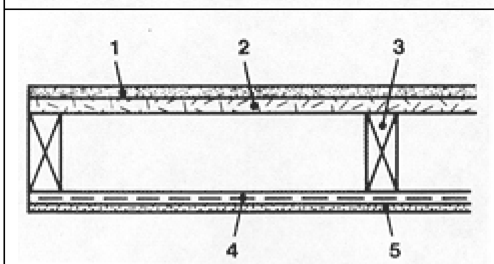
Sketch	Brief Description	STC
	1. 8x8x18” 3-cell lightweight concrete masonry units (38 lbs./block).	49
	1. 8x8x18” 3-cell lightweight concrete masonry units (34 lbs./block). 2. Expanded mineral loose-fill insulation.	51
	1. 8x8x18” 3-cell lightweight concrete masonry units (38 lbs./block). 2. Expanded mineral loose-fill insulation.	51
	1. 8x8x18” 3-cell lightweight concrete masonry units (33 lbs./block). 2. Grout in cells. 3. #5 bar in each cell.	48
	1. 8x8x18” 3-cell lightweight concrete masonry units (33 lbs./block). 2. Grout in cells. 3. #5 bar each cell. 4. Paint two coats flat latex each side.	55
	1. 12x8x16” 3-cell lightweight concrete masonry units (43 lbs./block).	39

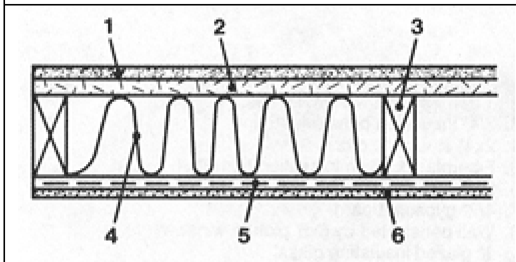
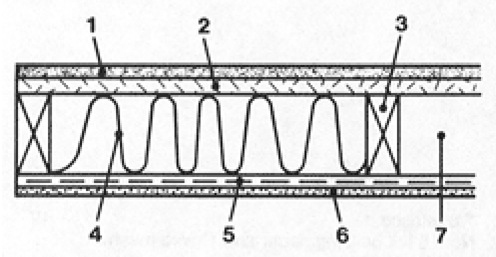
A-4

Sketch	Brief Description	STC
	1. 12x8x16. 3-cell lightweight concrete masonry units (43 lbs./block). 2. Paint both sides with 3 coats of latex block filler.	50
	1. 12x8x16" 3-cell lightweight concrete masonry units (43 lbs./block). 2. Paint one side only with 3 coats latex block filler.	51
	1. 6" cast concrete wall (71 psf).	57
	1. 6" cast concrete wall. 2. "Z" furring channels. 3. ½" gypsum board.	59
	1. 6" cast concrete wall. 2. "Z" furring channels. 3. 1", 8-pcf rockwool. 4. ½" gypsum board.	62
	1. 6" cast concrete wall. 2. 2x2" wood furring. 3. 1 ½" 4-pcf rockwool. 4. ½" gypsum board.	63

A-5

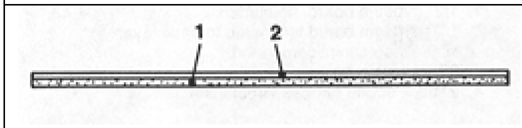
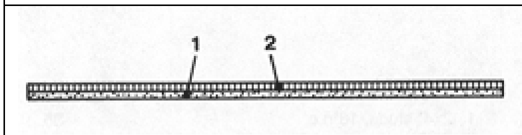
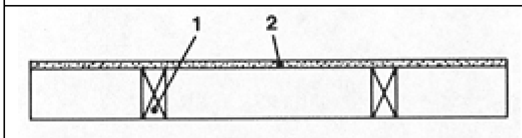
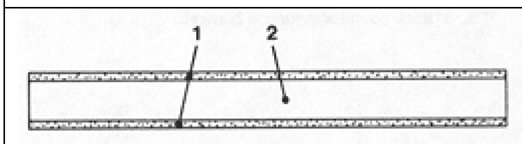
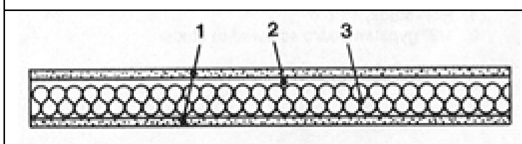
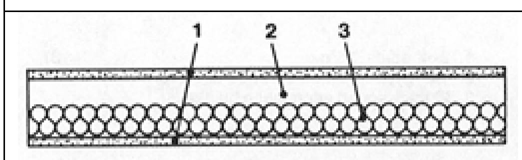
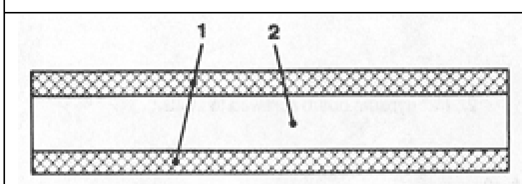
Sketch	Brief Description	STC
	1. 8” cast concrete wall (96.6 psf).	58
	1. 8” cast concrete wall. 2. 2x2” wood furring. 3. ½” gypsum board.	59
	1. 8” cast concrete wall. 2. 2x2” wood furring. 3. 1 ½”, 4 psf rockwall. 4. ½” gypsum board.	63
	1. Face brick. 2. ½” air space, with metal ties. 3. ¾” insulation board sheathing. 4. 2x4” studs 16”o.c. 5. Resilient channel. 6. ½” gypsum board.	54
	1. Face brick. 2. ½” air space, with metal ties. 3. ¾” insulation board sheathing. 4. 2x4” studs 16”o.c. 5. Fiberglas building insulation (3 ½”). 6. Resilient channel. 7. ½” gypsum board.	56

Sketch	Brief Description	STC
	1. Face brick (9x14’ wall). 2. ½” air space, with metal ties. 3. ¾” insulation board sheathing. 4. 2x4” studs 16”o.c. 5. Fiberglas building insulation (3 ½”). 6. Resilient channel. 7. ½” gypsum board. 8. Wall penetrated by 6x5' picture window 1” glazed insulating glass.	39
	1. 7/8” stucco. 2. No.15 felt building paper and 1” wire mesh. 3. 2x4” studs 16”o.c. 4. Resilient channel. 5. ½” gypsum board screwed to channel.	49
	1. 7/8” stucco. 2. No.15 felt building paper and 1” wire mesh. 3. 2x4” studs 16”o.c. 4. Fiberglas building insulation (3 ½”). 5. Resilient channel. 6. ½” gypsum board screwed to channel.	57
	1. 5/8 x 10” redwood siding. 2. ½” insulation board sheathing. 3. 2x4” wood studs 16”o.c. 4. Resilient channel. 5. ½” gypsum board screwed to channel.	43

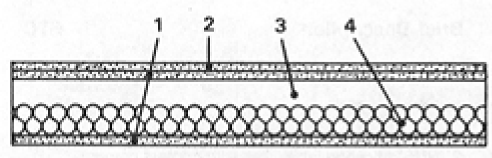
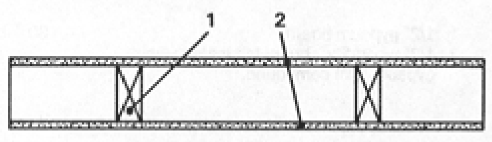
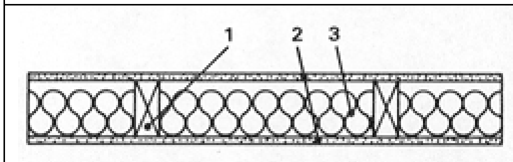
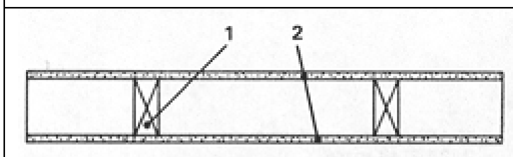
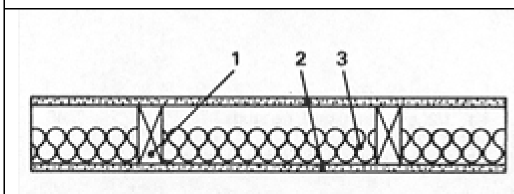
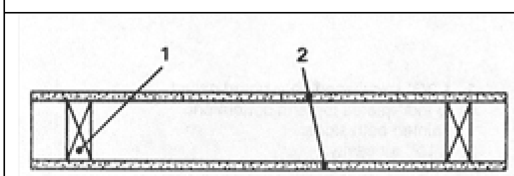
Sketch	Brief Description	STC
	1. 5/8x10” redwood siding. 2. ½” insulation board sheathing. 3. 2x4” wood studs 16”o.c. 4. Fiberglas building insulation (3 ½”). 5. Resilient channel. 6. ½” gypsum board screwed to channel.	47
	1. 5/8x10” redwood siding (9x14' wall). 2. ½” insulation board sheathing. 3. 2x4” wood studs 16.o.c. 4. Fiberglas building insulation (3 ½”). 5. Resilient channel. 6. ½” gypsum board screwed to channel. 7. a. Wall penetrated by a 6x5' picture window, 1” glazed insulating glass. b. Wall penetrated by a 6x5' 16 panel window, glazed single strength.	(a.38) (b.35)

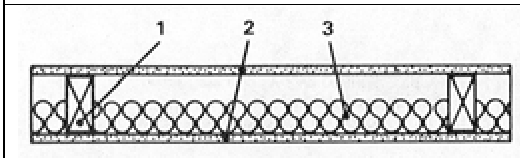
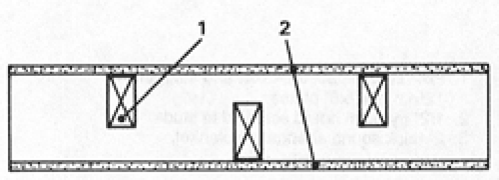
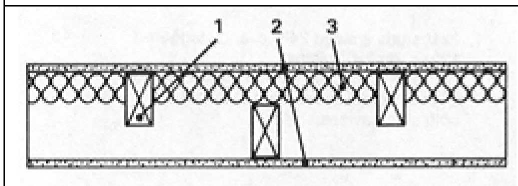
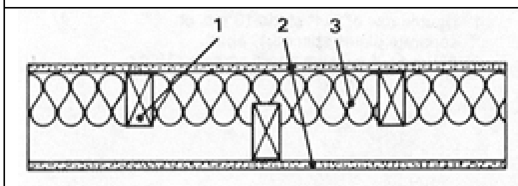
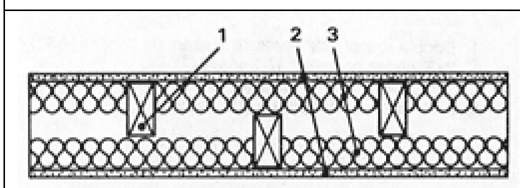
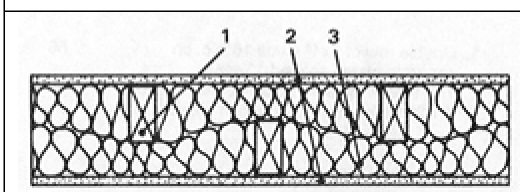
A-8

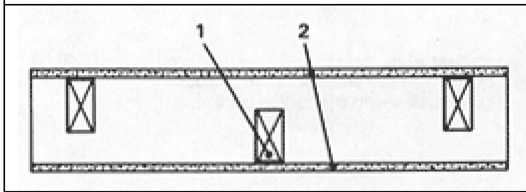
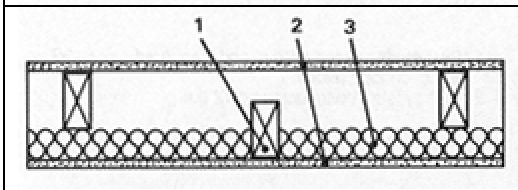
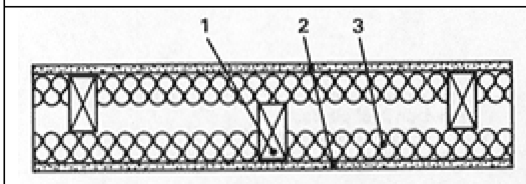
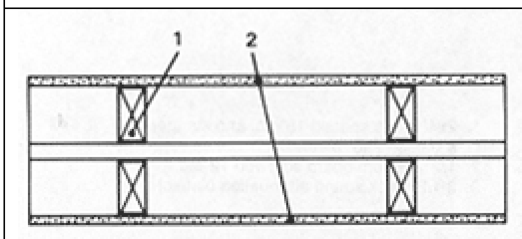
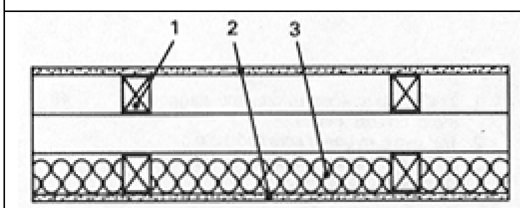
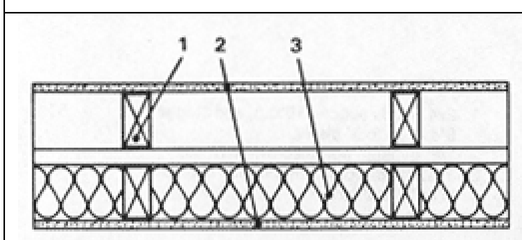
WALLS: Interior: Wooden Studs

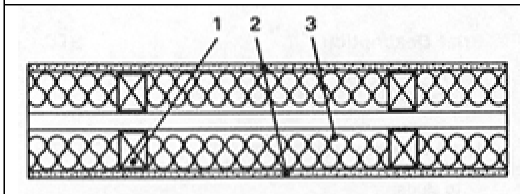
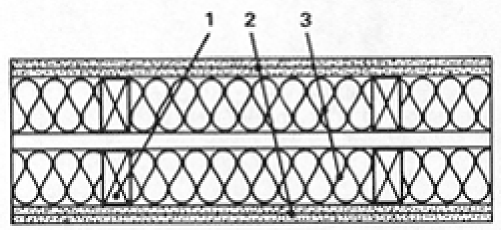
Sketch	Brief Description	STC
	1. ½” gypsum board. 2. 3/16” plywood laminated with contact cement.	28
	1. ½” gypsum board. 2. ½” wood-fiber board laminated with gypsum joint compound.	30
	1. 2x4” studs, 16”o.c. 2. 5/8” gypsum board screwed to studs.	28
	1. ½” gypsum board, no studs. 2. 2 ½” air space.	30
	1. ½” gypsum board, no studs. 2. 2 ½” air space. 3. 2” thick sound attenuation blanket.	44
	1. ½” gypsum board, no studs. 2. 3 5/8” air space. 3. 2” thick sound attenuation blanket.	45
	1. 1 3/8” thick wood-fiber board nailed to 2x4” plates top and bottom and painted both sides. 2. 3 ½” air cavity.	44

A-9

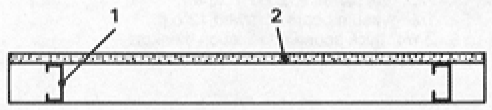
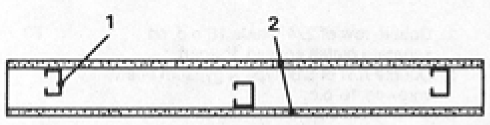
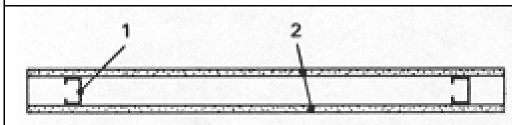
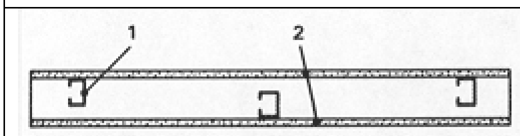
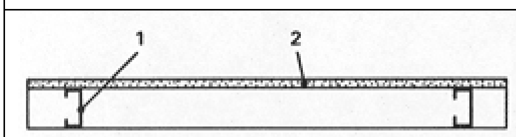
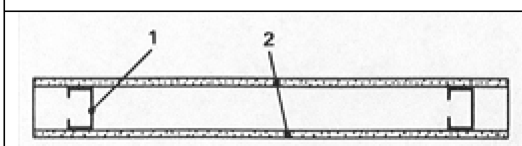
Sketch	Brief Description	STC
	1. ½” gypsum board, no studs. 2. ½” gypsum board laminated to base layer with gypsum joint compound. 3. 3 5/8” air cavity. 4. 2” thick sound attenuation blanket.	48
	1. 2x4” studs, 16”o.c. 2. 3/8” gypsum board nailed to studs.	35
	1. 2x4” studs, 16”o.c. 2. 3/8” gypsum board nailed to studs. 3. 3” thick sound attenuation blanket.	41
	1. 2x4” studs, 16”o.c. 2. ½” gypsum board screwed to studs.	34
	1. 2x4” studs, 16”o.c. 2. ½” gypsum board screwed to studs. 3. 2” thick sound attenuation blanket.	37
	1. 2x4” studs, 24”o.c. 2. ½” gypsum board screwed to studs.	36

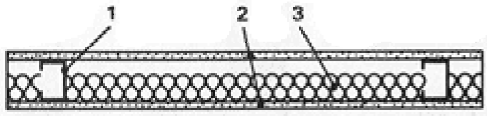
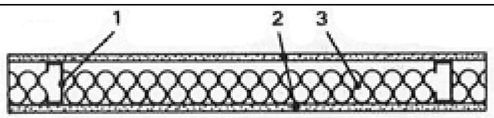
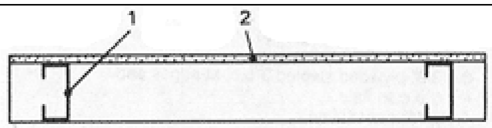
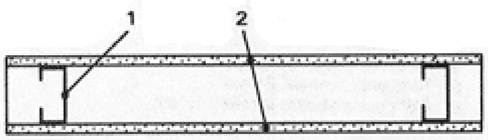
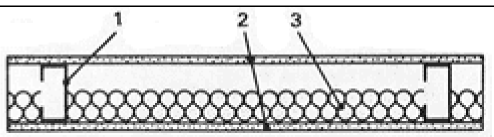
Sketch	Brief Description	STC
	1. 2x4"studs, 24"o.c. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	40
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c.	39
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 2 ¼" thick sound attenuation blanket.	48
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 3 ½" thick sound attenuation blanket.	49
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 2 ¼" thick sound attenuation blankets in both stud cavities.	49
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 3 ½" thick sound attenuation blankets in both stud cavities.	51

Sketch	Brief Description	STC
	1. 2x4" studs spaced 24"o.c. and staggered 12"o.c. on 2x6" plates. 2. ½" type X gypsum board screwed 12"o.c.	42
	1. 2x4" studs spaced 24"o.c. and staggered 12"o.c. on 2x6" plates. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	46
	1. 2x4" studs spaced 24"o.c. and staggered 12"o.c. on 2x6" plates. 2. ½" type X gypsum board screwed 12"o.c. 3. 2" thick sound attenuation blankets in both stud cavities.	48
	1. Double row of 2x4" studs 16"o.c. on separate plates spaced 1" apart. 2. ½" type X gypsum board screwed 12"o.c.	47
	1. Double row of 2x3" studs 16"o.c. on 2x3" plates spaced 2 ½" apart. 2. ½" gypsum board screwed 16"o.c. 3. 2 ¼" thick sound attenuation blanket.	55
	1. Double row of 2x4" studs 16"o.c. on separate plates spaced 1" apart. 2. ½" type X gypsum board screwed 12"o.c. 3. 3 ½" thick sound attenuation blanket.	56

Sketch	Brief Description	STC
	1. Double row of 2x4" studs 16"o.c. on separate plates spaced 1" apart. 2. ½" gypsum board screwed 12"o.c. 3. 2 ¼" thick sound attenuation blankets in both stud cavities.	56
	1. Double row of 2x4" studs 16.o.c. on separate plates spaced 1" apart. 2. Double row of 5/8" type X gypsum board screwed 16.o.c. 3. 3 ½" thick sound attenuation blankets in both stud cavities.	63

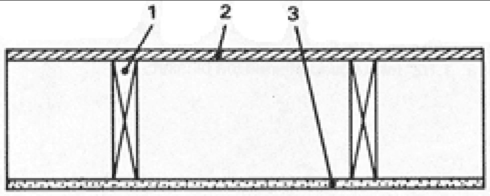
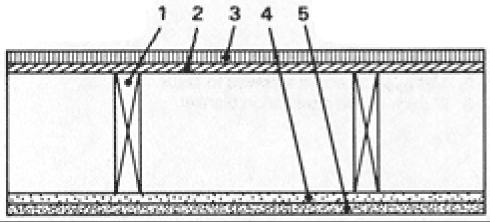
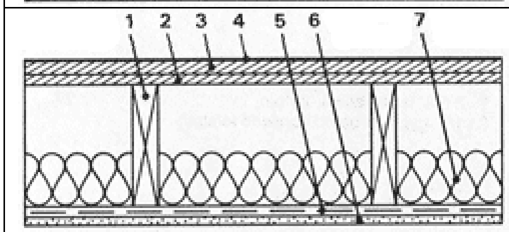
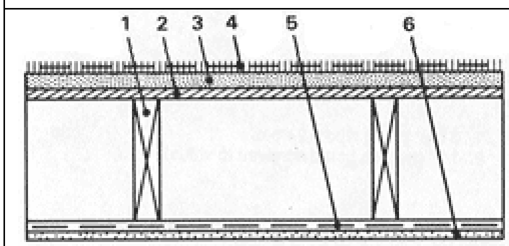
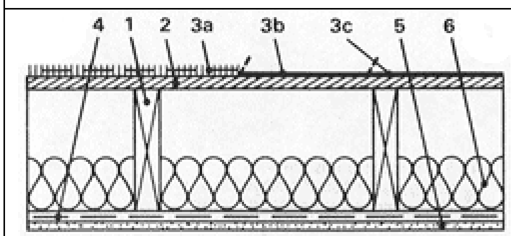
WALLS: Interior: Metal Studs

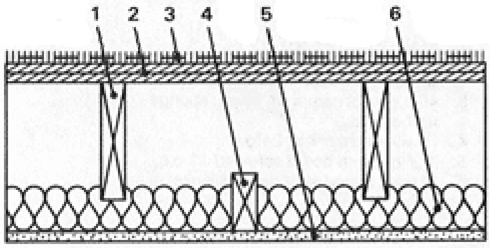
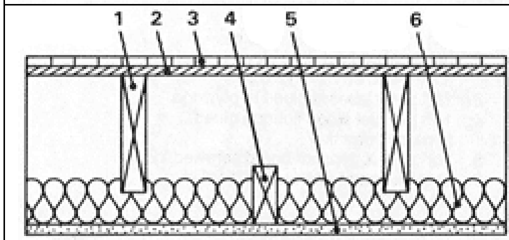
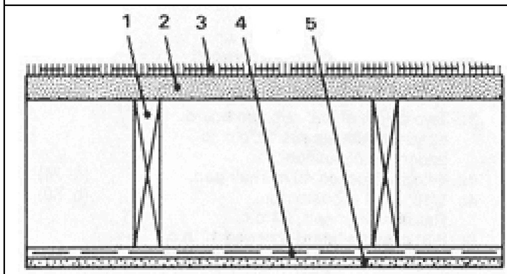
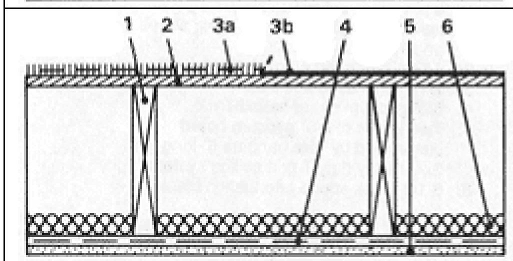
Sketch	Brief Description	STC
	1. 1 5/8” metal studs, 24”o.c. 2. 1/2. vinyl-faced gypsum board screwed to studs.	27
	1. 1 5/8” metal studs spaced 24”o.c. and staggered 12”o.c. on 2 ½” metal tracks. 2. 1/2” gypsum board screwed to studs.	34
	1. 1 5/8” metal studs, 24”o.c. 2. 5/8” gypsum board screwed 12”o.c. at edges and 24”o.c. in field.	37
	1. 1 5/8” metal studs spaced 24”o.c. and staggered 12”o.c. on 21/2” metal channels. 2. 5/8” gypsum board screwed to studs.	38
	1. 2 ½” metal studs, 24”o.c. 2. 1/2” vinyl-faced gypsum board screwed to studs.	27
	1. 2 1/2” metal studs, 24”o.c. 2. 5/8” gypsum board screwed to studs.	37

Sketch	Brief Description	STC
	1. 2 ½” metal studs, 24”o.c. 2. 5/8” gypsum board screwed 12”o.c. at edges and 24”o.c. in field. 3. 1 ½” thick sound attenuation blanket.	42
	1. 2 ½” metal studs, 24”o.c. 2. ½” gypsum board screwed to studs. 3. 2” thick sound attenuation blanket.	44
	1. 3 5/8” metal studs, 24”o.c. 2. 1/2. gypsum board screwed to studs.	27
	1. 3 5/8” metal studs, 24”o.c. 2. ½” gypsum board screwed to studs.	36
	1. 3 5/8” metal studs, 24”o.c. 2. ½” gypsum board screwed to studs. 3. 2” thick sound attenuation blanket.	44

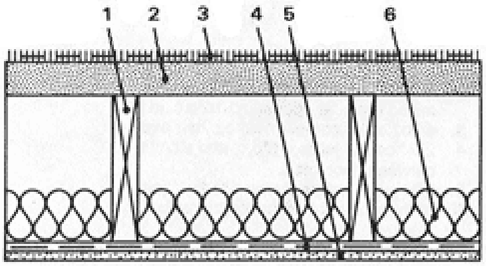
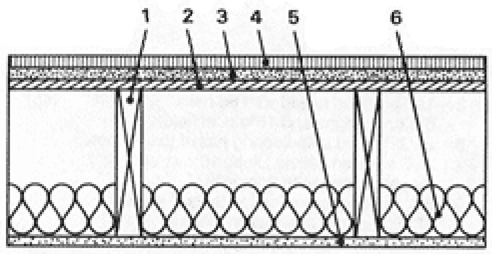
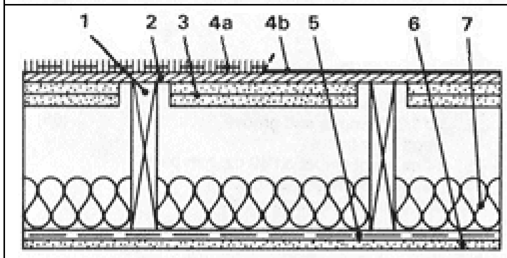
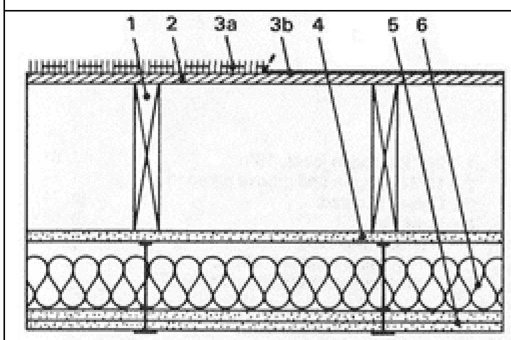
A-15

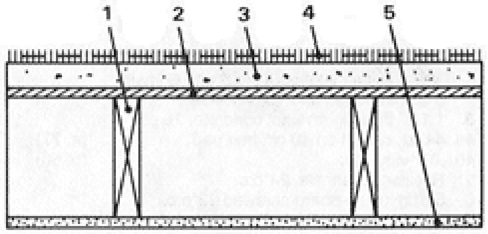
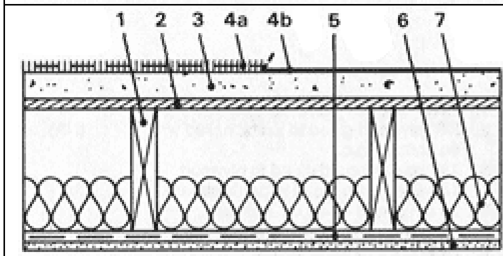
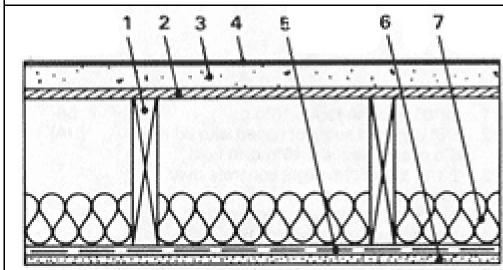
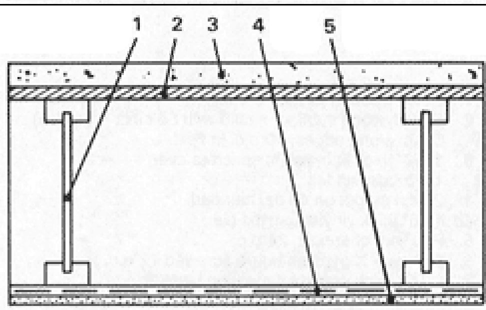
Floors: Wood

Sketch	Brief Description	STC (IIC)
	1. 2x8" wooden joists, 16"o.c. 2. 7/8" tongue and groove nailed to joints. 3. 3/8" gypsum nailed to joints.	NA (32)
	1. 2x8" wooden joists, 16"o.c. 2. ½" plywood nailed. 3. 25/32" hardwood flooring. 4. 1/2" gypsum nailed to joists. 5. Ceiling tire.	NA (37)
	1. 2x8" wooden joists, 16"o.c. 2. 5/8" tongue and groove plywood nailed with 8d nails 6"o.c. 3. 3/8" plywood stapled 3"o.c. at edges and 6"o.c. in field. 4. .075" sheet vinyl. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed 12"o.c. 7. 3" thick sound attenuation blanket.	46 (44)
	1. 2x8" wooden joists, 16"o.c. 2. 5/8" plywood nailed with 8d nails. 3. ½" nominal wood-fiber board glued to plywood. 4. 44 oz. carpet on 50 oz. pad. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed 12"o.c.	48 (65)
	1. 2x8" wooden joists, 16"o.c. 2. 19/32" tongue and groove plywood nailed with 8d nails 6"o.c. at edges and 10"o.c. in field. 3. a. 44 oz. carpet on 40 oz. hair pad. b. .075" sheet vinyl. c. 1/16" sheet vinyl. 4. Resilient channels, 24"o.c. 5. 5/8" gypsum board screwed 12"o.c. 6. 3" thick sound attenuation blanket.	48 (a. 69) (b. 45) (c.43)

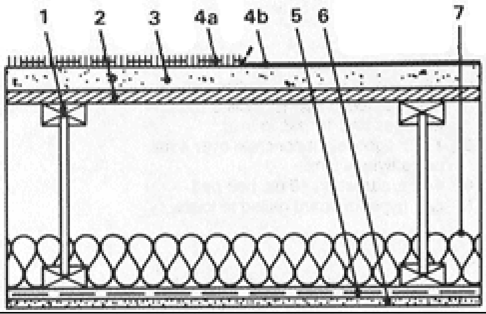
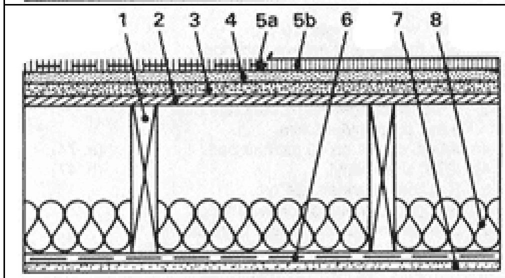
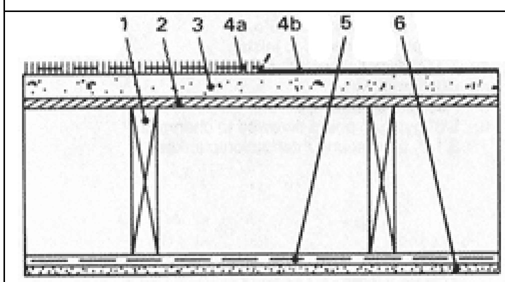
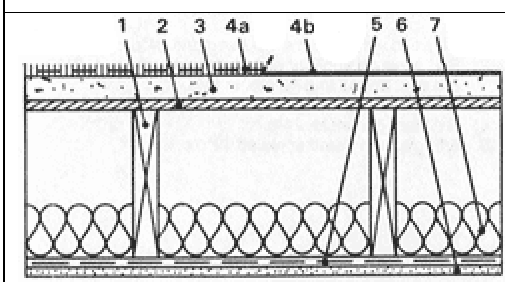
Sketch	Brief Description	STC (IIC)
	1. 2x8” wooden joists, 16”o.c. 2. 1 1/8” tongue and groove plywood nailed 6”o.c. at edges and 16”o.c. in field. 3. 44 oz. wool carpet on 40 oz. hair pad. 4. 2x4” ceiling joists, 16”o.c. and staggered between floor joists. 5. 5/8” gypsum board nailed to 2x4” joists. 6. 3” thick sound attenuation blanket.	53 (80)
	1. 2x8” wooden joists, 16”o.c. 2. 1/2” plywood nailed with 8d nails 6”o.c. at edges and 16”o.c. in field. 3. 25/32” wood strip flooring nailed to sub floor. 4. 2x4” wooden ceiling joists, 16”o.c. and staggered between floor joists. 5. 5/8” gypsum board nailed to 2x4” joists. 6. 3” thick sound attenuation blanket.	54 (45)
	1. 2x10” wooden joists, 16”o.c. 2. 1 11/32” tongue and groove wood-fiber board. 3. 44 oz. wool carpet on 40 oz. hair pad. 4. Resilient channels, 24”o.c. 5. 5/8” gypsum screwed 12”o.c.	49 (68)
	1. 2x10” wooden joists, 16”o.c. 2. 19/32” tongue and groove plywood. 3. a. Carpet and pad. b. Vinyl tile. 4. Resilient channels, 24”o.c. 5. 5/8” gypsum screwed 12”o.c. 6. 1” thick sound attenuation blanket.	51 (a. 74) (b.51)

A-17

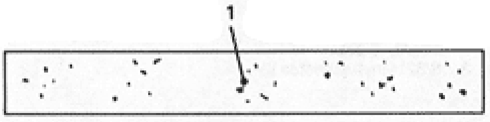
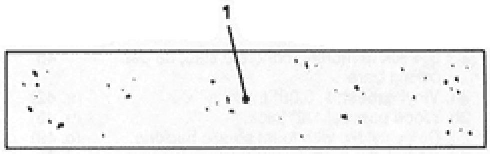
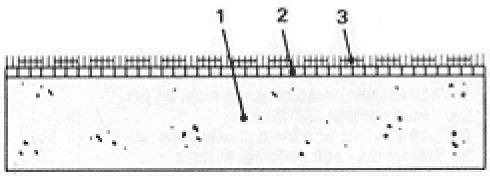
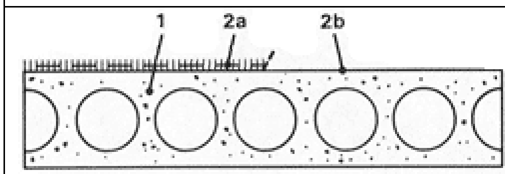
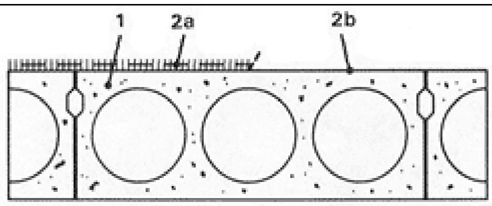
Sketch	Brief Description	STC (IIC)
	1. 2x10” wooden joists, 16”o.c. 2. 1 11/32” tongue and groove wood-fiber board. 3. 40 oz. wool carpet on 80 oz. sponge rubber pad. 4. Resilient channels, 24”o.c. 5. 1/2” gypsum board screwed 12”o.c. 6. 3” thick sound attenuation blanket.	50 (72)
	1. 2x10” wooden joists, 16”o.c. 2. 5/8” plywood sub floor glued to joists, nailed with 8d nails 12”o.c. 3. ¼” particleboard glued to plywood. 4. ½” parquet wood flooring glued to particleboard. 5. ½” type-X gypsum board screwed 12”o.c. 6. 3” thick sound attenuation blanket.	43 (NA)
	1. 2x10” wooden joists, 16”o.c. 2. 5/8” tongue and groove plywood nailed with 8d nails 6”o.c. along edges and 10”o.c. in field. 3. Two layers of 5/8” gypsum board attached with screws 12”o.c. to underside of sub floor. 4. a. 44 oz. carpet on 40 oz. hair pad. b. 1/16” vinyl asbestos tile. 5. Resilient channels, 24”o.c. 6. 5/8” gypsum board screwed 12”o.c. 7. 3 ½” thick sound attenuation blanket.	56 (a. 74) (b.50)
	1. 2x10” wooden joists, 16”o.c. 2. 5/8” tongue and groove plywood nailed with 8d nails 6”o.c. along edges and 10”o.c. in field. 3. a. 44 oz. carpet on 40 oz. hair pad. b. 1/16” vinyl asbestos tile. 4. 5/8” gypsum board nailed 7”o.c. 5. Two layers of 5/8” gypsum board suspended by wire hangers 5” long in a 2x4' heavy-duty T grid ceiling system. 6. 3 ½” thick sound attenuation blanket.	49 (a. 68) (b.47)

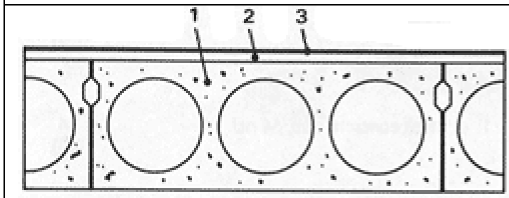
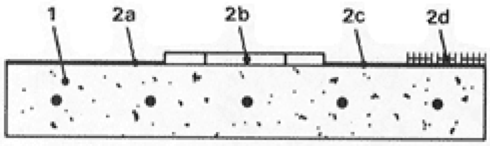
Sketch	Brief Description	STC (IIC)
	1. 2x8” wooden joists, 16”o.c. 2. 5/8” tongue and groove plywood nailed to joists with 8d nails 6”o.c. at edges and 10”o.c. in field. 3. 1 5/8” lightweight concrete over 4 mil. polyethylene film. 4. 44 oz. carpet on 40 oz. hair pad. 5. 5/8” gypsum board nailed to joists.	47 (66)
	1. 2x8” wooden joists, 16”o.c. 2. 5/8” tongue and groove plywood nailed to joists with 8d nails 6”o.c. at edges and 10”o.c. in field. 3. 1 5/8” thick lightweight concrete over 4 mil. polyethylene film. 4. a. 44 oz. carpet on 40 oz. hair pad. b. .075” sheet vinyl. 5. Resilient channels, 24”o.c. 6. 5/8” gypsum board screwed 12”o.c. 7. 3” thick sound attenuation blanket.	53 (a. 74) (b. 47)
	1. 2x10” wooden joists. 16”o.c. 2. 5/8” plywood nailed to joists. 3. 3. 1 ½” thick lightweight concrete, 13 psf. 4. Cushioned vinyl. 5. Resilient channels, 24”o.c. 6. 5/8” gypsum board screwed to channels. 7. 3 ½” thick sound attenuation blanket.	NA (51)
	1. Plywood web I-beams 12” deep and 24”o.c. 2. 3/4” plywood sub floor nailed with 6d nails 6”o.c. at edges and 10”o.c. in field. 3. 1 ½” thick lightweight concrete, 15 psf. 4. Resilient channels, 24”o.c. 5. 5/8” gypsum board screwed 12”o.c.	57 (NA)

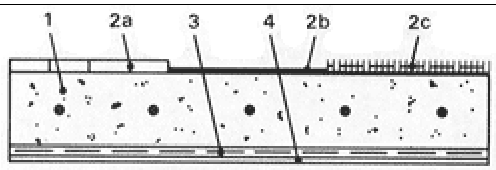
A-19

Sketch	Brief Description	STC (IIC)
	1. Plywood web I-beams 12” deep and 24”o.c. 2. 3/4” plywood sub floor nailed with 6d nails 6”o.c. at edges and 10”o.c. in field. 3. 1 1/2” thick lightweight concrete, 15 psf. 4. a. 44 oz. carpet on 40 oz. hair pad. b. .07” vinyl tile. 5. Resilient channels, 24.o.c. 6. 5/8” gypsum board screwed 12”o.c. 7. 3” thick sound attenuation blanket.	58 (a. 77) (b. 50)
	1. 2x10” wooden joists, 16”o.c. 2. 5/8” plywood glued to joists, nailed with 8d nails 12”o.c. 3. ¼” particleboard glued to plywood. 4. ½” fiberboard glued to particleboard. 5. a. 76 oz. carpet on 50 oz. hair pad. b. 1/2” parquet wood flooring. 6. Resilient channels, 24”o.c. 7. ½” type-X gypsum board screwed 12”o.c. 8. 3” thick sound attenuation blanket.	51 (NA)
	1. 2x10” wooden joists, 16”o.c. 2. 5/8” plywood sub floor nailed with 8d nails 6”o.c. along edges, 10”o.c. in field. 3. 1 1/2” thick lightweight concrete over 15 lb. asphalt felt. 4. a. 20 oz. carpet on 40 oz. hair pad. b. 1/16” thick vinyl-asbestos tile. 5. Resilient channels, 24”o.c. 6. ½” type-X gypsum board screwed 12”o.c.	56 (NA)
	1. 2x10” wooden joists, 16”o.c. 2. 5/8” plywood sub floor nailed with 8d nails 6”o.c. along edges, 10”o.c. in field. 3. 1 ½” thick lightweight concrete over 15 lb. asphalt felt. 4. a. 20 oz. carpet on 40 oz. hair pad. b. 1/16” thick vinyl-asbestos tile. 5. Resilient channels, 24”o.c. 6. 5/8” type-X gypsum board screwed 12”o.c. 7. 3 ½” thick sound attenuation blanket.	61 (NA)

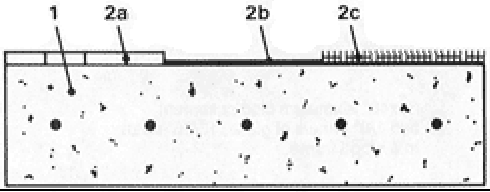
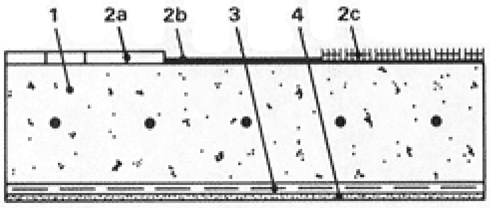
FLOORS: Concrete

Sketch	Brief Description	STC (IIC)
	1. 4” thick concrete slab, 54 psf.	44 (25)
	1. 6” thick concrete slab, 75 psf.	55 (34)
	1. 6” thick concrete slab. 2. ½” wood-fiber board glued to concrete. 3. 44 oz. carpet on 40 oz. hair pad.	NA (81)
	1. 6” thick hollow-core concrete panel, 45 psf. 2. a. Carpet and pad. b. No floor covering.	48 (a. 69) (b. 23)
	1. 8” thick hollow-core concrete panel, 57 psf. 2. a. 66 oz. carpet on 50 oz. hair pad. b. No floor covering.	50 (a. 74) (b. 28)

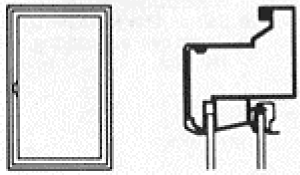
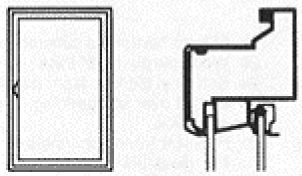
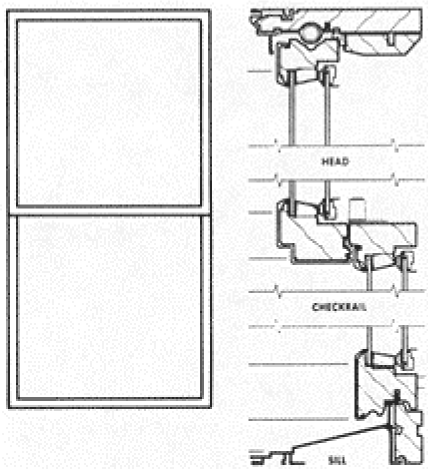
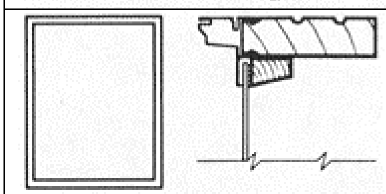
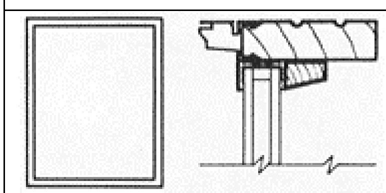
<table>
<tr><th>Sketch</th><th>Brief Description</th><th>STC
(IIC)</th></tr>
<tr><td>
</td><td>1. 8” thick hollow-core concrete panels, 57 psf.
2. 1/4” inorganic felt-supported underlayment board, .6 psf.
3. 3/32” vinyl-asbestos tile.</td><td>50
(51)</td></tr>
<tr><td>
</td><td>1. 3” thick reinforced concrete slab, 35 psf, ceiling bare.
2.
a. Vinyl asbestos, 0.08” thick.
b. Wood parquet 1/2” thick.
c. Soft vinyl tile with foam plastic backing.
d. Carpet over soft padding, at least ¼” thick.</td><td>45

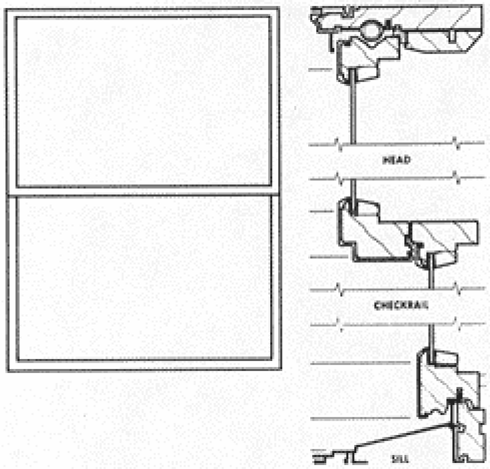
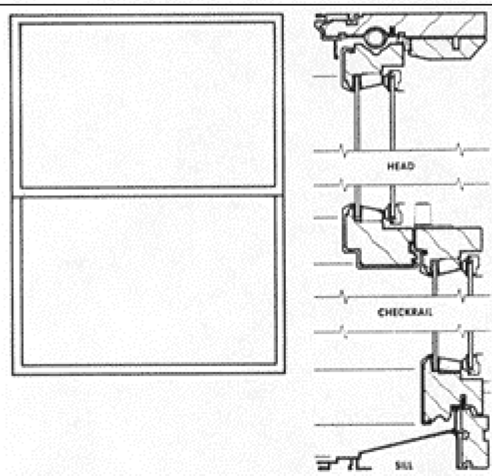
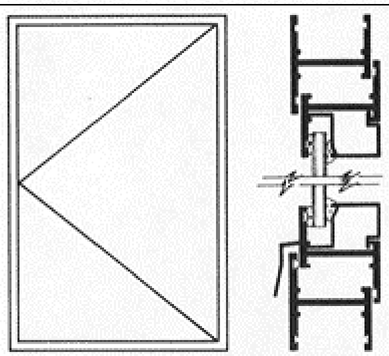
(a. 42)
(b.45)
(c. 49)
(d. 70)</td></tr>
<tr><td>
</td><td>1. 3” thick reinforced concrete slab, 35 psf.
2.
a. Wood parquet ½” thick.
b. Soft vinyl tile with foam plastic backing.
c. Carpet over soft padding, at least ¼” thick.
3. Resilient furring channels on ½” fiberglass blanket.
4. ½” gypsum board.</td><td>56

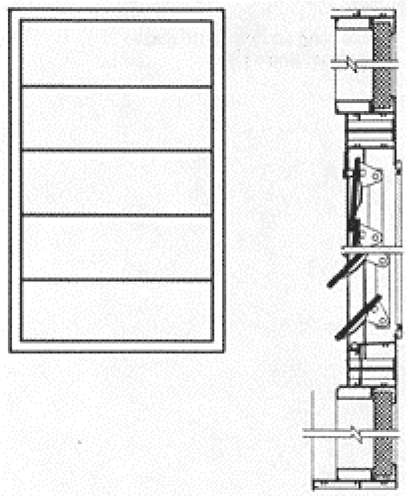
(a.51)
(b. 55)
(c. 70)</td></tr>
</table>

Sketch	Brief Description	STC (IIC)
	1. 5” thick reinforced concrete slab, 55 psf. ceiling bare. 2. a. Wood parquet ½” thick. b. Soft vinyl tile with foam plastic backing. c. Carpet over soft padding, at least ¼” thick.	51 (a. 46) (b. 50) (c. 70)
	1. 5” thick reinforced concrete slab, 55 psf. 2. a. Wood parquet ½” thick. b. Soft vinyl tile with foam plastic backing c. Carpet over soft padding, at least ¼” thick. 3. Resilient furring channels on ½” fiberglass blankets. 4. ½” gypsum board.	56 (a. 51) (b. 55) (c. 75)

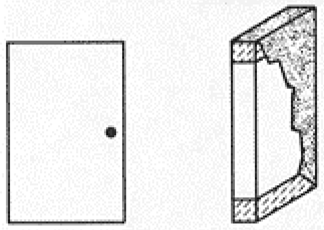
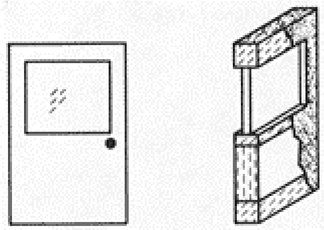
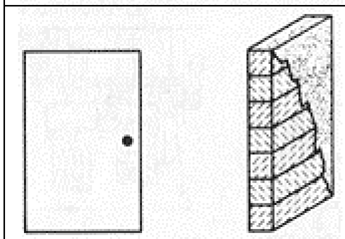
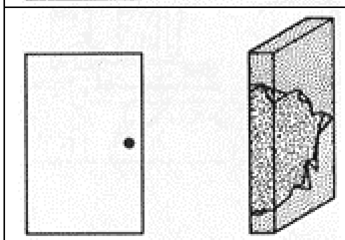
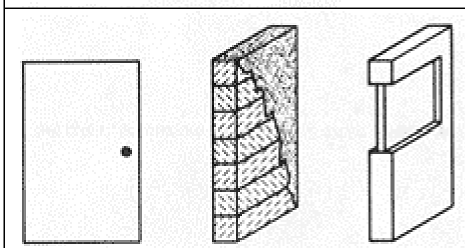
A-23

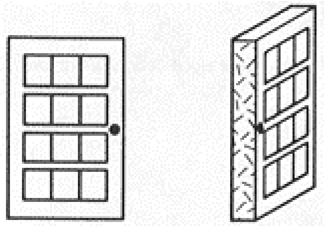
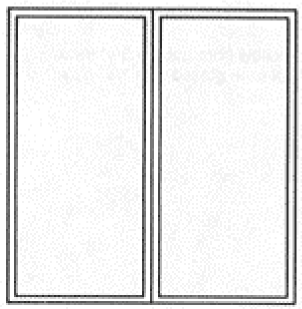
Sketch Front / Cross Section	Brief Description	STC
	30x48" aluminum clad casement, two 1/8" panels of glass, 13/16" apart in a wood frame.	29
	30x48" aluminum clad casement, one 3/32" panel and one 1/8" panel, 13/16" apart in a wood frame.	31
	32x24x24" aluminum double-hung windows (32" wide with 24" high upper sash and a 24" high lower sash), each sash has one 3/32" panel and one 1/8" panel, 13/16" apart in a wood frame.	29
	6x5' picture window glazed double strength, single panel.	29
	6x5' picture window plus storm sash, glazed double strength single panel, 3 ¾" separation between panels.	38

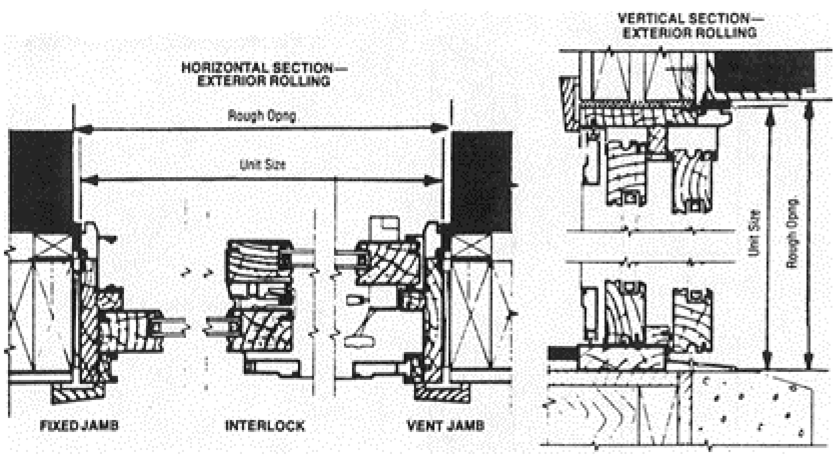
Sketch Front / Cross Section	Brief Description	STC
	3x5' double hung window, 7/16" glazed insulating glass, single panel.	26
	3x5' double hung window, 7/16" glazed insulating glass, single panel plus storm sash, glazed single strength, single sealed separation between panels: upper 1 ½", lower 2 13/16".	35
	3x4' awning window, glazed double strength, cranked shut.	24

Sketch Front / Cross Section	Brief Description	STC
	3x4' jalousie window, glazed ¼” glass, 4 ½” wide louvers with ½” in overlap, cranked tight shut.	20

DOORS: Exterior

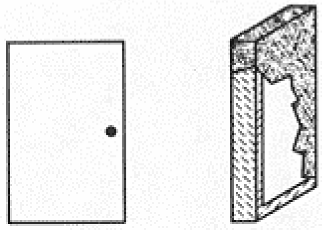
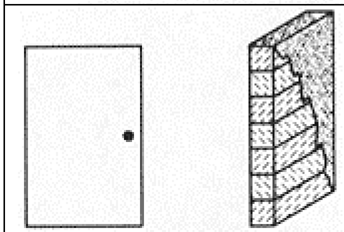
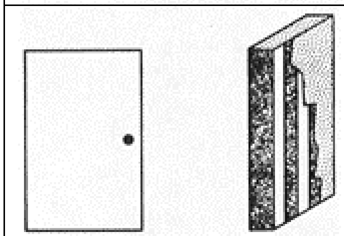
Sketch Front / Cross Section	Brief Description	STC
	3x7' hollow-core wood door, 1 ¾” thick.	20
	3x7' hollow-core door, 1 3/4” thick, 30% of area glazed with 1/8” glass.	19
	3x7' solid-core wood door, 1 ¾” thick.	27
	3x7' steel-faced door, 1 ¾” thick, rigid polyurethane core.	26
	3x7' solid-core wood door, 1 ¾” thick plus an aluminum storm door, glazed single strength.	34

Sketch Front / Cross Section	Brief Description	STC
	3x7' wood French door, 12 lights glazed single strength, mounted in frame, brass weather strip.	26
	6x6' sliding glass doors, ¾" insulating glass (2 pieces 1/8" tempered glass), one door opens, other is permanent in place.	28



*All exterior doors are sealed with a weathering strip around the frame. Interior doors do not have a weather strip and are not flush to the floor to permit the installation of a carpet.

DOORS: Interior

Sketch Front / Cross Section	Brief Description	STC
	3x7' solid-core wood door, 1 ¾” thick, weight 1.5 lb/ft².	17
	3x7' solid-core wood door, 1 ¾” thick, weight 4.0 lb/ft².	20
	3x7' hollow-core steel door, 1 ¾” thick, weight 5.0 lb/ft².	17

Appendix B References

Appendix B
General References

Books:
Acoustical and Thermal Performance of Exterior Residential Walls. Doors and Windows; NBS Building Science Series 77, U.S. Department of Commerce/National Bureau of Standards, 1975.

Acoustics Noise and Buildings; Parkin, Humphreys and Cowell; Faber and Faber; London; 1979.

Airborne Sound Transmission Loss, Characteristics of Wood Frame Construction; Fred F. Rudder, Jr.; USDA, Forest Service; General Technical Report FPL-43.

Handbook of Architectural Acoustics and Noise Control; Michael Retting; Tab Book; Blue Ridge Summit, Pa.; 1979.

Quieting: A Practical Guide to Noise Controls; U.S. Department of Commerce/National Bureau of Standards; NBS Handbook 119; 1976.

Institutions and Organizations:

Amerada Architectural Glass.
DeSco Windows.
Georgia-Pacific.
Industrial Acoustics Company.
National Concrete Masonry Association.
Office of Noise Control; California Department of Health Services.
Overly Manufacturing Company.
Paella Products.
Portland Cement Association.
U.S. Gypsum Company.

Testing Laboratories:

Cedar Knolls Acoustical Laboratories.
Geiger and Hamme.
Kaiser Gypsum.
Kodaras Acoustical.
National Institute of Standards and Technology.
National Research Council of Canada.
Riberbank Acoustical Laboratories.

Replace whole Ventilation Appendix (except B201.1.2 & B201.3; Tables TABLE B201.1 a & b) with:

The ventilation rate shall be as defined in IRC section M1507.3.3as equation 15-1 (shown below) Ventilation rate in cubic feet per minute = (0.01 x total square foot area of house) + [7.5x (number of bedrooms + 1)] * coefficient

Where coefficients are as follows:
Balanced/Distributed/Mixed Coefficient 0.75
Example; HRV's/ERV's/ or supply linked with exhaust fan with forced air (furnace/AC) run time

Unbalanced/Distributed/Mixed Coefficient1.0
Example; Exhaust fan or supply fan or supply air duct to air handler with forced air (furnace/AC) run time

Unbalanced/Distributed/Not Mixed Coefficient1.25
Example; Multi point exhaust fan without a forced air system

Unbalanced/Not Distributed/Not Mixed Coefficient 1.5
Example; Single point exhaust fan without a forced air system

"Distributed" shall apply where a ducted system serving heating, cooling and/or ventilation equipment supplies air directly to each bedroom and the largest common area; otherwise "not distributed" shall apply.

" Mixed" shall apply where not less than 70% of the whole building air volume is recirculated each hour by one or more mechanical systems, otherwise "not mixed" shall apply. Where a central heating or cooling air handler fan is used to provide the mixing, the design heating or cooling airflow rate shall be used to determine the operation time setting required.

"Balanced" shall apply where two or more fans simultaneously supply outdoor air and exhaust air where the total supply fan flow and the total exhaust fan flow are within 20 percent of each other; otherwise "not balanced" shall apply. Where outdoor air is supplied by a central forced air system, "balanced" shall apply only where the fan for such system operates simultaneously with the exhaust fan(s).

Retain and renumber:
Tables TABLE B201.1 a & b Ventilation Air Requirements
Add:
These tables are taken from the IRC 1507.3.3(1)

Add new section:
Balanced air flow is supply and exhaust within 20%. Points 10

Retain & renumber:

B201.1.2 Alternative Ventilation. Other methods may be used to provide the required ventilation rates when approved by a licensed design professional.

B201.3 Airflow Measurement. The airflow required by this section is the quantity of outdoor ventilation air supplied and/or indoor air exhausted by the ventilation system as installed and shall be measured using a flow hood, flow grid, or other airflow measuring device. Ventilation airflow of systems with multiple operating modes shall be tested in all modes designed to meet this section.

Reason:

Co-proponent is Joseph Lstiburek, representing himself.

The newest ASHRAE ventilation rate is excessive (ASHRAE 62.2-2013). This removes the reference to ASHRAE, and references the 2018 IRC. The NGBS should use the IRC ventilation rate in M1507.3.3, which is the same as the equation already in the NGBS.

This change adds consideration of ventilation quality. Balanced ventilation performs the best, hence less ventilation is needed. For a broader discussion of ventilation and what works best see
"***Balancing Act - Exhaust-Only Ventilation Does Not Work***" (BSI-012) at https://buildingscience.com/documents/building-science-insights/bsi-012-balancing-act-exhaust-only-ventilation-does-not-work
and "***First Deal with the Manure and Then Don't Suck***" (BSI-070)
at https://buildingscience.com/documents/insights/bsi-070-first-deal-with-the-manure

An example:
2,500 ft2 house with 3 bedrooms yields a base flow rate of 55 cfm
Balanced, mixed and distributed yields a flow rate of 41.25
Unbalanced, mixed and distributed yields a flow rate of 55 cfm
Unbalanced, not mixed but distributed yields a flow rate of 68.75 cfm
Unbalanced, not mixed, not distributed yields a flow rate of 82.5 cfm

Current ASHRAE Standard 62.2 yields a flow rate of 105 cfm - leading to high humidity problems in hot humid and mixed humid climates and excessive dryness in cold climates
ASHRAE Standard 62.2 - 2010 yields a flow rate of 55 cfm
Canadian Standard is 40 cfm for the above house but the requirement is for balanced, mixed and distributed ventilation via HRV's. So we are basing our rates on Canadian cold climate rates that have been in effect for 25 years.
The Minnesota rate is similar to the Canadian rate but does not have a requirement for mixing and distribution and balancing. We are more conservative than Minnesota.
The MASCO Environments for Living Program had to reduce the ventilation rates in Florida and Texas to the ASHRAE Standard 62.2 - 2010 rates to address the part load humidity and mold problems.

Substantiating information for proposal 6150 (Section 702.2.1 ICC IECC analysis) and 6149 (Section 305.3.5.1 Energy consumption reduction) submitted by Steve Rosenstock:

From the 2010 ASHRAE Energy Targets Report:

"The Vision 2020 Ad Hoc also realized that in order to make such a vision a reality, they would need to define a single meaning for net-zero
energy building. The conclusion they reached is supported by this Energy Targets Ad Hoc. Quoting from the Vision 2020 report:
"Ultimately, the only way to measure if a building is a NZEB is to look at the energy crossing the boundary. Other definitions, including source, emissions, and cost, are based on this measured information and include weighting factors and algorithms to get to the metric of interest. Because of the complications involved in making these computations, **site energy measurements** have been chosen through an agreement of understanding between ASHRAE, the American Institute of Architects (AIA), the U.S. Green Building Council (USGBC), and the Illuminating Engineering Society of North America (IESNA)."

From the ASHRAE February 2015 Letter to DOE:

"Recommendation II: Define "Net Zero Energy Building" Using Site Energy"

"However, the Society believes that the multiple and varying weighting factors and algorithms required for estimating source energy conversions are often inconsistent and ultimately cloud and complicate understanding. Since source energy conversion factors vary widely from place to place and across time, the use of fixed national average conversion factors could lead to inconsistent estimates of consumption.

Thus, in this case the best method for determining if a building is a NZEB is to look at the energy crossing the boundary at the site of the building; hence "site" energy is the best choice to use."

From the AGA paper of November 2015:

Based on the table from the report, buildings using renewable energy would get the worst "scores", as the incorrect estimated source multipliers are highest for renewable energy and lowest for natural gas.

Note: These are excerpts from
(1) ASHRAE Report of the Technology Council Ad Hoc Committee on Energy Targets 2010,
(2) ASHRAE letter to DOE RE: ROI on the Development of a Common Definition for Zero Energy Buildings, and
(3) Dispatching Direct Use: Achieving Greenhouse Gas Reduction with Natural Gas in Homes and Business paper 2015.
The full documents can be found on www.homeinnovation.com/ngbs

Table 1

National average full-fuel-cycle energy factors for electricity generated with different fuel types and for fossil fuels

Energy Type	Process energy efficiency (percent)						
	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	FFC Energy Conversion Factor
Electricity							
Coal	98.0	98.6	99.0	32.9	93.5	29.4	3.40
Oil	96.3	93.8	98.8	32.0	93.5	26.7	3.75
Natural Gas	96.2	97.0	99.3	43.2	93.5	37.4	2.67
Nuclear	99.0	96.2	99.9	32.6	93.5	29.0	3.45
Hydro	100.0	100.0	100.0	90.0	93.5	84.2	1.19
Biomass	99.4	95.0	97.5	24.4	93.5	21.0	4.76
Wind	100.0	100.0	100.0	26.0	93.5	24.3	4.11
Solar	100.0	100.0	100.0	12.0	93.5	11.2	8.91
Geothermal	100.0	100.0	100.0	16.0	93.5	15.0	6.68
U.S. Average	98.0	97.8	99.3	35.7	93.5	31.8	3.15
Fossil Fuels Used in Buildings							
Natural Gas	96.2	97.0	99.0	100.0	99.0	91.5	1.09
Heating Oil	94.9	89.1	99.7	100.0	99.6	84.0	1.19
Propane/LPG	94.6	93.6	99.2	100.0	99.2	87.1	1.15

Source: *Full-Fuel-Cycle energy and Emissions Factors for Building Energy Consumption – 2013 Update*. Gas Technology Institute.[2]

Steve Rosenstock, P.E.
Senior Manager, Energy Solutions
Edison Electric Institute
srosenstock@eei.org
202-508-5465

ENERGY STAR® Product Specification
Residential Windows, Doors, and Skylights

Eligibility Criteria
Version 6.0

Following is the Version 6.0 ENERGY STAR product specification for Windows, Doors, and Skylights. A product shall meet all of the identified criteria if it is to earn the ENERGY STAR.

1) **Definitions:** Below are the definitions of the relevant terms in this document. Most definitions are based on or pulled directly from the National Fenestration Rating Council (NFRC) 600 except where otherwise noted.

Product Types

A. Window: An assembled unit consisting of a frame/sash component holding one or more pieces of glazing functioning to admit light and/or air into an enclosure and designed for a vertical installation in an external wall of a Residential Building. Includes Transoms.

B. Door: A sliding or swinging entry system designed for and installed in a vertical wall separating conditioned and unconditioned space in a Residential Building. Includes Sidelites. ENERGY STAR recognizes three categories of Doors and Sidelites:

   i) Opaque: A Door or Sidelite with no glazing (per NFRC 100).

   ii) ≤ ½-Lite: A Door with ≤ 900 in^2 (0.581 m^2) of glazing or a Sidelite ≤ 281 in^2 (0.181m^2) of glazing (per NFRC 100). Includes ¼- and ½-lite Doors and Sidelites.

   iii) > ½-Lite: A Door with > 900 in^2 (0.581 m^2) of glazing or a Sidelite with > 281 in^2 (0.181m^2) of glazing (per NFRC 100). Includes ¾-lite and fully glazed Doors and Sidelites.

C. Skylight: A Window designed for sloped or horizontal application in the roof of a Residential Building, the primary purpose of which is to provide daylighting and/or ventilation.

Product Subcategories

D. Sliding Door: A Door that contains one or more manually operated panels that slide horizontally within a common frame.

E. Swinging Door: A Door system having, at a minimum, a hinge attachment of any type between a leaf and jamb, mullion, or edge of another leaf or having a single, fixed vertical axis about which the leaf rotates between open and closed positions.

F. Sidelite: A fenestration product with the NFRC product code FXSL.

G. Transom: A fenestration product with the NFRC product code FXTR.

H. Tubular Daylighting Device (TDD) or Tubular Skylight: A non-operable device primarily designed to transmit daylight from a roof surface of a Residential Building to an interior ceiling surface via a tubular conduit. The device consists of an exterior glazed weathering surface, a light transmitting tube with a reflective inside surface and an interior sealing device, such as a translucent ceiling panel. TDDs are considered Skylights.

I. Dynamic Glazing Product: Any fenestration product that has the fully reversible ability to change its performance properties, including U-Factor, Solar Heat Gain Coefficient (SHGC), or Visual Transmittance. This includes, but is not limited to, shading systems between the glazing layers and Chromogenic Glazing.

i) Chromogenic Glazing: A broad class of changeable glazings that have means to reversibly vary their optical properties, including active materials (e.g., electrochromic and Suspended Particle Device/SPD) and passive materials (e.g., photochromic, thermochromic, etc.).

ii) Internal Shading System: Operable blinds or shades positioned between glass panes in a Window, Door, or Skylight.

Performance Metrics

J. U-Factor: The heat transfer per time per area and per degree of temperature difference (Btu/h $ft^2 \cdot {}^\circ F$). The U-Factor multiplied by the interior-exterior temperature difference and by the projected fenestration product area yields the total heat transfer through the fenestration product due to conduction, convection, and long-wave infra-red radiation.

K. Solar Heat Gain Coefficient (SHGC): The ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation.

L. Air Leakage: The volume of air flowing per unit time per unit area (cfm/ft^2) through a fenestration system due to air pressure or temperature difference between the outdoor and indoor environment.

Other

M. Residential Building: A structure used primarily for living and sleeping that is zoned as residential and/or subject to Residential Building codes. For the purposes of ENERGY STAR, Residential Building refers to buildings that are three stories or less in height.

N. Insulating Glass Unit (IGU): A preassembled unit, comprising lites of glass, which are sealed at the edges and separated by dehydrated space(s).

O. North American Fenestration Standard (NAFS): The common name for the American Architectural Manufacturers Association (AAMA)/Window & Door Manufacturers Association (WDMA)/Canadian Standards Association (CSA) 101/I.S.2/A440 testing standard.

2) **Scope:**

A. Included Products: Products that meet the definition of a residential Window, Door, or Skylight as specified herein are eligible for ENERGY STAR qualification, with the exception of products listed in Section 2.B.

B. Excluded Products: Products that are assembled onsite, including but not limited to sash packs or sash kits; Windows, Doors, or Skylights that are intended for installation in non-Residential Buildings; Window, Door, or Skylight attachments that are not included in a product's NFRC-certified rating.

3) **Qualification Criteria:**

A. Energy Efficiency Requirements: To qualify for ENERGY STAR, products shall have NFRC-certified U-Factor and, where applicable, SHGC ratings at levels which meet or exceed the minimum qualification criteria specified in Tables 1-3. Windows and Skylights shall meet the criteria for a given ENERGY STAR Climate Zone. Doors shall meet the criteria for a given glazing level. Dynamic Glazing Products shall meet the criteria while in the minimum tinted state for Chromogenic Glazing products or the "fully open" position for Internal Shading Systems. All criteria have an effective date of January 1, 2015, unless otherwise noted.

Table 1: Energy Efficiency Requirements for Windows

Climate Zone	U-Factor[1]	SHGC[2]
Northern*	≤ 0.27	Any
North-Central	≤ 0.30	≤ 0.40
South-Central	≤ 0.30	≤ 0.25
Southern	≤ 0.40	≤ 0.25

***** The effective date for the Northern Zone prescriptive criteria for windows is January 1, 2016.

Table 2: Energy Efficiency Requirements for Doors			
Glazing Level	**U-Factor**[1]	**SHGC**[2]	
Opaque	≤ 0.17	No Rating	
≤ ½-Lite	≤ 0.25	≤ 0.25	
> ½-Lite	≤ 0.30	Northern and North-Central	≤ 0.40
		South-Central and Southern	≤ 0.25

Table 3: Energy Efficiency Requirements for Skylights		
Climate Zone	**U-Factor**[1]	**SHGC**[2]
Northern	≤ 0.50	Any
North-Central	≤ 0.53	≤ 0.35
South-Central	≤ 0.53	≤ 0.28
Southern	≤ 0.60	≤ 0.28

[1] Btu/h ft^2·˚F
[2] Solar Heat Gain Coefficient

B. Equivalent Energy Performance: To qualify for ENERGY STAR, Windows may also have NFRC-certified U-Factor and, where applicable, SHGC ratings at levels which meet or exceed the equivalent energy performance criteria specified in Table 4. These criteria allow Windows with energy performance equivalent to the prescriptive criteria to qualify in the Northern Zone. Equivalent performance criteria are not applicable to the North-Central, South-Central, or Southern Zones or to Doors or Skylights.

Table 4: Equivalent Energy Performance for Windows		
Climate Zone	**U-Factor**[1]	**SHGC**[2]
Northern*	= 0.28	≥ 0.32
	= 0.29	≥ 0.37
	= 0.30	≥ 0.42

* The effective date for the Northern Zone equivalent energy performance criteria for windows is January 1, 2016.

[1] Btu/h ft^2·˚F
[2] Solar Heat Gain Coefficient

C. Air Leakage Requirements: To qualify for ENERGY STAR, products shall have Air Leakage ratings at levels which meet or exceed the minimum qualification criteria specified in Table 5 and adhere to the labeling requirements laid out below.

Table 5: Air Leakage Requirements	
Product	**Air Leakage Rating**
Window, Sliding Door, or Skylight	≤ 0.3 cfm/ft^2
Swinging Door	≤ 0.5 cfm/ft^2

i) Windows, Sliding Doors, and Skylights shall demonstrate adherence to this requirement by either
   (1) Displaying "≤ 0.3" in the Air Leakage portion of the NFRC temporary label.
   OR
   (2) Placing one of the following labels on the product:
      (a) AAMA Gold Label
      (b) Keystone Certifications, Inc. NAFS Structural Certification Label
      (c) National Accreditation & Management Institute, Inc. (NAMI) NAFS Structural Certification Label
      (d) WDMA Hallmark Certification Label
   NOTE: The U.S. Environmental Protection Agency (EPA) may consider similar labels offered by other Certification Bodies on a case by case basis.

ii) Swinging Doors shall demonstrate adherence to this requirement by either:
   (1) Displaying "≤ 0.5" in the Air Leakage portion of the NFRC temporary label.
   OR

(2) Placing one of the following labels on the product:
   (a) AAMA Gold Label
   (b) Keystone Certifications, Inc. NAFS Structural Certification Label
   (c) NAMI NAFS Structural Certification Label
   (d) WDMA Hallmark Certification Label

NOTE: EPA may consider similar labels offered by other Certification Bodies on a case by case basis.

iii) Manufacturers shall test and/or add the necessary labeling as their products come up for NFRC re-certification.

D. Installation Instructions: To qualify for ENERGY STAR, products shall have installation instructions readily available online or packaged with the product. This information does not need to be included on product labels. Electronic versions of instructions may be provided on the website of a retailer, manufacturer, and/or industry association. Retailers, manufacturers, and industry associations may include in these instructions whatever disclaimers they feel are necessary to limit their liability. EPA understands that the manufacturer cannot write installation instructions for every situation and that generic instructions covering the most common situations are acceptable to fulfill this requirement. The installation instructions shall include:

i) A list of hardware and tools required for installation, including those provided by the manufacturer and those not provided by the manufacturer.

ii) Diagrams/pictures and descriptions of the product or a typical product of similar type and parts provided by the manufacturer.

iii) General guidance on safely removing old products and preparing the frame for installation. Guidance should direct consumers to relevant content on proper management of lead paint, such as www.epa.gov/lead. (Inclusion of diagrams/pictures is preferred, but optional.)

iv) General information on proper disposal or recycling of products being removed.

v) Detailed flashing instructions including diagrams/pictures or reference to the applicable flashing manufacturer's instructions, as applicable to the product.

vi) Instructions on properly shimming the product to achieve an installation that is flush, level, and plumb. (Inclusion of diagrams/pictures is preferred, but optional.)

vii) Guidance on sealing and weatherproofing to prevent air and water infiltration at the product-wall interface. (Inclusion of diagrams/pictures is preferred, but optional.)

viii) Variations of the above based on whether the job is a pocket installation, rough opening installation with exterior sheathing intact, and/or rough opening installation with exterior sheathing removed, as applicable to the product.

Disclaimer: EPA makes no warranties, expressed or implied, nor assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of the contents of installation instructions, or any portion thereof. Further, EPA cannot be held liable for defects or deficiencies resulting from the proper or improper application of installation instructions.

4) **Test Requirements:**

A. When testing residential Windows, Doors, and Skylights, the test methods shown in Table 6 shall be used to determine ENERGY STAR qualification:

Table 6: Test Methods for ENERGY STAR Qualification

ENERGY STAR Requirement	Test Method Reference
U-Factor	NFRC 100
SHGC	NFRC 200
Air Leakage	ASTM E283 in accordance with NFRC 400 or AAMA/WDMA/CSA 101/I.S.2/A440-11

B. All products containing IGUs shall have them certified according to NFRC procedures.

5) **Effective Date:** The ENERGY STAR Residential Windows, Doors, and Skylights Version 6.0 specification shall take effect on January 1, 2015, with the exception of the Northern Zone prescriptive and equivalent energy performance criteria for windows, which shall take effect on January 1, 2016. To qualify for ENERGY STAR, a product model shall meet the ENERGY STAR specification in effect on the model's date of manufacture. The date of manufacture is specific to each unit and is the date on which a unit is considered to be completely assembled.

6) **Future Criteria Revisions:** ENERGY STAR reserves the right to change the specification should technological and/or market changes affect its usefulness to consumers, industry, or the environment. In keeping with current policy, revisions to the specification are arrived at through industry discussions. In the event of a specification revision, please note that the ENERGY STAR qualification is not automatically granted for the life of a product model.

ENERGY STAR Qualification Criteria for Residential Windows, Doors, and Skylights

Windows

Climate Zone	U-Factor[1]	SHGC[2]	
Northern*	≤ 0.27	Any	Prescriptive
	= 0.28	≥ 0.32	Equivalent Energy Performance
	= 0.29	≥ 0.37	
	= 0.30	≥ 0.42	
North-Central	≤ 0.30	≤ 0.40	
South-Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

Air Leakage ≤ 0.3 cfm/ft^2

[1] Btu/h ft^2·°F
[2] Solar Heat Gain Coefficient

***** The effective date for the Northern Zone prescriptive and equivalent energy performance criteria for windows is January 1, 2016.

Doors

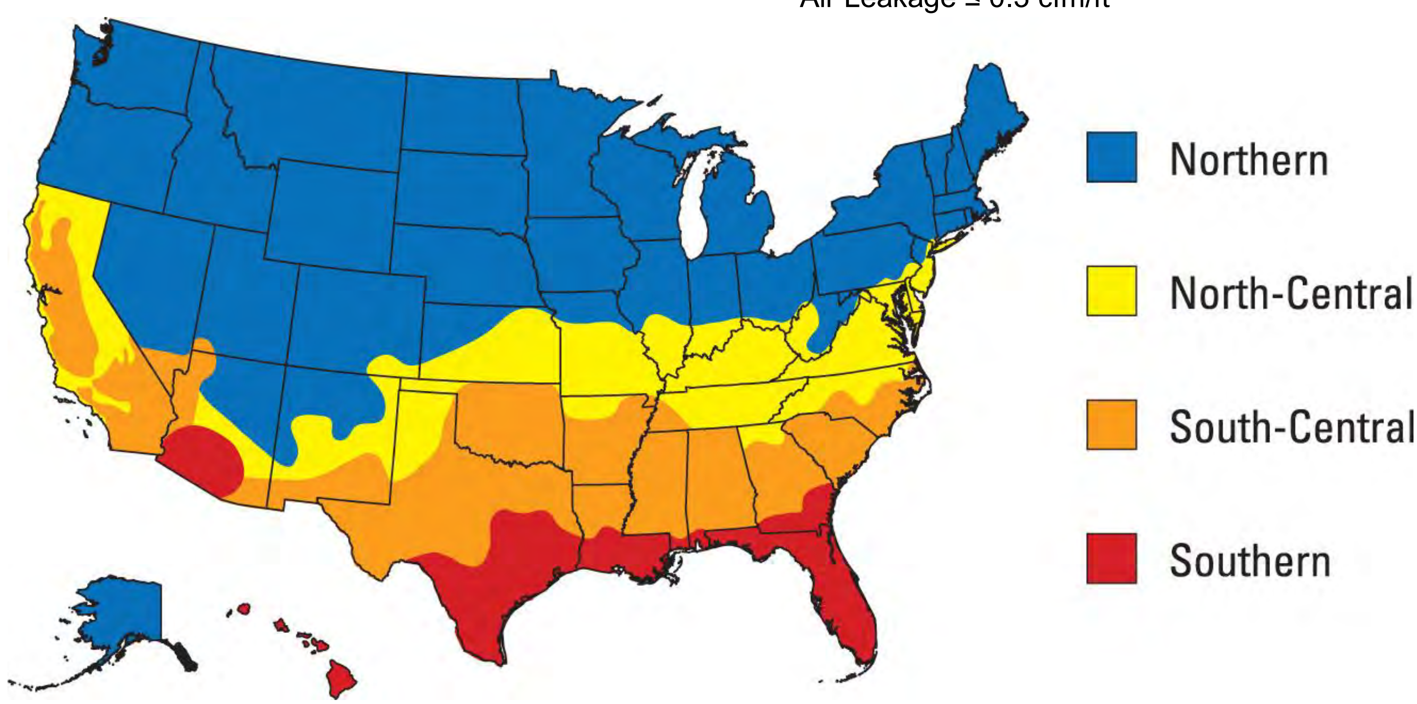
Glazing Level	U-Factor[1]	SHGC[2]	
Opaque	≤ 0.17	No Rating	
≤ ½-Lite	≤ 0.25	≤ 0.25	
> ½-Lite	≤ 0.30	Northern North-Central	≤ 0.40
		Southern South-Central	≤ 0.25

Air Leakage for Sliding Doors ≤ 0.3 cfm/ft^2
Air Leakage for Swinging Doors ≤ 0.5 cfm/ft^2

Skylights

Climate Zone	U-Factor[1]	SHGC[2]
Northern	≤ 0.50	Any
North-Central	≤ 0.53	≤ 0.35
South-Central	≤ 0.53	≤ 0.28
Southern	≤ 0.60	≤ 0.28

Air Leakage ≤ 0.3 cfm/ft^2



Note: A complete list of ENERGY STAR Climate Zones by state and county or, where applicable, zip code is available at https://www.energystar.gov/index.cfm?fuseaction=windows_doors.search_climate.

Substantiating information for proposal 6168 (Section 703.3.3 Heat pump heating efficiency) submitted by Steve Rosenstock:

Below is the key table for the committee's consideration (note that at colder temperatures, the efficiency is below what a gas furnace or boiler would have):

Table 3 Summary of results of space heating tests.

Ambient Temperature	Engine Speed	Heating Capacity	Fuel Consumption	Gas COP
°F	rpm	Btu/hr	Btu/hr	
9.6	3607	43658	65423	0.67
17.2	3610	49492	66238	0.75
35.1	3598	66354	65006	1.02
47.1	3636	77098	64672	1.19
46.7	3392	72678	57918	1.26
46.7	2991	65453	49020	1.34
61.8	3228	82114	55223	1.49
74.8	2760	76361	51993	1.47

Steve Rosenstock, P.E.
Senior Manager, Energy Solutions
Edison Electric Institute
srosenstock@eei.org
202-508-5465

NOTE: This is an excerpt of CRADA FINAL REPORT NFE 10-02997. The full document can be found on www.homeinnovation.com/ngbs

Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

LogID 6065

Country Update for Sweden

Signhild Gehlin*, Olof Andersson**, Leif Bjelm***, Per-Gunnar Alm*** and Jan-Erik Rosberg***

*Swedish Centre for Shallow Geothermal Energy, PO Box 1127, S-22104 Lund, Sweden

**Geostrata HB, Kärrsångarvägen 14, S- 247 35 S Sandby, Sweden

***Engineering Geology, Lund University, PO Box 118, S-221 00 Lund, Sweden

signhild.gehlin@geoenergicentrum.se, olle.geothermal@hotmail.com

leif.bjelm@tg.lth.se, per-gunnar.alm@tg.lth.se, jan-erik.rosberg@tg.lth.se

Keywords: Low temperature geothermal energy, direct use, ground source heat pumps, country update, Sweden

ABSTRACT

This paper presents the status of geothermal energy use and market in Sweden. Geothermal energy in Sweden is dominated by low temperature, shallow geothermal energy systems and direct use. The vast majority of installed geothermal energy systems are ground source heat pumps (GSHP) for space heating and domestic hot water heating for single family buildings. About 20% of the Swedish buildings use GSHP, making Sweden a leading country within this technology. The market for larger shallow geothermal energy systems for residential as well as non-residential buildings has been expanding during the last years. Shallow geothermal energy systems provide some 15 TWh of heating and cooling in Sweden (excluding free cooling), with a total installed capacity of 5.6 GW. Most part of Sweden lacks the geological conditions for deep geothermal exploitation. However, there is one plant in Lund from the mid-1980's that is still in operation, providing some 200 GWh of geothermal heat, or about 20% of the heat demand, annually to the Lund district heating system.

1. INTRODUCTION

The extensive use of ground source heat pumps (GSHP) nationwide has made Sweden the European leader in geothermal energy utilization, in terms of installed units and capacity, as well as extracted thermal energy (Antics et al. 2013). Approximately one fifth of all single-family houses in Sweden are heated by a GSHP.

Geothermal energy utilization started in Sweden in the 1970's and 1980's, triggered by the oil crises, and the following nationwide efforts towards an oil-independent energy system. Heat pump technology was promoted, favored by the national power production strategy based on nuclear and hydropower. Ground source heat pump technology developed rapidly during the 1990's, and continuous improvement of heat pump COP today allows for rates around 4-5 for low temperature heated buildings.

As for deep geothermal energy, exploitation in Sweden remains minimal. Only one plant, taken into operation in the 1980's, is currently in operation in the very south of Sweden.

1.1 Geology of Sweden

The massive Baltic shield and its diverse crystalline eruptive and metamorphic rocks characterize the Swedish geology. Especially in the southern parts there are sedimentary rock formations of significant thickness, spot-wise containing porous sandstones at considerable depth and with very good hydraulic properties. The geothermal gradient is around 28-30°C/km in the south and seldom more than 15-16°C within the Baltic shield regions. The bedrock is commonly covered by glacial deposits.

Ground temperatures vary between +8°C in the south of Sweden down to +2°C in the north. The ground temperatures feature the annual mean temperature in the air at the location, but is slightly higher in the north due to the insulating effect from snow cover in the winter.

2. DEEP GEOTHERMAL ENERGY IN SWEDEN

Most part of Sweden lacks geological conditions suitable for deep geothermal exploitation. There is today only one deep geothermal plant in operation in Sweden; the Lund geothermal heat pump plant that was taken into operation in the mid 1980's. The plant provides today a little less than 200 GWh of geothermal heat, or roughly 20% of the local heat demand, annually, to the district heating system in Lund. Deep geothermal energy utilization for electricity production and direct use is non-existent in Sweden.

2.1 The Lund geothermal heat pump plant

The Lund deep geothermal plant is the largest geothermal heat pump set-up in Sweden. The first unit was taken into operation in 1984, and the second in 1985. It was first reported in Bjelm and Schärnell (1983). The geothermal concept relies on a set of very porous sandstones belonging to Campanian of Upper Cretaceous sitting in the border zone between the Danish-Polish embayment and the Tornquist tectonic deformation zone crossing the province of Scania. The sandstone aquifer was explored and test pumped by means of two explorations wells, confirming a very permeable aquifer with a transmissivity of about 3 x 10^{-3} m^2/s. The four production wells initially produced 450 l/s (1,620 m^3/h). Production temperature was initially around 22°C and has decreased to about 16-17°C for some of the production wells. The decrease is mainly due to the thermal breakthrough in the production field. The two heat pumps deliver 21 and 27 MW of heat respectively. Production from the Lund geothermal heat pump plant to the district heating net is currently around 200 GWh. The gravel pack in the injection wells tends to settle and has therefore been subject to air-lift treatment several times each year. Recently a new hydro-jetting method was introduced for cleaning the wells, and the specific injection capacity has been significantly improved (Andersson and Bjelm, 2013). Up to 30% improvement has been verified for some of the wells. In one case the specific injection capacity increased from 37 m^3/(h bar) to 199 m^3/(h bar).

2.2 Deep geothermal exploration projects

Geothermal research is going on at Lund University, Engineering Geology, since 1977. It is the main scientific body in Sweden for the exploration and utilization of deep geothermal energy resources. All together Engineering Geology has been involved in more than 15 deep geothermal exploration and production well drillings in Sweden and about the same amount of high temperature projects in Nevada, USA.

The latest deep exploration wells in Sweden were drilled 2002-2005. One of the wells was drilled to a depth of 3,700 m, the lower half in crystalline basement, partly as a drilling technology project (Bjelm (2006), Bjelm and Rosberg (2006)). The wells were never put into production due to limited water production from the second well.

Complementary site investigations were carried out for drilling of new geothermal production wells for the Lund plant. The project was initiated due to cooling of the original production wells. A seismic campaign was carried out for an enhanced geological and geophysical understanding of the production field and for final well site selections. New wells were designed and planned but have so far not been realized.

Two geothermal exploration boreholes were drilled in Malmö by E.ON some 20 km west of Lund in 2002-2003. The wells were drilled to a depth of 2 km where Triassic sandstones occur. Only one of the wells provided sufficient production capacity, and they were therefore abandoned (Malmö Stad 2007).

The Royal Institute of Technology in Stockholm started exploration for geothermal energy related to impact craters about a decade ago. Two core-drilled wells of 1,000 m depth were drilled at Birka, nearby Stockholm, but were abandoned when found too dry (Henkel et al. 2005). Fracturing the formation was planned but could not be realized.

A number of shallow exploration wells were recently drilled in the Siljan impact crater area, exploring a shallow geothermal sandstone aquifer. The formation may also contain natural gas resources, dissolved in the geothermal water.

In 2009, the National Science Foundation released around 4 million US dollar to Lund University for purchasing and implementing a top-of-the-line core-drilling package capable of drilling to a depth of 2,500 m in NQ size (hole size 76 mm and core size 47.6 mm). Lund is responsible for serving all national research institutions, with deep drilling capability and expertise. It may also be used outside Sweden if need be (Andersson and Bjelm 2013; Rosberg and Lorenz 2012). The first deep core drilling with the national rig started in late April 2014 close to Åre in central Sweden and in the geological provinces of the Scandinavian mountain range. The intention is to drill to 2,500 m. There are several scientific subtasks in the so called COSC-1 project. One of them is heat flow properties of the bedrock.

3. SHALLOW GEOTHERMAL ENERGY IN SWEDEN

Sweden has a heating dominated climate; however for commercial buildings the cooling demand is commonly predominant on an annual basis due to internal heat loads. To meet the heating demand, GSHPs is by far the most widely used technology for shallow geothermal energy utilization in Sweden, in particular for single-family houses. There are around two million single-family houses in Sweden, and approximately 20-25% of these houses are today heated with a GSHP. Market development for these small systems has been very strong for several years, however during the last few years the number of new installed small systems has stabilized. Instead there is a steady growth of larger GSHP systems for residential as well as commercial buildings. Also the market for underground thermal energy storage (UTES) for large facilities is steadily growing. The two main UTES categories used are Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES), and are used for both heating and cooling purposes, preferably combined.

Geothermal energy is considered an environmentally friendly technology by the general public and tends to increase the commercial value of a building. Geothermal energy has played a major part in replacing fossil fuel heating in the Swedish building stock, especially for small residential buildings. As the market for larger geothermal energy systems increases, it helps to regulate the pricing of alternative energy sources such as biofuel and district heating. This has led to a strong reaction from the district heating sector, which has a dominant market share in space heating and domestic hot water heating in Swedish buildings, and now leads an aggressive campaign against the use of heat pumps in general.

The vast majority of the Swedish shallow geothermal energy systems in Sweden are vertical boreholes in hard rock. Some recent market trends are that boreholes for GSHPs and BTES systems tend to be drilled to an increasing depth, which can be seen in Figure 1, and that the system size increases. Systems tend to be designed with increasing capacity and system efficiency.

3.1 Utilization of extraction systems

Shallow geothermal energy extraction systems use low temperature energy from the soil or upper parts of the bedrock as a heat source or heat sink either for space heating or cooling purposes. The typical Swedish shallow geothermal energy extraction system is a groundwater filled vertical closed loop GSHP system, drilled in crystalline rock, used for heat extraction only. The heat pump is typically electrically driven and is used for both space heating and domestic hot water (DHW) heating. These systems, mainly used for small to medium size systems for heating of residential buildings, are sometimes recharged with heat from exhaust air or solar.

About 20-25% of all shallow geothermal energy systems in Sweden are horizontal ground loops in soft ground material. Horizontal loops require larger surface areas, where plastic tubing is buried at about 1 m depth below the ground surface. In Sweden these systems are only used for heat extraction, and will freeze the moisture in the ground around the ground loops, thus taking advantage of the phase change energy. Horizontal ground loops work best in finely grained soil with high porosity and moisture content. They are most common in the south of Sweden where ground temperature is higher and deep layers of sedimentary formations cover the hard rock.

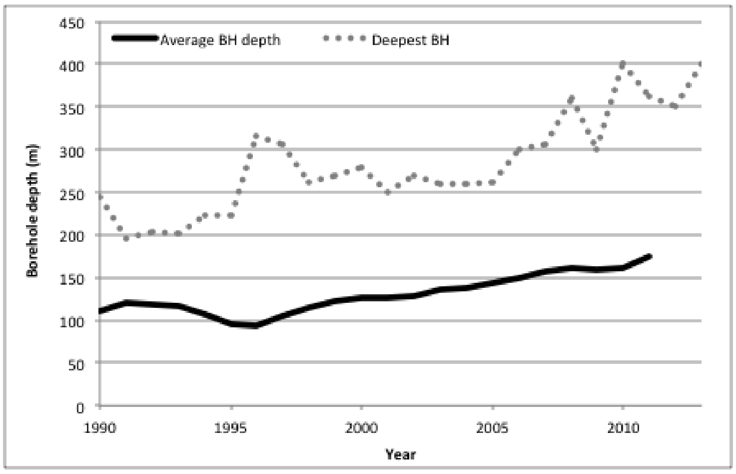


Figure 1: Average borehole depth and deepest borehole. SGU 2014.

Sales figures from the Swedish Heat Pump Association tell that currently some 500,000 ground source heat pumps are installed in Sweden, of which about 10,000 are open groundwater or surface water heat pump systems. Most of the open systems were installed in the 1980's and around 20 new such installations are reported each year. The last five years around 25,000 ground source heat pump units in sizes ranging from 5 to 10 kW have been installed per annum. The market for small units has stabilized these last few years but the market for larger systems is growing. Sweden is a world-leading nation in shallow geothermal energy usage, counted per capita.

Vertical boreholes in rock and ground water wells are also used for comfort cooling and free-cooling, for instance in the telecom and industrial sectors. Between 10-15% of the Swedish land area contain aquifers suitable for shallow geothermal energy utilization, and approximately 25% of the population lives in these areas (Andersson and Sellberg 1992), However, using groundwater is strictly regulated making the real potential considerably less.

Shallow geothermal energy extraction is also used as heat source for large heat pumps in district heating networks around Sweden. Figures from the Swedish District Heating Association show that in 2012 these plants provided some 0.65 TWh to the Swedish district heating network (Trad 2014). The use of ground- and surface water heat pumps in the Swedish district heating network has decreased in later years.

3.2 Utilization of underground thermal energy storage systems (UTES)

While shallow geothermal energy extraction systems are passively recharged by heat transport in the underground from the ground surface and with a minor contribution from the geothermal heat flux, underground thermal energy systems (UTES) actively store heat and cold in the underground, commonly as seasonal storage. This means that heat is stored from the summer season to be utilized during the winter season. Likewise, cold is stored during winter to be recovered during the summer for cooling purposes. Most of the Swedish larger shallow geothermal energy applications combine heating and cooling. The two commercial systems are Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). These are principally illustrated in Figure 2.

Figure 2: Aquifer Thermal Energy Storage (ATES) (left) and Borehole Thermal Energy Storage (BTES) (right). Illustration: Geotec.

ATES systems use groundwater for carrying the thermal energy into and out of an aquifer. The wells are normally designed with a double function - both as production- and injection wells. Energy is stored in the groundwater and in the grains (or rocks mass) that form the aquifer. Typical Swedish ATES operation temperatures are 12-16°C on the warm side and 4-8°C on the cold side of the aquifer (Andersson, 2007). ATES was introduced in Sweden during the mid 1980's and there are currently some 150 ATES system plants in operation. The growth rate has been quite steady the last decade at approximately 5% annually. The systems are large with high capacity, ranging between 500-5000 kW. ATES systems are sensitive to potential chemical problems such as corrosion and clogging by iron precipitation. They have high COP, in the order of 5-8. They are fast responding and highly efficient, and have generally low pay-back times, often less than 3 years (Andersson et al., 2013). The largest ATES system in Sweden is the Stockholm Arlanda Airport ATES plant, used for free-cooling and pre-heating of ventilation, and for de-icing of gates. It has been designed to a capacity of 10 MW and uses no heat pumps (Andersson 2009).

BTES systems consist of several closely spaced boreholes, normally 50 – 250 m deep, serving as heat exchangers to the underground. In Sweden the boreholes are typically groundwater filled and fitted with a closed loop single or double U-pipe. The heat transfer between the heat carrier and the underground is mainly conductive and the temperature change in the rock reaches only a few meters around each borehole. The temperature in the ground storage typically ranges between +2°C at end of winter and +8°C at the end of summer. The market for BTES systems in Sweden is growing and there are currently some 400 large systems with more than 20 boreholes in operation, for combined heating and cooling of mainly commercial and institutional buildings. The rate of growth is at present approximately 10% per annum. The systems have capacities ranging between 50-500 kW. COP is in the order of 5-6. The size of the systems tends to increase and include an increasing number of boreholes and deeper boreholes (Andersson et al., 2013). The largest BTES system in Sweden is currently being built for the Karlstad University Campus, with 204 boreholes to a depth of 240-250 m, giving a total of 48,240 drilled meters boreholes (Svensk Geoenergi, 2014).

There are two high temperature BTES systems in operation in Sweden today. One is used for seasonal solar heat storage for residential heating without heat pump and has a solar fraction of 40% after 12 years in operation (Heier 2013). The other is used for seasonal storage of industrial waste heat (Andersson & Rydell 2012).

4. CONCLUSIONS

Sweden is a world leading country in shallow geothermal energy utilization (Lund et al., 2010), and geothermal energy has a general goodwill among the public as an environmentally friendly and economically feasible technology. The market is dominated by shallow geothermal energy systems, and in particular GSHP systems with vertical boreholes in hard rock. The potential for deep geothermal energy exploitation in Sweden is limited and only one plant is in operation.

The market for small GSHP systems has stabilized during the last years, but there is a steady market growth for larger systems for residential buildings as well as for larger ATES and BTES systems in the commercial and institutional sector. Systems for BTES tend to be designed with increasing size, deeper boreholes and higher capacities. In 2014 the largest BTES system in Europe with regard to drilled borehole meters is taken into operation at the Karlstad University Campus.

REFERENCES

Andersson,O. Sellberg, B.: Swedish ATES Applications. Experiences after Ten Years of Development. SAE International Engineering Conference, San Diego, Aug. 3-7, 1992

Andersson, O.: Aquifer Thermal Energy Storage (ATES). In Thermal energy storage for sustainable Energy Consumption, Chapter 6. Springer, (2007).

Andersson, O. The ATES Project at Stockholm Arlanda Airport-Technical Design and Environmental Assessment. Proceedings of Effstock, the 11th International Conference on Underground Thermal Energy Storage, June 2009, Stockholm, Sweden, (2009).

Andersson, O., and Bjelm, L.: Geothermal Energy Use, Country Update for Sweden. *Proceedings,* European Geothermal Congress 2013, Pisa, Italy, (2013).

Andersson, O., Ekestubbe, J., Ekdahl, A.: UTES (Underground Thermal Energy Storage – Applications and Market Development in Sweden, Journal of Energy and Power Engineering 7 (2013), p 669-678.

Andersson, O., Rydell, L. The HT-BTES plant at Xylem in Emmaboda, Sweden – Experiences from design, construction and initial operation. Proceedings of Innostock, the 12th International Conference on Underground Thermal Energy Storage, May 16-18 2012, Lleida, Spain, (2012).

Antics, M., Bertani, R., and Sanner, B.: Summary of EGC 2013 Country Update Reports on Geothermal Energy in Europe. *Proceedings*, European Geothermal Congress 2013, Pisa, Italy, (2013).

Bjelm, L. and Schärnell, L.: Large heat pump plants for district heating utilizing geothermal energy. Lund Institute of Technology, Dept. of Engineering Geology and Stal Laval Turbin AB, Finspång. International symposium on Geothermal Energy. Portland, USA. (1983).

Bjelm, L.: Under Balanced Drilling and Possible Well Bore Damage in Low Temperature Geothermal Environments. Proceedings, Thirty-First Conf. On Geothermal Reservoir Engineering. Stanford University, Stanford, California, (2006).

Bjelm, L. and Rosberg, J-E.: Recent Geothermal Exploration for Deep Seated Sources in Sweden. Engineering Geology, Lund University, Sweden. *Geothermal Resources Council Transactions*, **Vol. 30**, San Diego. (2006)

Heier, J. Energy Efficiency through Thermal Energy Storage: Possibilities for the Swedish Building Stock. Licentiate Thesis, The Royal Institute of Technology, Stockholm, Sweden. (2013).

Henkel, H., Bäckström, A., Bergman, B., Stephansson, O. and Lindström, M.: Geothermal Energy from Impact Craters? The Björkö Study, *Proceedings*, World Geothermal Congress 2005, Turkey, 5pp. (2005)

Lund, J.W., Freeston, D.H., and Boyd, T.L.: Direct Utilization of Geothermal Energy 2010 Worldwide Review. Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010.

Malmö Stad. Faktablad om Malmös lokala investeringsprogram LIP 2002-2005 (In Swedish). 2007.

Rosberg, J-E and Lorenz, H.: A new scientific drilling infrastructure in Sweden, Geophysical Research Abstracts, Vol. 14, EGU2012-7379 (2012)

Svensk Geoenergi, No. 1/2014, page 12. www.geoenergicentrum.se. 2014.

Trad, S. The Swedish District Heating Association. Personal communication (2014).

APPENDIX – STANDARD TABLES

TABLE 1. Present and planned production of electricity (* denotes contribution from wind power and ** denotes biomass)

	Geothermal		Fossil		Hydro		Nuclear		Other renewables *)Wind **) Biomass		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2014	-	-	No info	9,600	16,200	64,200	9,336	64,900	5,000* 3,000**	11,300* 6,000**		156,000
Under construction in Dec 2014	-	-	-	-	-	-	-	-	No info	No info		
Funds committed, Not yet under construction in Dec 2014	-	-	-	-	-	-	-	-	-	-	-	-
Estimated total projected use by 2020	-	-	No info	9,700	16,200	69,000	9,336	72,600	No info	11,300* 13,700**		174,000

TABLE 2. Utilization of geothermal energy for electric power generation as of 31 December 2014

There is no existing or planned geothermal electricity production in Sweden.

TABLE 3. Summary of geothermal direct heat use as of 31 December 2014

There is no existing or planned geothermal direct use in Sweden.

TABLE 4. Geothermal (ground-source) heat pumps as of 31 December 2014

Locality	Ground or Water Temp (°C)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type	COP	Heating Equivalent Full Load Hr/year	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
Lund	19	48,000	2	V	3.3	>7,000	720	-
Sweden (small V)*	-2/8	5-10	365,000	V	3-5	2,500	35,500	-
Sweden (small H)*	-5/+5	5-10	125,000	H	3-4	2,500	12,000	-
Sweden (small W)*	4-8	5-10	10,000	W	4-5	2,500	1,000	-
Sweden (ATES)*	4-16	500-5,000	150	W	5-8	3,000	1,260	360
Sweden (BTES)*	2-8	50-500	400	V	3-5	4,600	1,440	900
TOTAL			500,000	V W H	3-8		51,920	1,260

* Excluding free cooling

TABLE 5. Summary table of geothermal direct heat uses as of 31 December 2014

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr =10^{12} J/yr)	Capacity Factor
Individual Space Heating	-	-	-
District Heating	-	-	-
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	-	-	-
Fish Farming	-	-	-
Animal Farming	-	-	-
Agricultural Drying	-	-	-
Industrial Process Heat	-	-	-
Snow Melting	-	-	-
Bathing and Swimming	-	-	-
Other Uses (Specify)	-	-	-
SUBTOTAL	-	-	-
Geothermal Heat Pumps	5,600	51,920	0.3
TOTAL	5,600	51,920	0.3

TABLE 6. Wells drilled for electrical, direct and combined use of geothermal resources from January 1, 2010 to December 31, 2014 (excluding heat pump wells)

There are no wells drilled for electrical, direct and combined use of geothermal resources during this period, in Sweden.

TABLE 7. Allocation of professional personnel to geothermal activities (restricted to personnel with university degree)

Year	Professional Person-Years of Effort						
	Gov.	Publ. ut.	Universities	Paid For. Cons.	For. Aid prog.	Priv. ind.	Total
2010	-	2	5	-	-	2	9
2011	-	2	6	-	-	2	10
2012	-	2	7	-	-	3	12
2013	-	3	7	-	-	4	14
2014	-	3	7	-	-	4	14

TABLE 8. Total investment in geothermal energy (2014) in USD

Period	Research & Development Incl. Production	Field Development Incl. Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million USD	Million USD	Million USD	Million USD	%	%
1995-1999						
2000-2004	22.2					
2005-2009	0.07					
2010-2014	1				60	40

Cold Climate Housing Research Center
CCHRC

Ground Source Heat Pumps
in Cold Climates: Year Two

While ground source heat pumps are gaining popularity in cold climates, there are still questions about how they perform in cold soils. For example, how much heat do they remove from the ground and how does this affect their performance over the long term? To help answer these questions, the Cold Climate Housing Research Center installed a ground source heat pump at its facility in Fairbanks, Alaska in November 2013. CCHRC will monitor the heat pump for a 10-year period.

The CCHRC demonstration ground source heat pump has been running for two years. The heat pump replaced an oil fired boiler and is heating office space in the CCHRC building.

The efficiency of a heat pump is measured as the Coefficient of Performance, or COP–which is the ratio of how much heat is produced for each unit of electricity added. For example, a COP of 3 means the heat pump produces 3 units of heat for every 1 unit of electricity it consumes. As the temperature in the ground drops, the COP of the heat pump is expected to drop as well.

The COP of the heat pump dropped from 3.6 the first winter to 3.3 the second winter. There was a corresponding drop in the ground temperature. The center of the ground loop decreased from 34.5°F (1.4°C) in Oct. 2013 to 32.4°F (0.22°C) in Oct. 2015 at the level of the heat extraction coils (based on monthly average measurements).

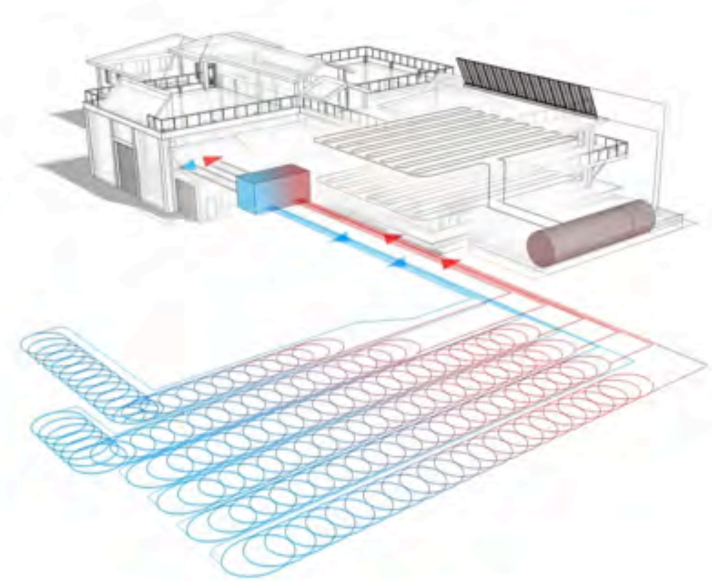


Figure 1.Graphic representation of ground loop location at CCHRC.

	million BTUs (mmBTU)	kilowatt-hours (kWh)
Heat produced	86.7	25,417
Electricity used	26.5	7,767

In its second year the heat pump supplied 86.7 mmbtu (25,417 kWh) of heat and used 7,767 kWh (26.5 mmbtu) of electricity. This is equivalent to a COP of 3.3 averaged over the course of the year.

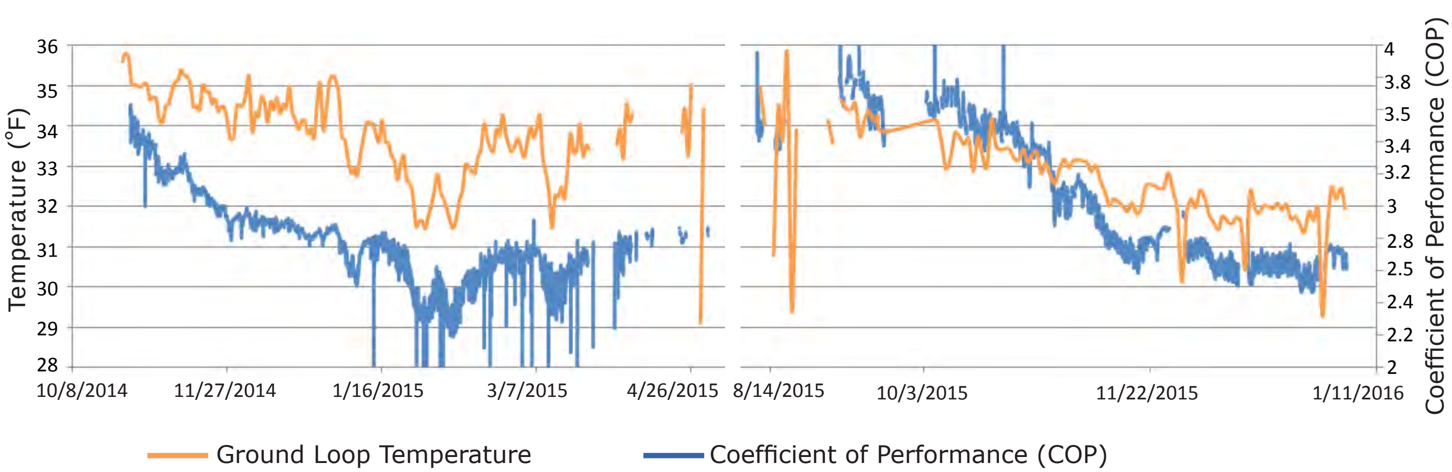
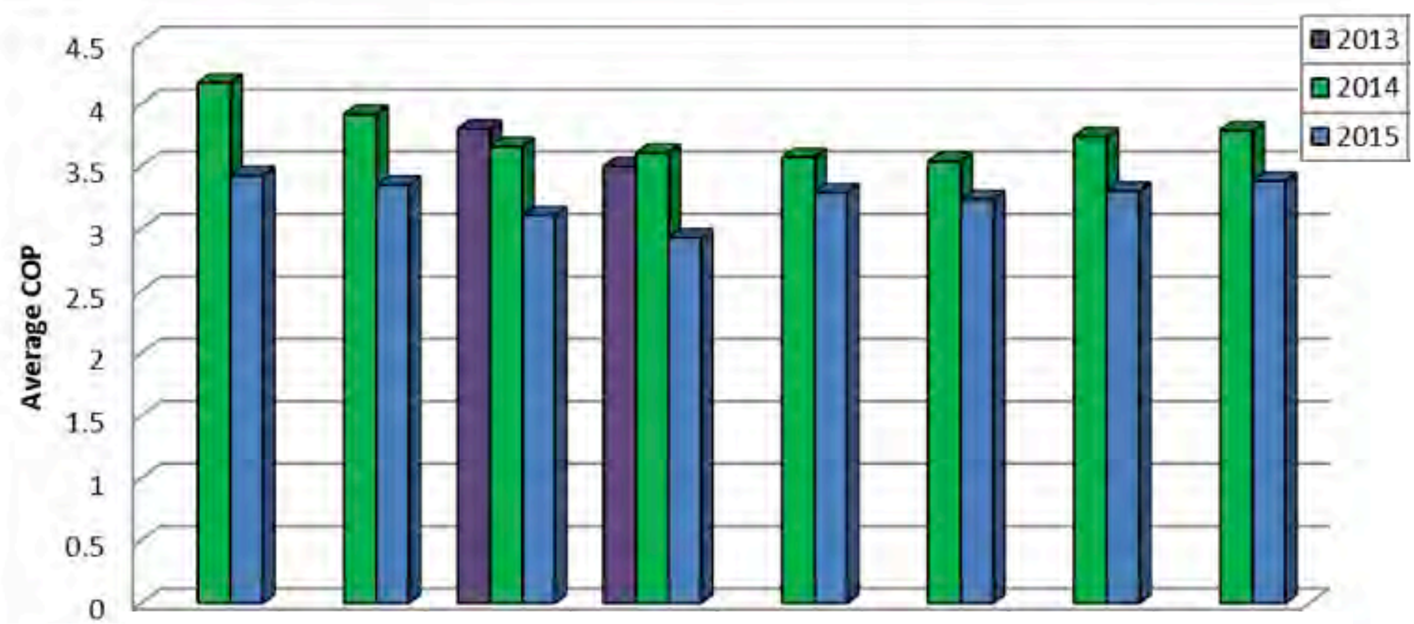


Figure 2. The COP varies throughout the year and is dependent on the temperature of the fluid coming from the ground loop and the temperature of the delivery water to the heating system. Figure 2 shows how the COP tracks with the dropping ground temperature.



	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Winter 1			3.8	3.5	3.6	3.5	3.7	3.8
Winter 2	4.2	3.9	3.7	3.6	3.3	3.2	3.3	3.4
Winter 3	3.4	3.3	3.1	2.9				

Figure 3. Average monthly COP for two winters. The average monthly COP dropped during the second winter.

The effects of heat extraction at that depth are clearly visible in Figure 4, which shows the temperature in the soil vs. the depth of the area under the center portion of the ground loop. The temperature of the ground near the ground loop coils is colder than other areas of the ground profile. The temperature hovered around freezing but did rise above freezing in October 2015.

The incoming fluid temperatures from the ground loop started at 33.9°F (1°C) in November 2013 and dropped to approximately 31.5°F (-0.3°C) in November 2015. The monthly average temperature for November has dropped by 1°F degree every year the heat pump has been running. The system is expected to reach a new equilibrium with the ground at some point, and the ground temperatures will stop dropping every year.

The heat pump will continue to supply heat to the building for the foreseeable future and the system will be monitored for at least 10 years to see if there is appreciable change in the ground temperature and thus in the efficiency of the heat pump.

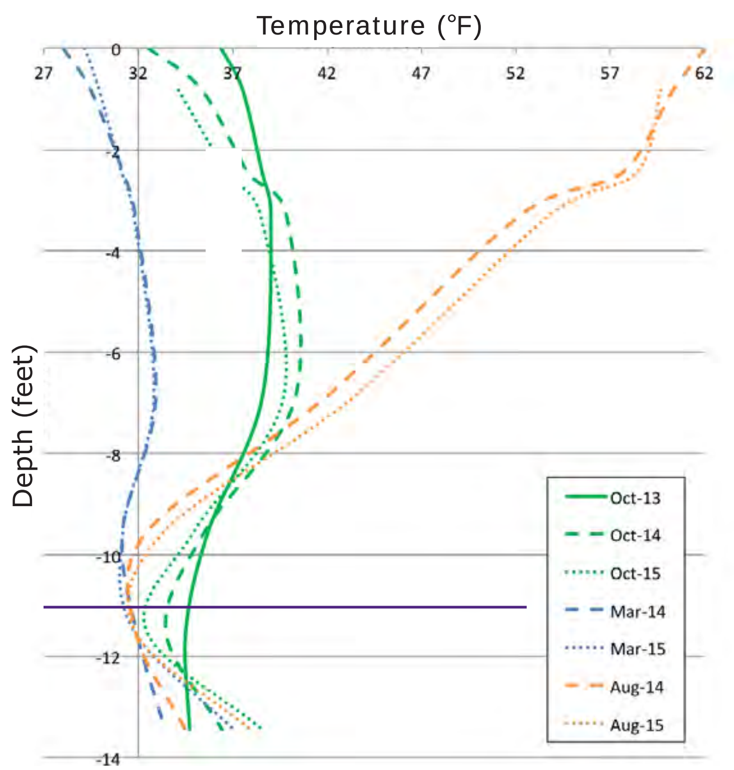


Figure 4. Ground temperatures under the center of the ground loop. The temperature at the level (around the purple line) of the heat extraction coils barely rose above freezing in October 2015.

Substantiating information for proposal 6166 (Section 703.5.1 Water heater Energy Factor) and 6167 (Section 703.5.5 Solar water heater) submitted by Steve Rosenstock:

Below are key tables for the committee's consideration:

Product class	Energy factor as of January 20, 2004	Energy factor as of April 16, 2015
Gas-fired Water Heater	0.67 – (0.0019 × Rated Storage Volume in gallons).	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.675 – (0.0015 × Rated Storage Volume in gallons). For tanks with a Rated Storage Volume above 55 gallons: EF = 0.8012 – (0.00078 × Rated Storage Volume in gallons).
Oil-fired Water Heater	0.59 – (0.0019 × Rated Storage Volume in gallons).	EF = 0.68 – (0.0019 × Rated Storage Volume in gallons).
Electric Water Heater	0.97 – (0.00132 × Rated Storage Volume in gallons).	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.960 – (0.0003 × Rated Storage Volume in gallons). For tanks with a Rated Storage Volume above 55 gallons: EF = 2.057 – (0.00113 × Rated Storage Volume in gallons).
Tabletop Water Heater	0.93 – (0.00132 × Rated Storage Volume in gallons).	EF = 0.93 – (0.00132 × Rated Storage Volume in gallons).
Instantaneous Gas-fired Water Heater.	0.62 – (0.0019 × Rated Storage Volume in gallons).	EF = 0.82 – (0.0019 × Rated Storage Volume in gallons).
Instantaneous Electric Water Heater.	0.93 – (0.00132 × Rated Storage Volume in gallons).	EF = 0.93 – (0.00132 × Rated Storage Volume in gallons).

Note: The Rated Storage Volume equals the water storage capacity of a water heater, in gallons, as specified by the manufacturer.

TABLE I.2—DOE ENERGY CONSERVATION STANDARDS FOR CONSUMER WATER HEATERS

Product class	Rated storage volume ***	Energy factor **
Gas-fired Storage	≥20 gal and ≤55 gal	$0.675 - (0.0015 \times V_s)$
	>55 gal and ≤100 gal	$0.8012 - (0.00078 \times V_s)$
Oil-fired Storage	≤50 gal	$0.68 - (0.0019 \times V_s)$
Electric Storage	≥20 gal and ≤55 gal	$0.960 - (0.0003 \times V_s)$
	>55 gal and ≤120 gal	$2.057 - (0.00113 \times V_s)$
Tabletop *	≥20 gal and ≤120 gal	$0.93 - (0.00132 \times V_s)$
Gas-fired Instantaneous †	<2 gal	$0.82 - (0.0019 \times V_s)$
Electric Instantaneous *	<2 gal	$0.93 - (0.00132 \times V_s)$

* Tabletop and electric instantaneous water heater standards were not updated by the April 2010 final rule.

** V_s is the "Rated Storage Volume" (in gallons), as determined by 10 CFR 429.17.

*** Rated Storage Volume limitations result from either a lack of test procedure coverage or from divisions created by DOE when adopting standards. The division at 55 gallons for gas-fired and electric storage water heaters was established in the April 16, 2010 final rule amending energy conservation standards. 75 FR 20112. The other storage volume limitations shown in this table are a result of test procedure applicability and are discussed in the July 2014 final rule. 79 FR 40542 (July 11, 2014).

† The standard for gas-fired instantaneous water heaters applies only to gas-fired instantaneous water heaters with a rated input of greater than 50,000 Btu/h.

TABLE II.1—CONSUMER WATER HEATER ENERGY CONSERVATION STANDARDS DENOMINATED IN UEF

Product class	Rated storage volume and input rating (if applicable)	Draw pattern	Uniform energy factor
Gas-fired Storage Water Heater	≥20 gal and ≤55 gal	Very Small	0.3456 − (0.0020 x V_r)
		Low	0.5982 − (0.0019 x V_r).
		Medium	0.6483 − (0.0017 x V_r).
		High	0.6920 − (0.0013 x V_r).
	>55 gal and ≤100 gal	Very Small	0.6470 − (0.0006 x V_r).
		Low	0.7689 − (0.0005 x V_r).
		Medium	0.7897 − (0.0004 x V_r).
		High	0.8072 − (0.0003 x V_r).
Oil-fired Storage Water Heater	≤50 gal	Very Small	0.2509 − (0.0012 x V_r).
		Low	0.5330 − (0.0016 x V_r).
		Medium	0.6078 − (0.0016 x V_r).
		High	0.6815 − (0.0014 x V_r).
Electric Storage Water Heaters	≥20 gal and ≤55 gal	Very Small	0.8808 − (0.0008 x V_r).
		Low	0.9254 − (0.0003 x V_r).
		Medium	0.9307 − (0.0002 x V_r).
		High	0.9349 − (0.0001 x V_r).
	>55 gal and ≤120 gal	Very Small	1.9236 − (0.0011 x V_r).
		Low	2.0440 − (0.0011 x V_r).
		Medium	2.1171 − (0.0011 x V_r).
		High	2.2418 − (0.0011 x V_r).
Tabletop Water Heater	≥20 gal and ≤120 gal	Very Small	0.6323 − (0.0058 x V_r).
		Low	0.9188 − (0.0031 x V_r).
		Medium	0.9577 − (0.0023 x V_r).
		High	0.9884 − (0.0016 x V_r).

TABLE II.1—CONSUMER WATER HEATER ENERGY CONSERVATION STANDARDS DENOMINATED IN UEF—Continued

Product class	Rated storage volume and input rating (if applicable)	Draw pattern	Uniform energy factor
Instantaneous Gas-fired Water Heater**.	<2 gal and >50,000 Btu/h	Very Small	0.80
		Low	0.81.
		Medium	0.81.
		High	0.81.
Instantaneous Electric Water Heater**.	< 2 gal	Very Small	0.91.
		Low	0.91.
		Medium	0.91.
		High	0.92.
Grid-Enabled Water Heater	>75 gal	Very Small	1.0136 − (0.0028 x V_r).
		Low	0.9984 − (0.0014 x V_r).
		Medium	0.9853 − (0.0010 x V_r).
		High	0.9720 − (0.0007 x V_r).

* V_r is the "Rated Storage Volume" (in gallons), as determined by 10 CFR 429.17.
** For instantaneous water heaters the standard is represented as a single value rather than as a function of storage volume. Because the UEF standard only applies to models with less than 2 gallons of storage volume, the coefficient becomes zero, and the standard does not vary for models between 0 and 2 gallons.

TABLE II.2—RESIDENTIAL-DUTY COMMERCIAL WATER HEATER ENERGY CONSERVATION STANDARDS DENOMINATED IN UEF

Product class	Draw pattern	Uniform energy factor
Gas-fired Storage	Very Small	0.2674 − (0.0009 × V_r)
	Low	0.5362 − (0.0012 × V_r)
	Medium	0.6002 − (0.0011 × V_r)
	High	0.6597 − (0.0009 × V_r)
Oil-fired Storage	Very Small	0.2932 − (0.0015 × V_r)
	Low	0.5596 − (0.0018 × V_r)
	Medium	0.6194 − (0.0016 × V_r)
	High	0.6740 − (0.0013 × V_r)
Electric Instantaneous **	Very Small	0.80.
	Low	0.80.
	Medium	0.80.
	High	0.80.

* V_r is the "Rated Storage Volume" (in gallons), as determined by 10 CFR 429.44.
** For instantaneous water heaters the standard is represented as a single value rather than as a function of storage volume. Because the UEF standard only applies to models with less than 2 gallons of storage volume, the coefficient becomes zero, and the standard does not vary for models between 0 and 2 gallons.

Steve Rosenstock, P.E.
Senior Manager, Energy Solutions
Edison Electric Institute
srosenstock@eei.org
202-508-5465

NOTE: These are excerpts from:
(1) Federal Register / Vol. 75, No. 73 / Friday, April 16, 2010, and
(2) Federal Register / Vol. 81, No. 250 / Thursday, December 29, 2016.
The full documents can be found on www.homeinnovation.com/ngbs

WHAT'S UP WITH A LANAI?

May 13, 2012 | Florida Living, Moving to Florida | 4 |

Potential Florida residents, people considering moving to Florida, are often greeted with a new term: lanai. Many TV viewers were introduced to the word lanai on the "Golden Girls" program, broadcast in the mid-80s. Still, many people outside of Florida do not know what they were talking about.

Just what is a lanai and do you need one?

The word lanai is used to describe a covered porch or veranda in tropical locations. It is a great space for a container garden.

A lanai in Florida can be any covered area outside of the house, usually screened, that is used as a living space. Most of the time, the lanai is furnished with casual tables, chairs, benches and chaise lounges.

Many swimming pools are contained within the lanai, along with additional pool type furnishings and toys. The screen enclosure is referred to as the pool cage.

We were on an airplane landing in Orlando a few years ago; sitting in front of us were two teenage girls. As the plane descended over a residential area, the girls remarked, "Look, all of those homes have batting cages in the back". Obviously, it was their first visit to Florida.

A ceiling fan, installed in the lanai, makes sitting outside comfortable, even on hot days. We use our lanai just about every day. In the summer, we start the days with coffee on the lanai and at noon, we eat lunch there as well. We often eat dinner at the lanai table in the fall and spring. Winter use depends on the temperatures; more often than not, we eat at least one meal outside.

If you have been reading our articles, you know we face wooded wetlands in our backyard. We have a good variety of wildlife visiting. So, anytime we are relaxing on the lanai, we keep an eye out for any of Mother Nature's critters walking by.

The direction your lanai faces makes a big difference.

When we were looking at houses to purchase, we really never gave any thought about where the sun was located in relation to the house. Our lanai faces north; I consider that to be perfect. We never get sun directly into the lanai; the pool, however, does get direct sun most of the year. Lanais that face east or west get either direct morning or evening sun, making it somewhat difficult to use during those times. Friends have a west facing lanai and it is almost impossible to sit out there on a hot summer evening. They had to have large blinds installed to block the sun from shining into their interior living area. South facing lanais have sun shining in almost all day long.

After living in Florida for over 10 years, a north facing lanai would be on my list of "must haves" for my home. You may not agree, but if you are considering moving to Florida, keep the orientation of the house in mind; it does affect your outdoor living. See more of our articles about Florida Living.

LogID 6251

Volume vs. Shell

	CFA s.f.	per floor s.f.	width	length	ceil. ht	walls	ceiling	floor		SFBE (shell area)		Volume	
Unit A	750 s.f.	750	30	25	8	880	750	750		2380		6000	
	Blower Door	300 cfm50							ELR50	0.13	ACH50	3.00	IECC-12
	Blower Door	500 cfm50							ELR50	0.21	ACH50	5.00	
	Blower Door	700 cfm50							ELR50	0.29	ACH50	7.00	IECC-09
	Blower Door	750 cfm50							ELR50	0.32	ACH50	7.50	
	Blower Door	1000 cfm50							ELR50	0.42	ACH50	10.00	
Unit B	1050 s.f	1050	30	35	9	1170	1050	1050		3270		9450	
	Blower Door	475 cfm50							ELR50	0.15	ACH50	3.02	IECC-12
	Blower Door	600 cfm50							ELR50	0.18	ACH50	3.81	
	Blower Door	800 cfm50							ELR50	0.24	ACH50	5.08	
	Blower Door	1100 cfm50							ELR50	0.34	ACH50	6.98	IECC-09
	Blower Door	1300 cfm50							ELR50	0.40	ACH50	8.25	
Unit C	1500 s.f	1500	30	50	9	1440	1500	1500		4440		13500	
	Blower Door	680 cfm50							ELR50	0.15	ACH50	3.02	IECC-12
	Blower Door	900 cfm50							ELR50	0.20	ACH50	4.00	
	Blower Door	1100 cfm50							ELR50	0.25	ACH50	4.89	
	Blower Door	1400 cfm50							ELR50	0.32	ACH50	6.22	
	Blower Door	1600 cfm50							ELR50	0.36	ACH50	7.11	IECC-09
Unit D	2400 s.f	1200	30	40	18	2520	1200	1200		4920		21600	
	Blower Door	1100 cfm50							ELR50	0.22	ACH50	3.06	IECC-12
	Blower Door	1300 cfm50							ELR50	0.26	ACH50	3.61	
	Blower Door	1600 cfm50							ELR50	0.33	ACH50	4.44	
	Blower Door	2000 cfm50							ELR50	0.41	ACH50	5.56	
	Blower Door	2500 cfm50							ELR50	0.51	ACH50	6.94	IECC-09
Unit E	3200 s.f	1600	32	50	18	2952	1600	1600		6152		28800	
	Blower Door	1450 cfm50							ELR50	0.24	ACH50	3.02	IECC-12
	Blower Door	1700 cfm50							ELR50	0.28	ACH50	3.54	
	Blower Door	2000 cfm50							ELR50	0.33	ACH50	4.17	
	Blower Door	2800 cfm50							ELR50	0.46	ACH50	5.83	
	Blower Door	3400 cfm50							ELR50	0.55	ACH50	7.08	IECC-09
Unit F	4800 s.f	2400	40	60	18	3600	2400	2400		8400		43200	
	Blower Door	2200 cfm50							ELR50	0.26	ACH50	3.06	IECC-12
	Blower Door	2500 cfm50							ELR50	0.30	ACH50	3.47	
	Blower Door	2800 cfm50							ELR50	0.33	ACH50	3.89	
	Blower Door	3800 cfm50							ELR50	0.45	ACH50	5.28	
	Blower Door	5000 cfm50							ELR50	0.60	ACH50	6.94	IECC-09

Max. ACH5(	Max. ELR5(	Point CZ3
5	0.33	3
4	0.28	5
3	0.23	6
2	0.18	8
1	0.13	8

Unit 8307 of Building 8 of The Oaks at Johns Creek:

1178	s.f.
10602	c.f.
3671	sfbe
688	cfm50
3.89	ACH50
0.187	ELR50

LogID 6153

Substantiating information for proposal 6153 (Section 706.8 Electrical vehicle charging station) submitted by Steve Rosenstock:

Below are is a key section from the presentation for the reason statement:

"AC Level 2 Charging*
– 208 –240 AC charging up to 80 amps, on-board vehicle charger
(~19kw)"

**Same charge coupler used for AC Level 1 and 2 charging*

Steve Rosenstock, P.E.
Senior Manager, Energy Solutions
Edison Electric Institute
srosenstock@eei.org
202-508-5465

NOTE: This is an excerpt of SAE J1772. The full document can be found on www.homeinnovation.com/ngbs

ERCOT

ERCOT Grid Operations

Wind Integration Report : 02/23/2017

Current Daily Values:

Peak Load	42,150 MW
Peak Load Hour (HE)	17
Wind at Peak Load Hour	13,426 MW

Max Wind	13,727 MW
Max Wind Time	17:00
Penetration at Max Wind Time	32.67 %

Max Wind Penetration	42.92 %
Max Wind Penetration Time	02:26
Wind Generation at Max Wind Penetration Time	11,266 MW

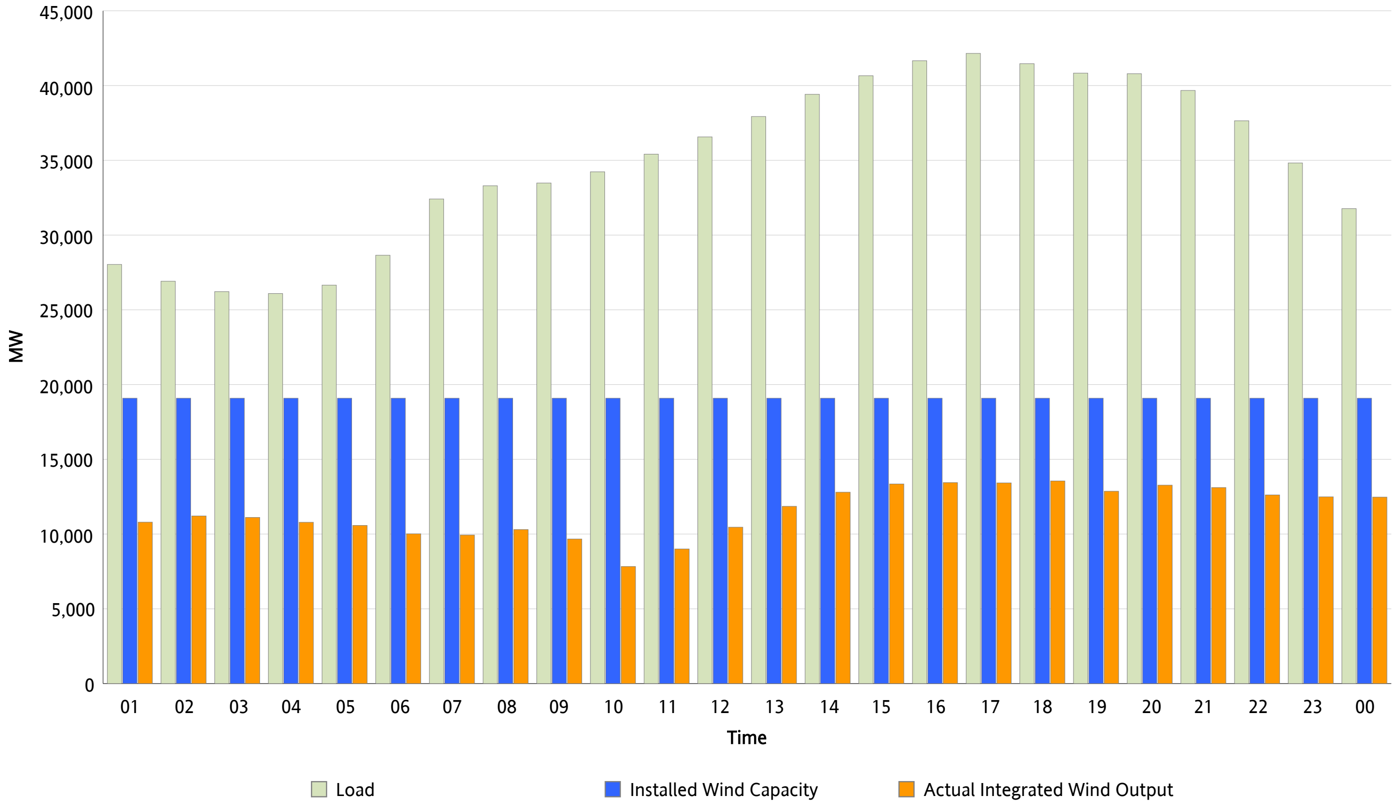
All Time Record Values:

Record Wind Generation	16,022 MW
Record Wind Generation Time	12/25/2016 10:40
Penetration at Record Wind Generation Time	47.09 %

Record Wind Penetration	48.28 %
Record Wind Penetration Time	03/23/2016 01:10
Wind Generation at Record Wind Penetration	13,154 MW

Hourly Average Actual Load vs. Actual Wind Output

02/23/2017

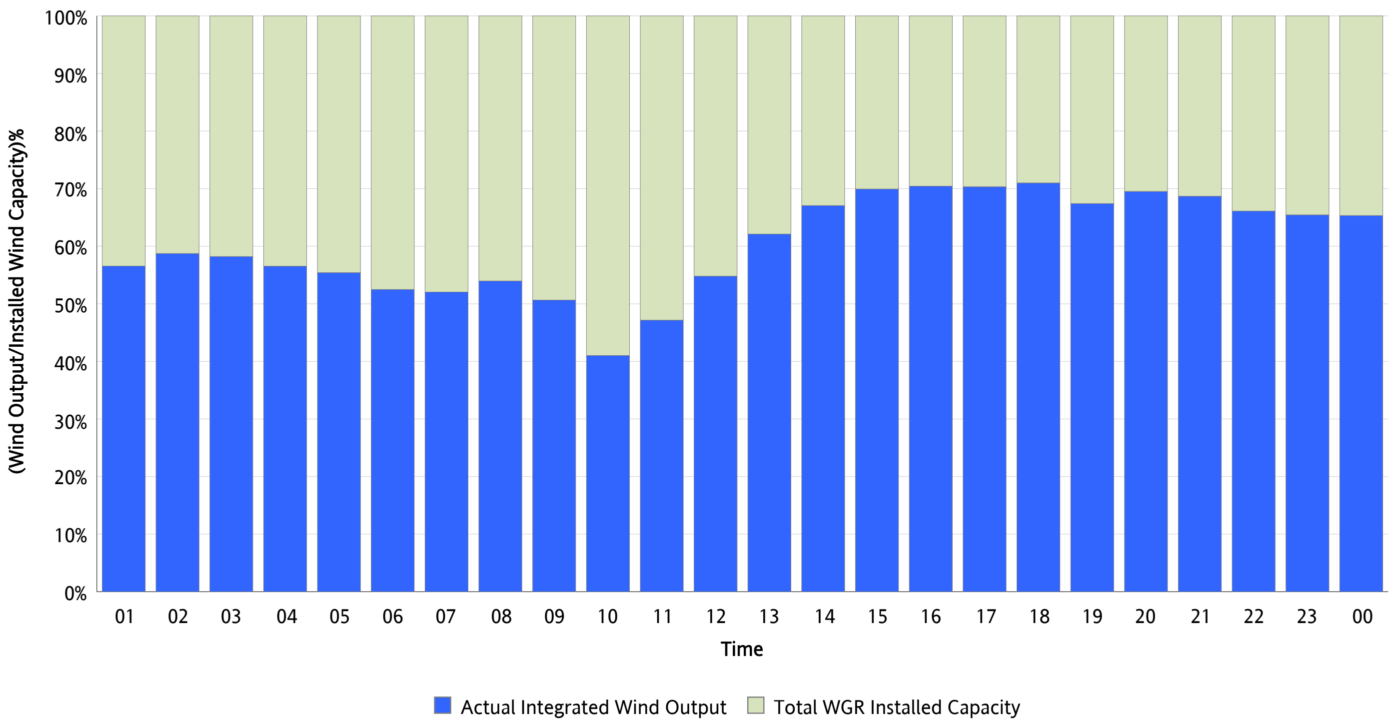


** Wind Record and Wind Max represent instantaneous values and the rest of the values are integrated over the hour.*

Capacity numbers used in the graphs are based on the expected commercial operation date of each Wind Generation Resource.

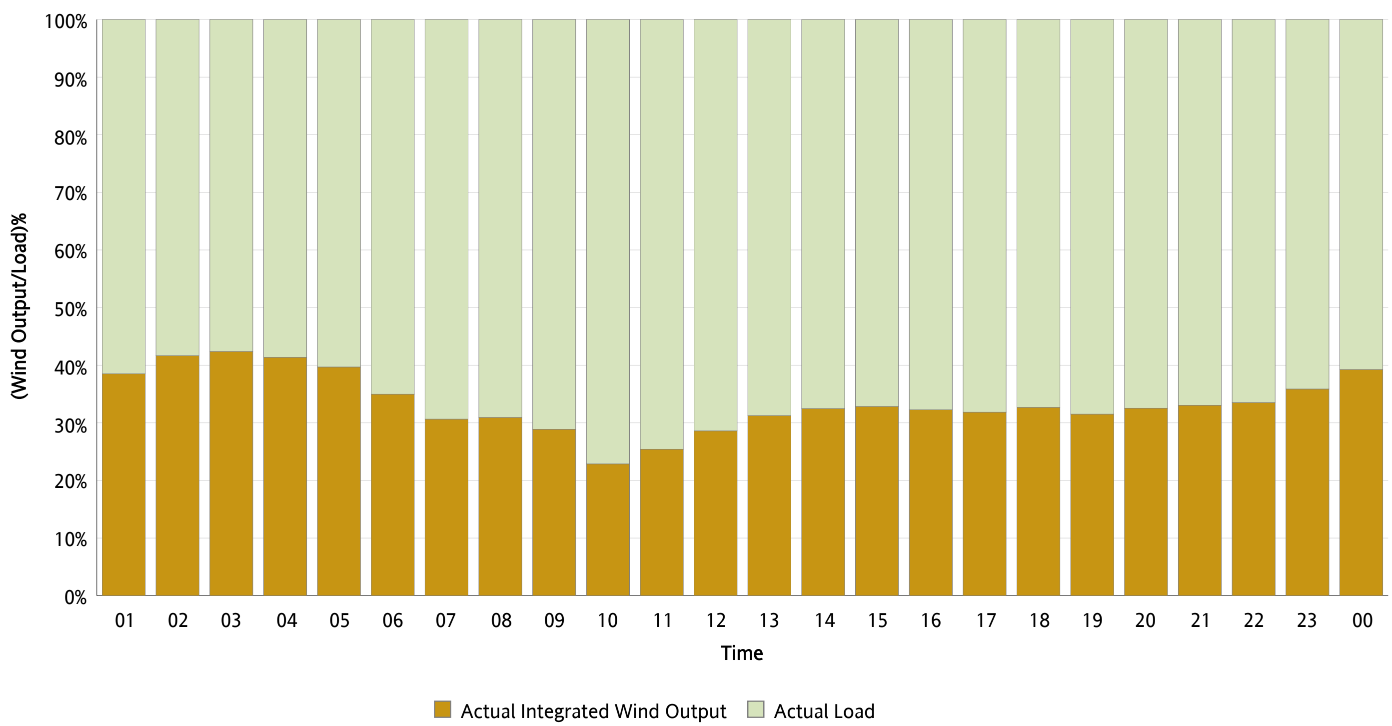
Actual Wind Output as a Percentage of the Total Installed Wind Capacity

02/23/2017



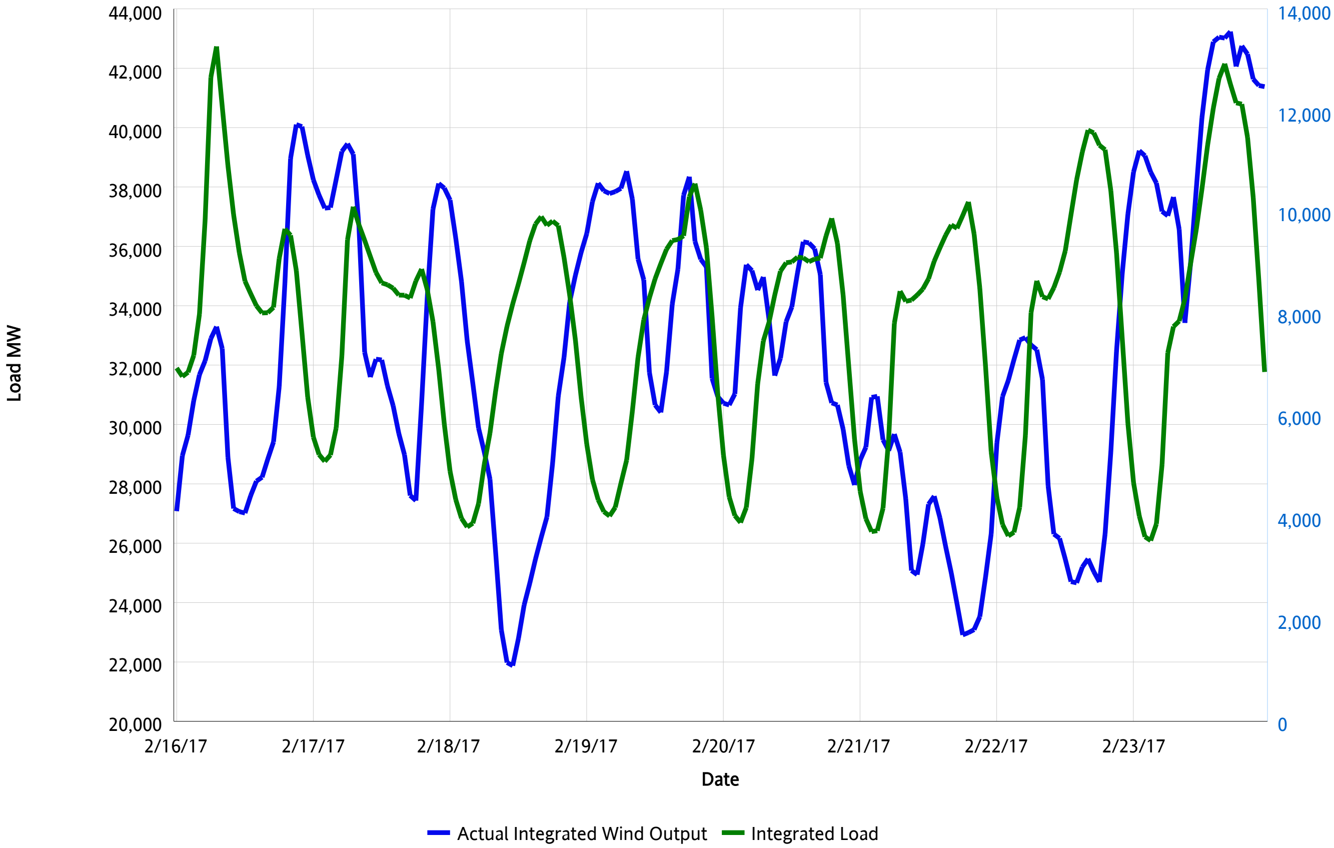
Actual Wind Output as a Percentage of the ERCOT Load

02/23/2017



ERCOT Load vs. Actual Wind Output

02/16/2017 - 02/23/2017



LogID 6220 & 6221

Renewables Watch

California ISO

For Operating Day: **Friday, February 24, 2017**

The Renewables Watch provides important information about actual renewable production within the ISO grid as California moves toward a 33 percent renewable generation portfolio. The information provided is as accurate as can be delivered in a daily format. It is unverified raw data and is not intended to be used as the basis for operational or financial decisions.

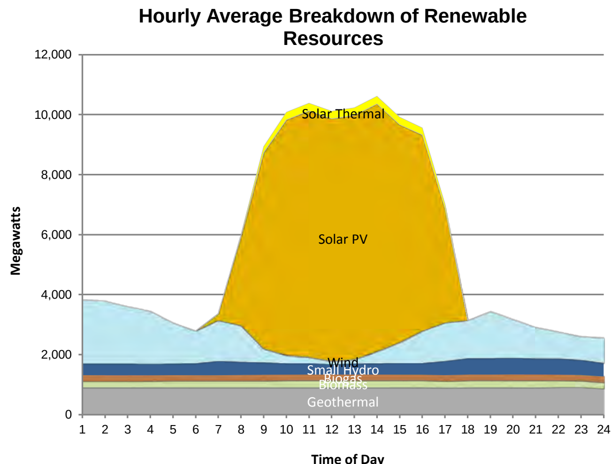
Renewables Production

24-Hour Renewables Production

Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	10:13	259	2,164
Solar	13:42	8,534	67,796
Wind	0:04	2,247	24,736
Small Hydro	17:42	567	10,685
Biogas	10:18	204	4,742
Biomass	17:25	241	5,407
Geothermal	22:24	907	21,597
Total Renewables			**137,127**

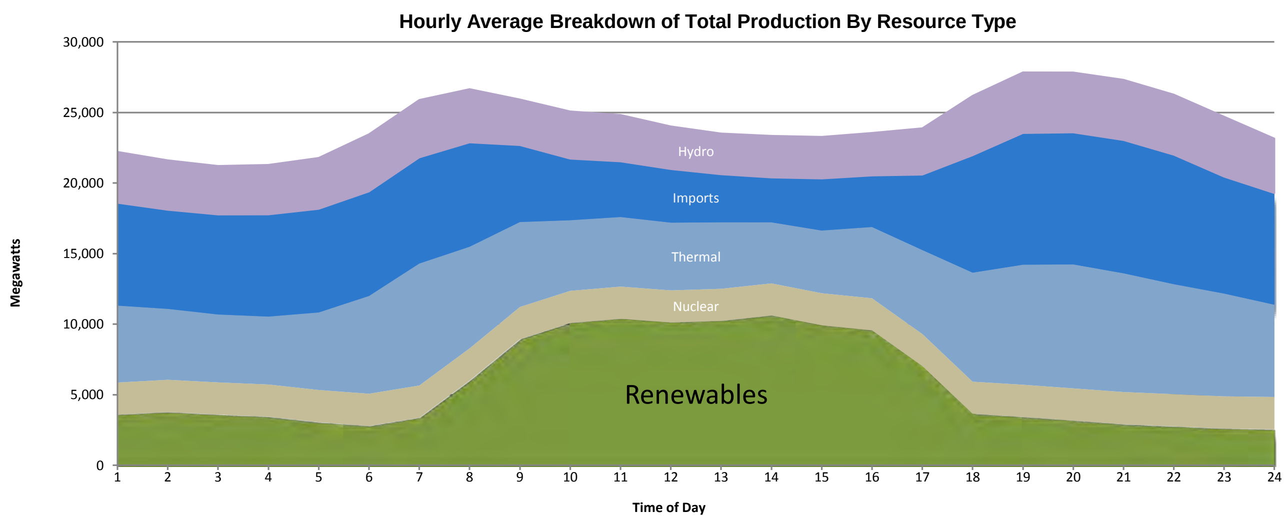
Total 24-Hour System Demand (MWh): *584,528*

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day.



This graph shows the production of various types of renewable generation across the day.

System Peak Demand (MW) *one minute average		**28,052**
Time:		**18:50**



This graph depicts the production of various generating resources across the day.

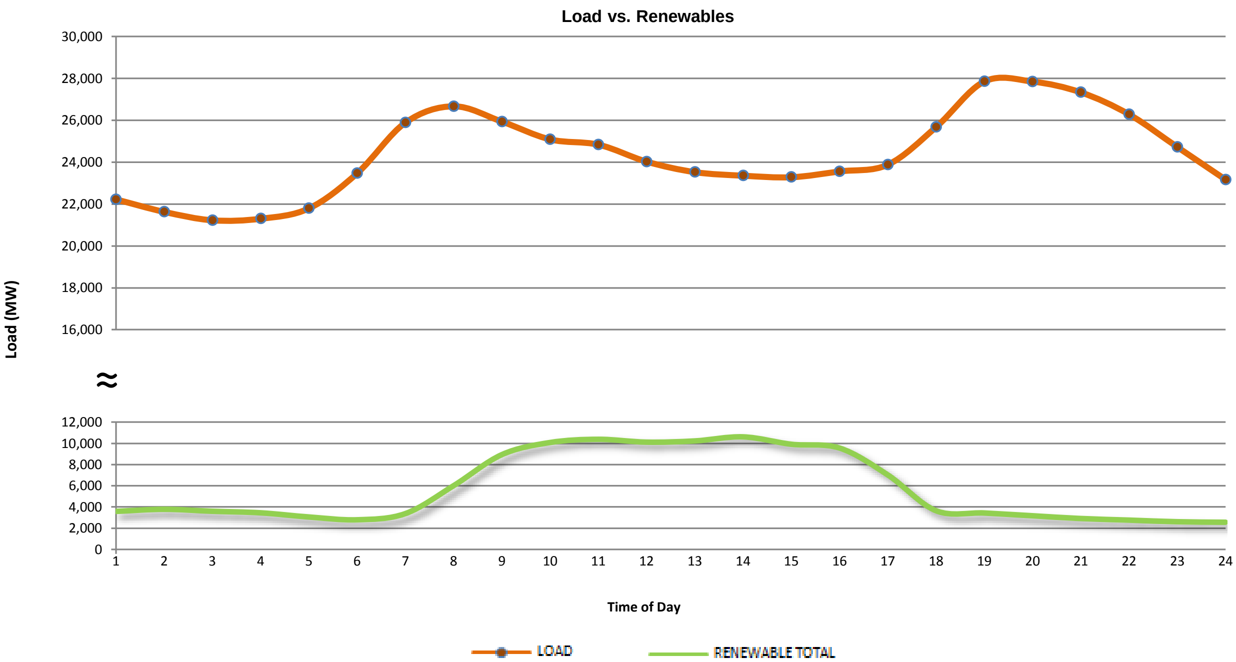
Previous Renewables Watch reports and data are available at http://www.caiso.com/green/renewableswatch.html

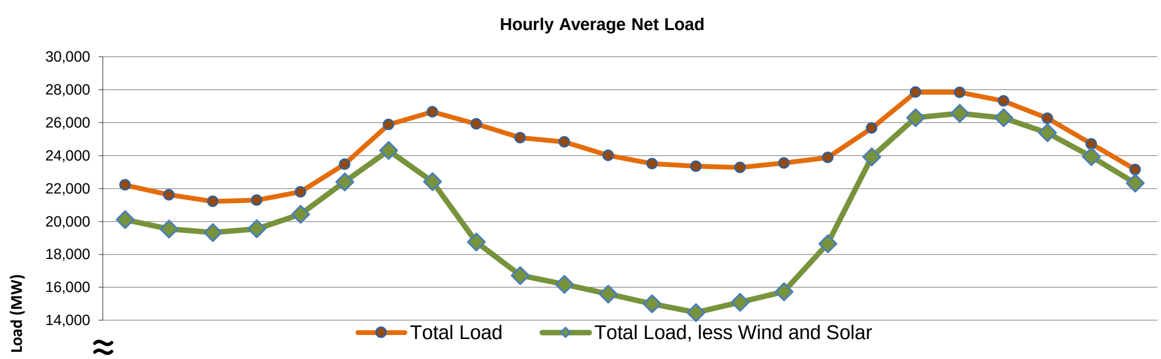
This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day. Solar PV and Solar thermal generators that are directly connected to the power grid. "Solar PV" is defined as solar generating units that utilize solar panels containing a photovoltaic material. "Solar Thermal" is defined as solar generating units that convert sunlight into heat and utilize fossil fuel or storage for production which may occur after sunset.

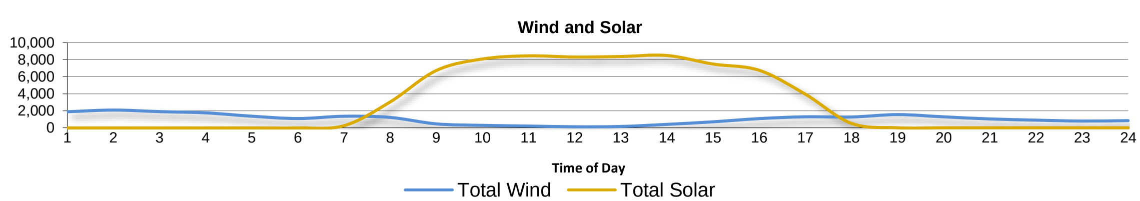
For Operating Day:

The first graph provided on this page shows how much energy renewable resources are contributing to the grid, and when those resources are producing their daily maximum and how that production correlates to the maximum energy demand.

Comparison to Load







The information contained in this report is preliminary and subject to change without notice. No inference, decision or conclusion should be made based on the information in this report or any series of these reports. All values are hourly average unless otherwise stated. Questions about this report should be directed to Jessica Garidel at jgaridel@caiso.com.

LogID 6220 & 6221

Renewables Watch

California ISO

For Operating Day: **Thursday, February 23, 2017**

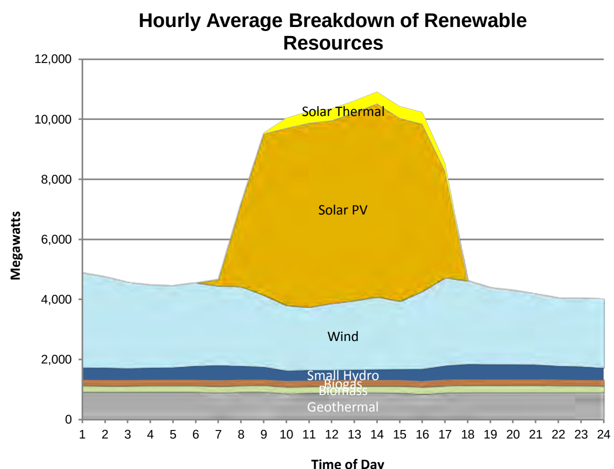
The Renewables Watch provides important information about actual renewable production within the ISO grid as California moves toward a 33 percent renewable generation portfolio. The information provided is as accurate as can be delivered in a daily format. It is unverified raw data and is not intended to be used as the basis for operational or financial decisions.

Renewables Production

24-Hour Renewables Production

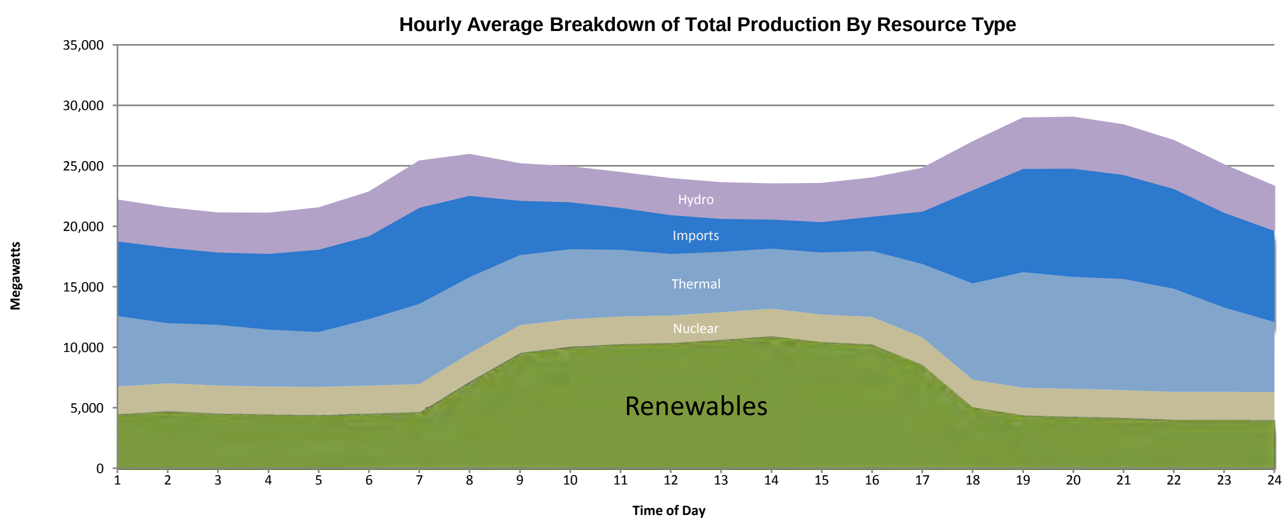
Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	9:25	394	2,999
Solar	13:04	6,630	54,440
Wind	0:02	3,213	60,341
Small Hydro	17:16	521	10,322
Biogas	15:44	203	4,752
Biomass	17:59	239	5,393
Geothermal	6:58	909	21,453
Total Renewables			**159,700**
Total 24-Hour System Demand (MWh):			*587,563*

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day.



This graph shows the production of various types of renewable generation across the day.

System Peak Demand (MW) *one minute average	29,180
Time:	18:53



This graph depicts the production of various generating resources across the day.

Previous Renewables Watch reports and data are available at http://www.caiso.com/green/renewableswatch.html

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day. Solar PV and Solar thermal generators that are directly connected to the power grid. "Solar PV" is defined as solar generating units that utilize solar panels containing a photovoltaic material. "Solar Thermal" is defined as solar generating units that convert sunlight into heat and utilize fossil fuel or storage for production which may occur after sunset.

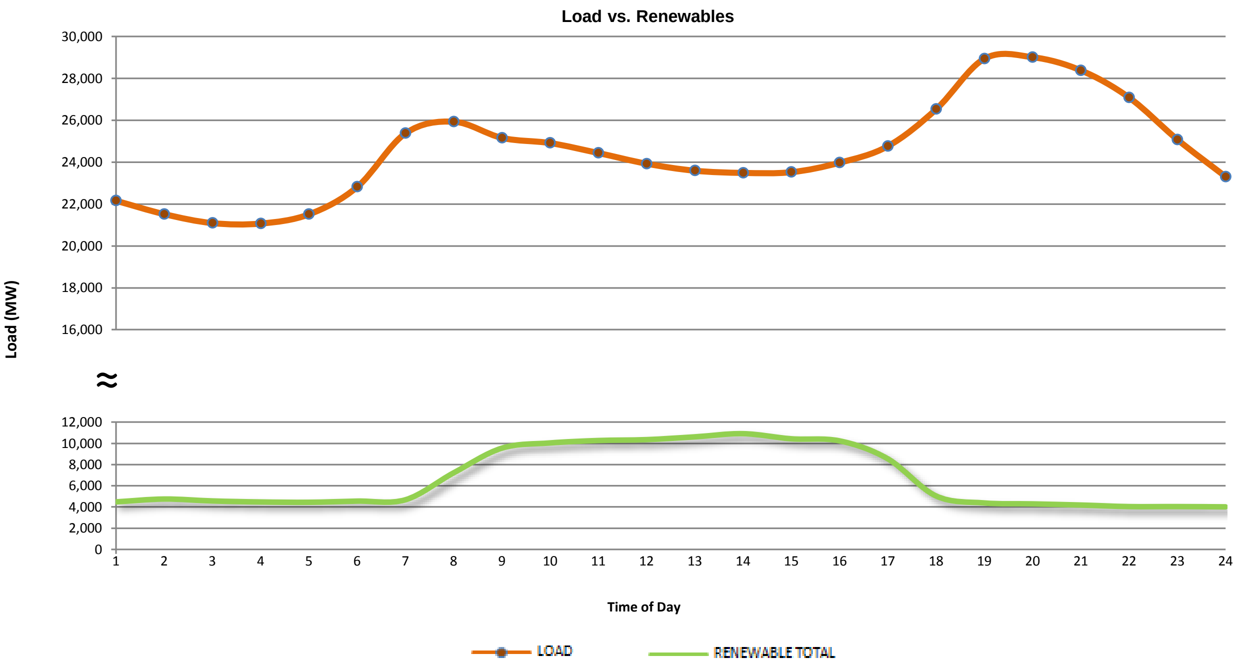
Renewables Watch

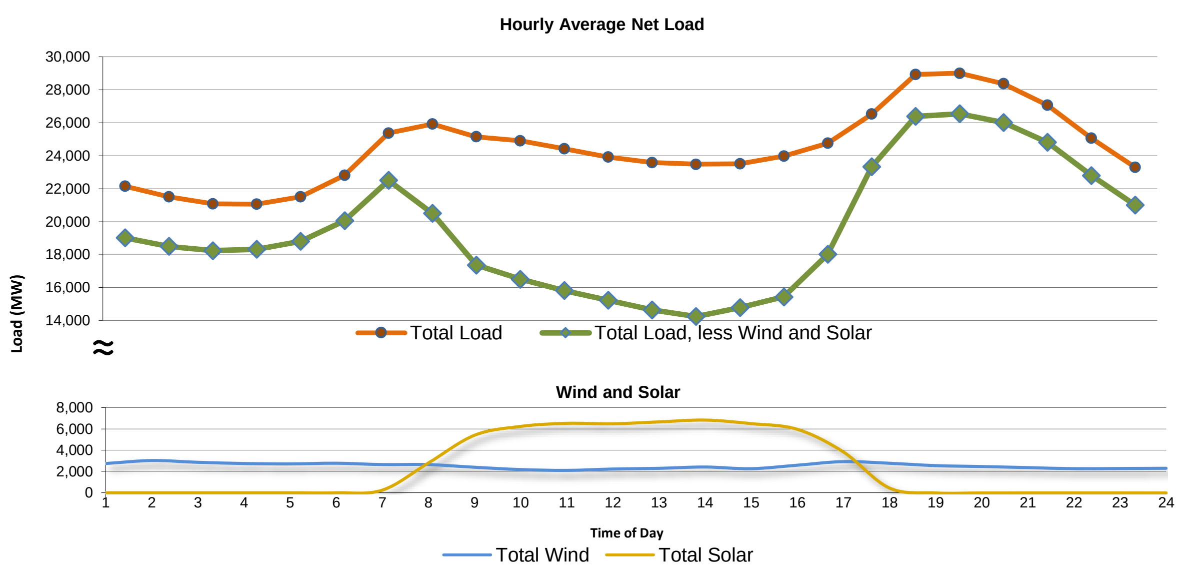
California ISO

For Operating Day:

The first graph provided on this page shows how much energy renewable resources are contributing to the grid, and when those resources are producing their daily maximum and how that production correlates to the maximum energy demand.

Comparison to Load





The information contained in this report is preliminary and subject to change without notice. No inference, decision or conclusion should be made based on the information in this report or any series of these reports. All values are hourly average unless otherwise stated. Questions about this report should be directed to Jessica Garidel at jgaridel@caiso.com.

Renewables Watch

California ISO

For Operating Day: **Wednesday, February 22, 2017**

The Renewables Watch provides important information about actual renewable production within the ISO grid as California moves toward a 33 percent renewable generation portfolio. The information provided is as accurate as can be delivered in a daily format. It is unverified raw data and is not intended to be used as the basis for operational or financial decisions.

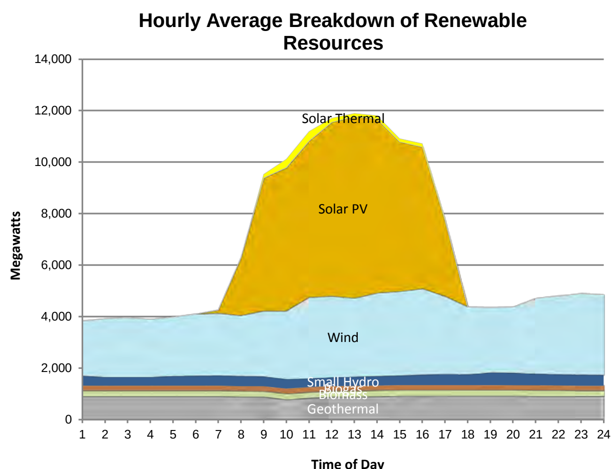
Renewables Production

24-Hour Renewables Production

Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	10:50	392	1,616
Solar	12:38	7,494	53,951
Wind	15:19	3,392	65,247
Small Hydro	18:44	502	9,682
Biogas	5:22	203	4,782
Biomass	18:28	236	5,391
Geothermal	13:40	909	21,379
Total Renewables			**162,047**
Total 24-Hour System Demand (MWh):			*577,183*

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day.

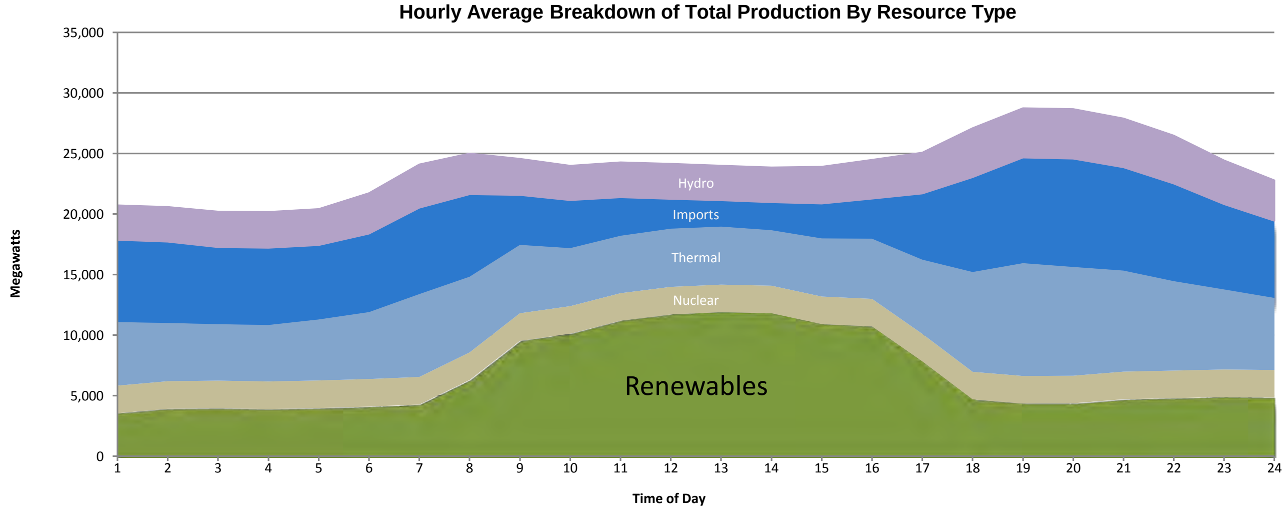
Hourly Average Breakdown of Renewable Resources



This graph shows the production of various types of renewable generation across the day.

System Peak Demand (MW) *one minute average	**28,916**
Time:	**18:45**

Hourly Average Breakdown of Total Production By Resource Type



This graph depicts the production of various generating resources across the day.

Previous Renewables Watch reports and data are available at **http://www.caiso.com/green/renewableswatch.html**

This table gives numeric values related to the production from the various types of renewable resources for the reporting day. All values are hourly average unless otherwise stated. Peak Production is an average over one minute. The total renewable production in megawatt-hours is compared to the total energy demand for the ISO system for the day. Solar PV and Solar thermal generators that are directly connected to the power grid. "Solar PV" is defined as solar generating units that utilize solar panels containing a photovoltaic material. "Solar Thermal" is defined as solar generating units that convert sunlight into heat and utilize fossil fuel or storage for production which may occur after sunset.

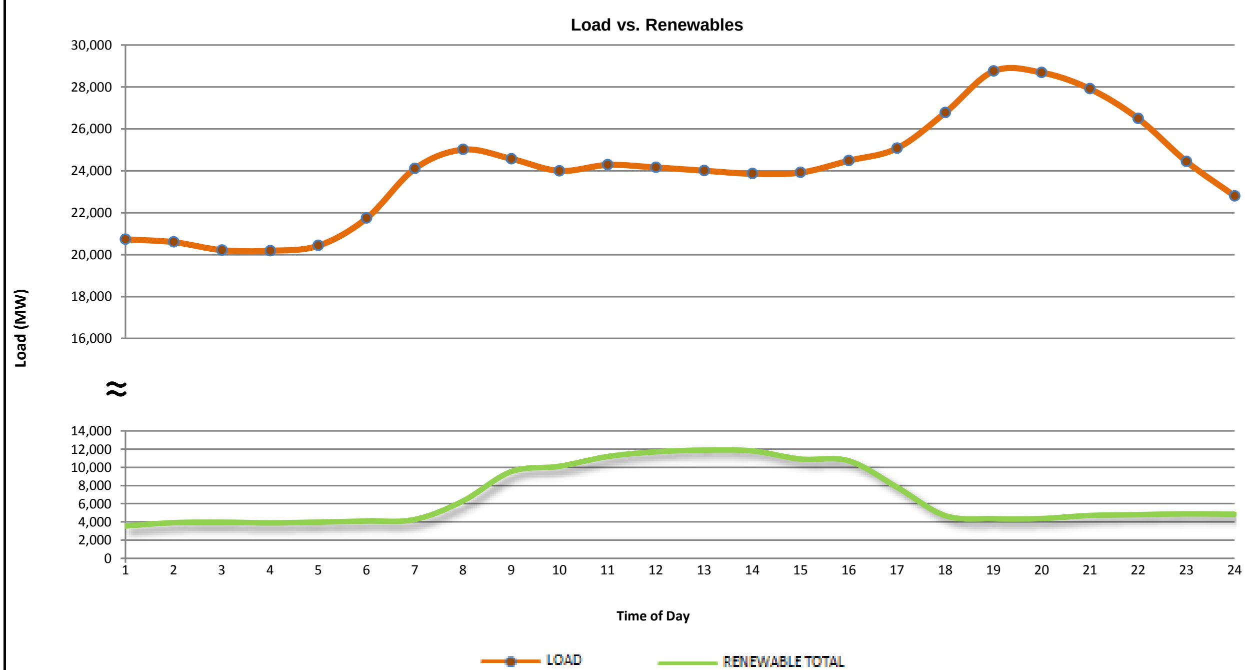
Renewables Watch

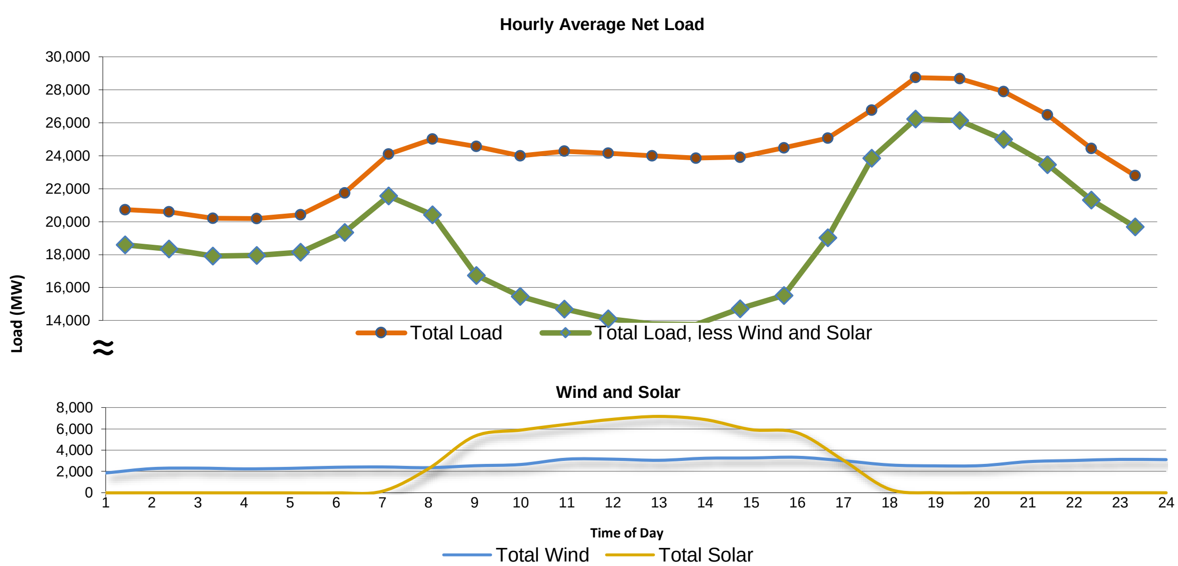
California ISO

For Operating Day:

The first graph provided on this page shows how much energy renewable resources are contributing to the grid, and when those resources are producing their daily maximum and how that production correlates to the maximum energy demand.

Comparison to Load





The information contained in this report is preliminary and subject to change without notice. No inference, decision or conclusion should be made based on the information in this report or any series of these reports. All values are hourly average unless otherwise stated. Questions about this report should be directed to Jessica Garidel at jgaridel@caiso.com.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

LogID 6171

Accounting Methodology for Source Energy of Non-Combustible Renewable Electricity Generation

October 2016

Acknowledgements

The author would like to thank the following individuals for their thoughtful review, comments, and suggestions in the preparation of this document: Madeline Salzman, Joan Glickman, Cody Taylor, and John Cymbalsky of the U.S. Department of Energy's (DOE's) Building Technologies Office; John Agan of the DOE's Office of Energy Policy and Systems Analysis; Barbara Fichman and Nanda Srinivasan of DOE's Energy Information Administration; Alexandra Sullivan, Cindy Jacobs, and Jean Lupinacci of the U.S. Environmental Protection Agency; and Paul Torcellini of the National Renewable Energy Laboratory.

Author

Paul Donohoo-Vallett, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Strategic Priorities and Impacts Analysis

Intro

As non-combustible sources of renewable power (wind, solar, hydro, and geothermal) do not consume fuel, the "source" (or "primary") energy from these sources cannot be accounted for in the same manner as it is for fossil fuel sources. The methodology chosen for these technologies is important as it affects the perception of the relative size of renewable source energy to fossil energy, affects estimates of source-based building energy use, and overall source energy based metrics such as energy productivity. This memo reviews the methodological choices, outlines implications of each choice, summarizes responses to a request for information on this topic, and presents guiding principles for the U.S. Department of Energy, (DOE) Office of Energy Efficiency and Renewable Energy (EERE) to use to determine where modifying the current renewable source energy accounting method used in EERE products and analyses would be appropriate to address the issues raised above.

Issue

The current *fossil fuel equivalency* approach used in many EERE products and analyses assumes non-combustible renewable electricity (RE) generation has an average heat rate of fossil fuels (9,510 BTU/kWh as of 2015), while an alternate *captured energy* approach uses the heat content of the electricity produced (3,412 BTU/kWh). Neither option is strictly technically more accurate or correct as both are a matter of methodological choice related to particular applications. However, the *fossil fuel equivalency* approach as currently used both within and outside of EERE affects source energy estimates of energy used in buildings and may create inconsistent policy signals as the amount of renewable electricity generation grows. Therefore, the guidelines provided at the end of this document indicate that it can be appropriate for EERE to use the *captured energy* approach in certain applications.

Note that other methodological choices regarding source energy and site-to-source ratio calculations (e.g. geographic resolution of site-to-source ratios, marginal versus average site-to-source ratios, how to account for on-site renewable electricity, nuclear energy and combustible renewable source energy calculations) are not considered here.

Background

Source energy is a concept used to evaluate energy consumption when different types of energy sources need to be accounted for equitably, such as in buildings (e.g. electricity, natural gas, steam, fuel oil) or large sectors of the economy (e.g. coal, natural gas, petroleum).[1] Using source energy allows all of these energy types to be evaluated on a common energy metric. This concept is used in a variety of EERE and related Federal Government products, publications, tools, and reports. Examples are listed below:

EERE products and reports that use source energy:

- Impact Assessments for Appliance Standards
- Market reports (e.g. LEDs)
- Home Energy Score & Asset Score
- Federal Energy Management Program (FEMP) Source Energy Reporting[2]
- Energy efficiency metrics (e.g. Energy Productivity)

Zero Energy Buildings Definition Related Federal Government Products that use source energy:

- ENERGY STAR Portfolio Manager® (EPA)
- Annual Energy Outlook (EIA)
- Monthly Energy Review (EIA)

1 U.S. Environmental Protection Agency, "Energy Star Portfolio Manager Technical Reference – Source Energy." July 2013. Available at: http://go.usa.gov/xjwwT

2 FEMP reports source energy by agency in the Comprehensive Annual Energy Data and Sustainability Performance report, Table T-4: http://go.usa.gov/xZWxQ

3 Energy Information Administration, "Monthly Energy Review." Accessed August 2016. Available at: http://www.eia.gov/totalenergy/data/monthly/

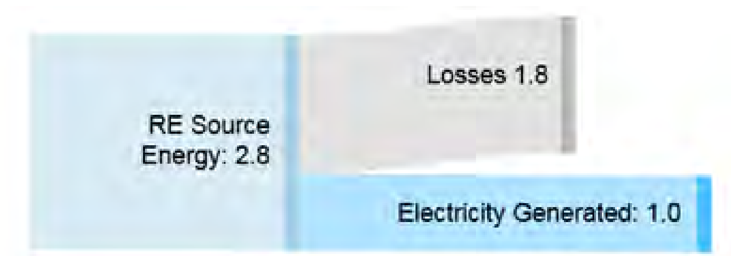
4 Energy Information Administration, "Annual Energy Review 2011", Appendix F: Alternatives of Estimating Energy Consumption, Accessed July 2016. Available at: http://www.eia.gov/totalenergy/data/annual/pdf/sec17.pdf

Most of these examples currently use the *fossil fuel equivalency* approach, and this has been consistent with how Energy Information Administration (EIA) has historically reported source energy using fossil fuel equivalency. However, EIA plans to introduce non-combustible renewable source energy using the *captured energy* in the *Monthly Energy Review*.[3] The details of the two methodologies are outlined below.

It is noted that these are not the complete set of methodological choices possible for non-combustible source energy accounting. Other examples include the incident energy methodology, which would use each technology's efficiency of converting the renewable resource (e.g. wind or solar energy) into electricity to determine source energy,[4] while another method would assume that non-combustible renewable generation consumes no source energy (e.g. 0 BTU/kWh). The request for information (RFI) and research informing this document focuses only on using *captured energy* as an alternative to *fossil fuel equivalence*.

Fossil Fuel Equivalency

This methodology uses the average heat rate of fossil generators and assigns it as the heat rate for non-combustible RE generation – currently 9,510 BTU/kWh, or about 35% efficiency as seen in the figure below. This value represents the source energy value of the fossil generation which is displaced by the RE generation. EIA reported that this methodology was developed in an earlier era when the penetration of RE generation was low, and it was generally displacing the use of fuel oil.[5]



A concern with this approach is that it does not accurately reflect the energy losses associated with different types of energy, as it assumes RE generation has the same energy losses in conversion as fossil generation, and that these losses represent similar economic loss. While RE generators do have losses in converting sunlight or wind energy into electricity, there is no economic value lost because there is no other direct use for the resource that was not captured (e.g. wind or sunlight) as there would be for coal or natural gas that was not combusted. When used for calculated metrics related to determining the efficiency of the power sector and the impact of energy efficiency measures, it introduces distortions due to the fictitious "losses" to the energy system.

Captured Energy

This methodology assumes that the source energy of RE generators is exactly equal to the electricity produced with no energy losses prior to transmission and distribution. This is equal to a heat rate of 3,412 BTU/kWh, or a conversion efficiency of 100%, as shown below.

This approach better shows the economically significant energy transformations in the United States because the "lost" RE energy does not incur any significant economic cost. However, this approach implies that conversion of noncombustible renewable energy is 100% efficient which is not physically true.

3 Energy Information Administration, "Monthly Energy Review." Accessed August 2016. Available at: http://www.eia.gov/totalenergy/data/monthly/

4 Energy Information Administration, "Annual Energy Review 2011", Appendix F: Alternatives of Estimating Energy Consumption, Accessed July 2016. Available at: http://www.eia.gov/totalenergy/data/annual/pdf/sec17.pdf

5 Ibid

Technical Considerations

As mentioned in the introduction, neither option is considered more technically "correct" or more "accurate" than the other, as each option needs to be considered along with its intended use to determine which is appropriate. As discussed by EIA, for their purposes, *fossil fuel equivalency* may be more appropriate when RE generation always displaces fossil fuel generation, and *captured energy* may be more appropriate when RE generation never displaces fossil fuels.[6] There are also additional confounding factors such as Renewable Portfolio Standards and priority dispatch of renewables that would make it extremely challenging to calculate a more representative conversion factor that accurately assesses what fuel source RE generation is displacing.

It is also noted that both methodologies only address the conversion of source energy to electricity generated at the generator. Both methods still need to reflect losses from transmission and distribution when used in a site-to-source ratio as seen in the sample calculation in the appendix.

Impact of Methodological Choice

The choice of methodology makes a difference when used in tools, products, and analyses, and the differences between the methods increase as the penetration of RE generation increases. Table 1 below outlines the quantitative impact on select source energy metrics of switching from the *fossil fuel equivalency* approach to a *captured energy* approach, under projected conditions from EIA's *Annual Energy Outlook 2016* and a hypothetical 50% renewable penetration scenario.

For total source energy, energy productivity, and average site-to-source ratios, increasing RE penetration under *fossil fuel equivalency* has minimal effect by definition as RE source energy has the same heat rate as the fossil fuels used. Instead, fuel switching from coal to natural gas is the primary driver of site-to-source ratio change regardless of RE penetration. As natural gas changes the ratio due largely to higher conversion efficiencies and lower source energy loss, it is inconsistent for the lower economic energy loss associated with RE to not also drive these changes. However, if the *captured energy* approach were instead used, increasing RE penetration causes a further decrease in source energy, an increase in energy productivity, and a decrease in the average site-to-source ratio, beyond the effects of coal to natural gas fuel switching alone.

The analysis shown in Table 1 also shows that the marginal site-to-source ratio would be reduced by ~10% if the *captured energy* methodology was used at current levels of RE penetration. This would likely decrease further in the future as more renewable generation is predicted to come online based on additional factors such as the Clean Power Plan and the tax credit extension which were not included in the modeling scenarios used to evaluate the marginal site-to-source ratio.[7]

The following sections discuss the impact of the methodological choice on specific EERE and other Federal Government programs in more detail.

6 Ibid

7 See note b for Table 1.

Table 1: Projected impact of *fossil fuel equivalency* and *captured energy* methodologies on selected relevant energy metrics, using 2015 data from EIA's *Monthly Energy Review* and future values from EIA's *Annual Energy Outlook 2016*. Note that these values are presented for illustrative purposes only.

Year (RE Generation %)[a]	Fossil Fuel Equivalency	Captured Energy	Impact
Total Economy-Wide Source Energy (Quads)			
2015 (12%)	97.7	94.5	As RE penetration increases, the difference between total economy-wide source energy calculated using *captured energy* and *fossil fuel equivalency* increases
2020 (18%)	100.6	95.9	
2030 (22%)	101.5	95.8	
2040 (26%)	107.2	100.0	
— (50%)	107.4	93.5	
Energy Productivity (GDP 2015 dollar-year$/MMBTU)			
2015 (12%)	$186	$191	Using *captured energy* approach causes RE deployment to increase energy productivity as compared to *fossil fuel equivalency*.
2020 (18%)	$230	$241	
2030 (22%)	$283	$300	
2040 (26%)	$330	$353	
— (50%)	$329	$378	
Average Site-to-Source Ratio			
2015 (12%)	3.00	2.77	RE deployment would cause the site-to-source ratio to decrease in the *captured energy* approach, while the *fossil fuel equivalency* is primarily sensitive to fuel switching from coal to natural gas.
2020 (18%)	2.83	2.49	
2030 (22%)	2.73	2.34	
2040 (26%)	2.71	2.27	
— (50%)	2.72	1.87	
Marginal Site-to-Source Ratio[b]			
2020 (14%)	2.70	2.34	*Captured energy* would decrease the projected source energy savings due electricity energy efficiency measures by ~10% relative to *fossil fuel equivalency*. The difference would increase as RE penetration increased and was more often the marginal generator.
2030 (13%)	2.28	2.10	
2040 (14%)	2.32	2.04	

a The 2015 numbers use data published in the *Monthly Energy Review* [8] and projected future values use data from the *Annual Energy Outlook* (AEO) 2016 reference case.[9] The 50% RE generation scenario uses the generation mix from 2040, but scales generation proportionally so non-combustible renewables accounts for 50% of all electricity generation.

b The marginal site-to-source ratio compares the difference in generation and source energy consumption between the AEO 2014 reference case and the high efficiency technology side case to estimate the marginal impact of reducing demand. AEO 2014 is used as the high-efficiency technology side case for AEO 2016 has not yet been released as of the time of this writing. The renewable penetrations achieved in AEO 2014 are lower than for AEO 2016 due to no Clean Power Plan, higher renewable capital costs, and no renewable tax credit extensions. This approach is similar to one developed by Lawrence Berkeley National Labs and used for assessing the impact of Appliance and Efficiency Standards.[10]

8 Energy Information Administration, "Monthly Energy Review." Accessed August 2016. Available at: http://www.eia.gov/totalenergy/data/monthly/

9 Energy Information Administration, "Annual Energy Outlook 2016." Accessed August 2016. Available at: http://www.eia.gov/forecasts/aeo/tables_ref.cfm

10 Coughlin, K, "Utility Sector Impacts of Reduced Electricity Demand," Lawrence Berkeley National Lab, LBNL-6864E, Accessed July 2016. Available at: http://www.osti.gov/scitech/servlets/purl/1165372

EERE Products and Reports

- **Appliance Standards:** The current methodology uses a marginal full fuel cycle site-to-source ratio to determine the source energy savings for a given unit of site energy reduction in consumption, due to a standard. This is derived from power sector modeling to project the change in power generation mix due to reductions in demand.[11] As shown in the example in the table above for marginal site-to-source ratios, switching to *captured energy* would decrease the total source energy saved due to an electricity-savings measure by ~10% at current levels of RE penetration. The difference between the two methodologies would increase as RE penetration increases as RE would more often be a marginal resource.

  Note that the emissions impacts, electricity consumption savings, and energy cost savings from appliance standards are not affected by the renewable accounting methodology choice. Neither is the assessment on the relative impacts of appliance standards on different electricity generation sources. Only the source energy savings are affected.

- **Energy Efficiency Market Reports:** Market reports, such as *LED Lighting Forecast* published by EERE, project the current and future source energy savings attributed to LED lighting. The *captured energy* approach would decrease current estimates of source energy saved by 7.7% and would continue to decrease as RE penetration increases in the future.

- **Economy-wide Energy Efficiency Metrics:** As seen in the table above, energy efficiency metrics that use source energy are also affected by the methodology choice. For example, energy productivity uses total source energy in the denominator. Under the *fossil fuel equivalency* approach, increasing penetration of RE has minimal effect on energy productivity, while fuel switching from coal to natural gas, or improvements in the heat rate of fossil generators do. Under the *captured energy* approach, increasing the amount of RE generation would also act to increase energy productivity.

- **Building Energy Performance Metrics:** EERE's building energy performance scoring tools — Home Energy Score and Building Asset Score — currently use site-to-source ratios using the fossil fuel equivalency method to estimate the source energy required for a home or building.[12] Changing to the *captured energy* approach would reduce the estimated source energy consumption from electricity use by 7.7%, and this impact would grow in magnitude as RE penetration increased. This would more correctly credit electricity with reduced fuel consumption and associated environmental impacts as RE penetration increases.

- **Zero Energy Buildings (ZEB) Definition**: This definition looks at buildings in terms of the energy flows to and from buildings, and uses site-to-source ratios based on the *fossil fuel equivalency* method to estimate the source energy used for a home or building. Changing to the *captured energy* approach would reduce the estimated source energy consumption from electricity use by 7.7%, and this impact would grow in magnitude as RE penetration increased. This would more correctly credit electricity with reduced environmental impacts as RE penetration increases. The definition calculates on-site renewable generation that is exported to the grid using the *fossil fuel equivalency* approach to properly balance the source energy of grid electricity displaced and allow buildings to achieve net zero status. This could be modified to *captured energy* as well to maintain the appropriate balance with delivered energy.

- **Federal Energy Management Program (FEMP) Reporting:** Since the 1980s, FEMP has been tracking progress toward statutory energy reduction goals in site-delivered energy using the *captured energy* approach for non-renewable energy sources. In general, FEMP reporting uses site-energy metrics, except for *Table T-4: Total Primary (Source) Energy Use in All End-Use Sectors, by Agency published as part of the Comprehensive Annual Energy Data and Sustainability Performance* report,[13] which currently uses *fossil fuel equivalency* for both renewable generation and purchased steam. If captured energy were used instead, the reported source energy use would be reduced by 7.7%, and this impact would grow in magnitude as RE penetration increased.

11 Coughlin, K, "Utility Sector Impacts of Reduced Electricity Demand," Lawrence Berkeley National Lab, LBNL-6864E, Accessed July 2016. Available at: http://www.osti.gov/scitech/servlets/purl/1165372

12 U.S. Department of Energy, "A Common Definition for Zero Energy Buildings," September 2015. Available at: http://go.usa.gov/xjwpH

13 Available at http://go.usa.gov/xZWxQ

Per 42 U.S.C. § 8259(4), when tracking progress toward statutory energy intensity reduction goals, FEMP assumes that on-site renewable generation consumes no captured or source energy (e.g. 0 Btu/kWh). As FEMP uses site-delivered energy as the unit for tracking progress towards energy goals, it also provides a credit to agencies that use combined heat and power plants which bring energy on-site to generate and displace the use of grid-supplied electricity.

Related Federal Government Products and Reports with EERE Equities

- **ENERGY STAR Portfolio Manager® (EPA):** Currently uses site-to-source ratios that use the *fossil fuel equivalency* approach. As shown in the table above, this currently does not capture the displacement of fossil fuel caused by increasing off-site renewable generation. The *captured energy* approach would continue to lower the site-to-source ratio as renewable generation increases.[14]

  EPA's ENERGY STAR Portfolio Manager® calculates on-site renewable generation source energy using the *captured energy* approach.[15] Using the *captured energy* methodology for off-site renewable generation to calculate site-to-source ratios for electricity would treat renewable generation consistently between on-site and off-site generation while still accounting for transmission and distribution losses. EPA has indicated that they plan to transition to the *captured energy* approach for off-site renewable generation in their next update. As indicated above, this will lower a building's total source energy consumption from grid electricity and this impact would increase in magnitude as RE generation increases.

- **EIA Products (Annual Energy Outlook and Monthly Energy Review):** Both of these EIA products employ the *fossil fuel equivalency* approach for reporting historical data and for projecting total source energy into the future, and in all associated products such as the annual energy flow diagram. Use of *captured energy* would show RE generation as a smaller portion of total source energy used in the economy, and would also reduce the reported conversion losses, showing the energy system to be more efficient (i.e. with less losses) as RE penetration increases.

  For projections, the reported total economy-wide source energy consumption is smaller when *captured energy* is used (see Table 1). If not appropriately attributed to fuel-switching, it may appear that the reduction in economy-wide source energy is due to energy efficiency improvements instead of increased RE generation.

  As noted previously, *Monthly Energy Review* will begin reporting both *fossil fuel equivalency* and *captured energy* source energy of RE in future editions.

Additional Impacts and Concerns

- **Stakeholder Confusion:** If the *captured energy* approach replaces *fossil fuel equivalency* in EERE products and metrics then external stakeholders may not fully understand that there are different methodologies behind a metric with the same name, such as site-to-source ratios.

- **Disconnect with Historical Data:** users of products that include a historical series of data and metrics that are impacted by a change in methodology may be burdened when comparing data between before and after the methodology change.

- **Incorrect Impression of Accuracy:** a switch of methodologies may imply that the *captured energy* methodology is more technically accurate than the *fossil fuel equivalency* methodology, whereas, as discussed in the "Technical Considerations" section, the answer is more nuanced.

- **Reduced Perception of Renewable Penetration:** The percentage of source energy for the entire economy provided by renewables is significantly reduced when using *captured energy*, and gives the impression that renewables are not as significant compared to other energy sources. However, reporting of actual electricity generation of renewable sources would be unchanged.

---

14 U.S. Environmental Protection Agency, "Energy Star Portfolio Manager Technical Reference – Source Energy." July 2013. Available at: http://go.usa.gov/xjwwT

15 U.S. Environmental Protection Agency, "Portfolio Manager and Green Power Tracking." Accessed July 2016. Available at: http://go.usa.gov/xjwfw

Request for Information Response Summary

In response to the request for information (RFI) on this topic,[16] EERE received 7 submissions representing 10 organizations. Responders who agreed to have responses made public were a mixture of electric and natural gas utilities, industry associations, and non-profit organizations (NRDC, NRECA, EEI, APPA, Southern Company, GTI, NPGA, APGA, Laclede Group).[17]

Support of "*captured energy*" methodology: Five responders (NRDC, NRECA, EEI, APPA, Southern Company) fully supported the methodological change of replacing the *fossil fuel equivalency* with the *captured energy* methodology. They noted the changes are needed as the current approach discounts the value of zero emitting renewable resources, and as a result on-site combustion of fossil fuels is valued over off-site generation of renewable resources. They also note that the *fossil fuel equivalency* approach runs counter to DOE energy conservation goals.

Opposition of "*captured energy*" methodology: Two responders (NPGA, Laclede) opposed the methodological change of replacing *fossil fuel equivalency* with *captured energy* methodology. They noted that "*captured energy*" approach does not capture upstream and downstream losses and does not yield an equitable comparison between generation technologies, although this appears to be a misunderstanding of how the change would affect energy accounting for losses.

Neutral comment in support of matching methodology to policy goals: Two responders (GTI, APGA) while neither explicitly supporting or opposing the proposed approach, highlighted the importance of matching the methodology choice with the desired goals or outcomes in order to avoid inappropriately using metrics or leading to perverse incentives. Commenters expressed concern that the proposed approach could be used to promote further electrification.

These commenters noted that the choice used to estimate energy savings from an efficiency measure nationally for accounting purposes would differ from one used to determine the impacts of an energy efficiency measure for a specific building in a specific location for the purposes of making investment decisions. They asserted that the marginal generator displacement methodology is more appropriate for the latter situation. It is noted that the marginal generation displacement methodology is currently used by the appliance standard program when reporting impact assessments.

In addition, four responders (NRDC, NRECA, EEI, APPA) proposed publishing and/or using a fossil-fuel site-source ratio which only includes the source energy from fossil fuel generation, to better match the policy aims of reducing fossil fuel use and greenhouse gas emissions. This would essentially assign no source energy to non-combustible renewable and nuclear energy generation (i.e. 0 BTU/kWh).

Marginal generation emissions factors are most appropriate for individual decisions: Commenters stressed the importance of using regional and marginal emissions factors when determining the impact of specific energy efficiency measures on air pollution. Some also noted that if the *captured energy* approach is used, the marginal factor would underestimate the impact of specific energy efficiency measures on fossil fuel displacement as RE generation is generally not the marginal generator displaced.

Transparency and robustness for values used and calculated and clarity in definitions: Commenters requested that DOE consider creating an annually updated publication which shows all the inputs and calculations used for calculating a site-to-source ratio. (NRDC, NRECA, EEI, APPA) Additional commenters encouraged further transparency and cooperation between DOE and EPA for updating the eGrid regional marginal emission factors. (GTI, APGA)

Support for using full-fuel cycle metrics: Commenters noted that using a full-fuel cycle metric for comparison between fuels is the most equitable methodology, and that the site-to-source ratio only considers source energy consumed at the site of generation and does not account for the embedded "upstream" energy required for mining, processing, and transportation of the fuels in the fuels consumed at the generator. (GTI, APGA, NPGA, Laclede)

16 "Request for Information: Accounting Conventions for Non-Combustible Renewable Energy Use," 81 Federal Register 30, Feb. 15, 2016, pp 7778 – 7779. Available at: http://go.usa.gov/xjw7z

17 Comments available at: http://go.usa.gov/xjwAW

Guidelines on Methodology Choice

As many of the RFI responses noted, it is important to match the methodological choice with the goals of a given policy or metric. After reviewing the impacts of the methodological choices and examining the distorting effect of the *fossil fuel equivalency* methodology in various calculations, the following guiding principles were developed to indicate where it is appropriate to use the *captured energy* methodology.

As noted previously, these guidelines do not address any other aspects regarding source energy or site-to-source ratios (e.g. calculating a site-to-source ratio, marginal versus average site-to-source ratios, accounting for source energy from nuclear and combustible renewable generation, regional versus national accounting, on-site renewable electricity accounting)

1. **Using the *captured energy* methodology when calculating marginal or average site-to-source ratios to calculate source energy savings avoids the fictitious source energy savings and consumption arising from the *fossil fuel equivalency* methodology.** Even though switching to the *captured energy* approach would lower the total amount of projected savings from energy efficiency actions when using the marginal site-to-source ratio, it would be a more accurate assessment of savings and would avoid larger magnitude distortions in the future as RE generation increases both in reality and in modeled projections.

2. **Using the *captured energy* methodology when using site-to-source ratios to score the energy use of buildings provides a policy-consistent signal to building managers that electricity use consumes less source energy as RE generation increases.** This allows more equitable comparisons that better reflect the losses to the energy system associated with different fuel types, including on-site renewables.

3. **Use of the *captured energy* methodology allows increased RE generation to affect derived metrics such as energy productivity.** This approach would allow fuel switching to non-combustible renewable generation to be reflected in metrics such as energy productivity more similarly to fuel switching from coal to natural gas, and better aligned with the economic energy losses of these fuels.

4. **Use of the *captured energy* methodology for off-site renewable electricity generation allows for consistent treatment of conversion to source energy.** For methodologies that account for the source energy of on-site renewable energy production and consumption (i.e. on-site renewable energy is 3,412 BTU/kWh and not 0 BTU/kWh), *captured energy* maintains consistency between the conversion to source energy for on-site and off-site renewable generation.

18 As noted in the *Zero Energy Buildings Definition,* exported on-site RE generation can converted to source energy as if it were grid provided electricity to properly balance out the displaced source energy consumption.

19 See above footnote.

Appendix A: Example Site-to-Source Calculation for 2015

	Generation (GWh)[a]	Conversion (BTU/kWh)[c]		Source Energy (Quads)[d]	
Fossil Fuels					
Coal	1,356,057	10,428		14.14	
Petroleum	28,443	10,814		0.31	
Natural Gas	1,335,068	7,907		10.40	
Other Gases	12,963	—		0.10[e]	
Other Non-Fossil					
Nuclear	797,178	10,459		8.34	
Other	13,239[b]	—		0.19[e]	
Combustible RE					
Wood	42,358	—		0.42[e]	
Waste	21,833	—		0.30[e]	
Non-Combustible RE		**Fossil Fuel Equivalency**	**Captured Energy**	**Fossil Fuel Equivalency**	**Captured Energy**
Hydropower	251,168	9,510	3,412	2.39	0.86
Wind	190,927	9,510	3,412	0.16	0.06
Solar	26,473	9,510	3,412	1.82	0.65
Geothermal	16,767	9,510	3,412	0.25	0.09
			Total Source:	**38.82**	**35.86**

Net Generation of Electricity	4,087,381[f]	3,412	13.95
T&D Losses & Unaccounted	290,564[f]	3,412	0.99
		Total Domestic Generation for End Use:	**12.95**

	Fossil Fuel Equivalency	Captured Energy
Site to Source Ratio:	**3.00**	**2.77**

Data Sources:

a *EIA Monthly Energy Review* (MER) Table 7.2a; b *EIA Electric Power Monthly* Table 1.1; c EIA MER Table A6; d Calculated unless otherwise noted; e EIA MER Table 7.3a; f EIA MER Table 7.1; Note that this methodology includes generation from all sectors, and excludes fuel consumption used for useful heat output at CHP facilities. This table is presented as an illustrative example only.

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

For more information, visit: energy.gov/eere

DOE/EE-1433 • October 2016

CrossMark

Environmentally Beneficial Electrification: Electricity as the End-Use Option

For decades, policymakers have viewed appliances that are fueled 'on site' by natural gas as environmentally preferable to electric appliances that rely on electricity generated at an off-site 'source,' such as at a coal or natural gas power plant. Several trends in energy generation and end-use technology, however, are changing the environmental value of using electric appliances to produce heat and hot water in buildings, requiring a more systems-based approach to energy efficiency tools and revisions to the methodology for calculating 'source' energy metrics.

Keith Dennis

Keith Dennis *is Senior Principal of End-Use Solutions and Standards at the National Rural Electric Cooperative Association (NRECA) in Arlington, VA. He has previously worked at the US DOE, White House Council on Environmental Quality, and in the private sector as a third-party verifier of energy projects. He holds an A.B. in Engineering and Environmental Sciences from Dartmouth College, a Bachelor of Engineering and Master of Engineering Management from the Thayer School of Engineering at Dartmouth College, and a Master of Studies in Environmental Law,* summa cum laude, *from Vermont Law School. He is a licensed professional engineer.*

This article and the opinions within are the responsibility of the author and do not represent the opinion of NRECA nor its members. The author thanks Chuck Foster for his significant contributions to the ideas contained in this article.

I. Introduction

Electrification changed the landscape of America, boosting the nation's economy and the quality of life. The National Academy of Engineers lists electrification as the most significant engineering achievement of all time.[1] Historical data from research by the World Bank demonstrates that access to electricity is one of the most powerful economic development multipliers, enabling people around the world to break free from subsistence and prosper.[2] Now, more than a century after the first poles and wires went up, the electric power

  http://dx.doi.org/10.1016/j.tej.2015.09.019

industry is undergoing a second revolution as the industry dramatically alters not only the fuel mix behind the electric grid but also the electric distribution system itself. Some federal, state, and local energy policies have not kept up with these changes, however. In fact, policies intended to promote efficiency and energy security could prove to be a hindrance to both those goals by failing to keep pace with grid modernization.

For decades, policymakers have viewed appliances that are fueled ''on-site'' – for example, natural gas-powered water heaters – as environmentally preferable to electric appliances that rely on electricity generated at an off-site ''source,'' such as at a coal or natural-gas-fired power plant. Historically, the amount of energy lost in generation and transmission has given electricity a negative reputation among environmentalists. Over the years, this view hardened into conventional wisdom. Trends in energy generation and end-use technology, however, are changing the environmental value of using electric appliances to produce heat and hot water in buildings. In fact, many experts now believe we are approaching a tipping point: we cannot meet the nation's CO_2 reduction goals if we continue to promote burning fossil fuel on-site in millions of homes across the country. The strategy of pursuing environmentally beneficial electrification has been suggested by the likes of Energy and Environmental Economics (E3)[3] and Lawrence Berkeley National Lab (LBNL)[4] in their assessments of how California will meet its aggressive climate goal, and by other experts in their solutions to address the issue of climate change on a more global scale.[5]

In order to better align energy policies with the optimal economic and environmental outcomes, industry and policymakers need to take a hard look at the discipline of energy efficiency and, more specifically, the technical analyses of the relative ''performance'' of end-use fuels underlying many efficiency standards.

Historically, the amount of energy lost in generation and transmission has given electricity a negative reputation among environmentalists.

This article examines the trends that are creating a landscape in which electric end-use is more and more *the* environmentally beneficial end-use option. It also identifies some technical practices in the energy efficiency field that must be modified in order to better achieve optimal economic and environmental policy objectives.

II. Revisiting Conventional Wisdom on Efficient Energy End Use

For decades, conventional wisdom has held that if consumers in the United States have access to natural gas, it should be their preferred choice for end-use space and water heating if their goal is to conserve energy resources.[6] This idea is based on the relatively inefficient conversion of fossil fuel (primarily coal and natural gas) to electricity in traditional electric generation facilities and delivery to load.

Take, for example, the use of electricity to heat water in a home using an electric resistance water heater with a standard efficiency of 90 percent. If natural gas is burned in a power plant that is 40 percent efficient at converting the fossil fuel energy to electricity, and some of that electricity is lost in transit on power lines, the overall efficiency of converting that fossil fuel to hot water is somewhere around 33 percent. By comparison, the efficiency of a standard 50-gallon natural gas water heater is 58 percent.[7] Since burning a unit of natural gas emits the same amount of carbon dioxide emissions no matter where it is burned, it follows that burning the fuel on-site rather than at a power plant

  http://dx.doi.org/10.1016/j.tej.2015.09.019

would result in lower emissions.[8]

Yet this simple example does not take into account key trends occurring in the electric system:

1) Not all electricity comes from vintage fossil fuel power plants and emissions rates associated with grid supplied electricity are declining;

2) End-use electric appliances have capabilities that are critical to integrating more renewable sources into the grid—they can help match energy load to variable renewable energy supply; and

3) Common heat pump technology can heat space and water with efficiencies of 200–300 percent.

All three of these new developments render the old conventional wisdom obsolete.

These trends need to be accounted for in energy efficiency tools widely used by consumers, contractors, and governmental organizations. A prime example of the lag in the energy efficiency industry is the ''source'' energy metric embedded in many prominent software tools and building codes. Tools that incorporate the source energy metric are designed to help consumers gauge and improve the relative energy efficiency of their buildings. However, this metric accounts for electricity from the grid as if it is less than one-third as efficient as on-site natural gas. As will be discussed later in this article, the source energy metric must be updated to align with policy objectives as our conventional wisdom on this issue changes.

Policy updates of this kind are not easy. Not only is it difficult to explain the technical workings of these tools, but the bureaucratic process of making changes can also be tedious. However, a failure to take on this challenge will have significant environmental consequences. The chairman of the American Gas Association still asserts that ''natural gas is three times as efficient as electricity, so we ought to be looking at policies that say that, that promote that, that encourage that.''[9] Yet LBNL simultaneously asserts that ''moving away from oil and natural gas and towards electricity is a key decarbonization strategy.''[10] Technical flaws in the current source metric produce tools that favor on-site fossil fuel by more than three to one over electricity. Those flaws should be corrected to level the playing field for electric end use so that technologies are evaluated on their real environmental and consumer merits, not outdated rules of thumb and outdated common wisdom. Use of this metric has led to policies such as California's Title 24, which creates a framework where on-site natural gas is given strong preference for water heating in homes, especially in replacement situations where the code's ''prescriptive path'' is unworkable for electric water heating.[11] If the source metric is not updated, Americans who depend on the government to provide objective and accurate efficiency tools to make environmentally sound decisions at their homes and businesses will be unwittingly making long-term investments in a more carbon-intensive energy future.

Not only is it difficult to explain the technical workings of these tools, but the bureaucratic process of making changes can also be tedious.

III. Trends Making Electricity *the* Environmental Choice

Technological trends, driven in part by policy trends, are creating a situation in which engineering-based analysis demonstrates that electric end use is the environmentally superior choice over on-site fossil fuel use for space and water heating, vehicles, and other equipment.[12] These trends include a long-term reduction in greenhouse gas intensity of the electric grid, increased efficiency of electric end-use appliances, and the increased need to manage

 1040-6190/, http://dx.doi.org/10.1016/j.tej.2015.09.019

end-use electric load to help integrate variable renewable resources. As these trends continue to develop, electricity will only increase in environmental performance while on-site fossil fuel use has reached the virtual limits of its efficiency.

A. Electric grid emissions trends and establishment of climate goals

Federal and state energy policies, combined with technology changes, have lowered the carbon intensity of the electric system. U.S. Energy Information Administration (EIA) data shows that in the decade between 2005 and 2014, carbon dioxide emissions per megawatt-hour declined by about 16 percent.[13] Non-carbon dioxide emitting sources currently make up more than 30 percent of the overall fuel mix powering the electric grid.[14] Regions that have historically been heavily dependent on coal are adding natural gas and renewables to their fuel mixes, a shift that will result in lowered GHG emissions. In January through May 2015, over 65 percent of electric generation capacity brought on line nationwide derived from non-emitting sources and the other 35 percent was natural gas.[15]

The EIA predicts that about 13 GW of coal-fired power plants will be retired by the end of 2015, and replaced with more than 13 GW of zero-emission wind, solar, and nuclear power plants by the end of this year.[16] EIA also projects that 60 gigawatts of coal-fired capacity will retire between 2012 and 2020, with 90 percent of the retirements happening by 2016.[17] The Environmental Protection Agency (EPA) estimates that coal-based generation will decline 20–22

percent in 2020 and 25–27 percent in 2030.[18]

Greenhouse gas emission reduction goals have been established on local, state, national and international levels. Some notable goals include the U.S. goal to reduce greenhouse gas emissions in the range of 17 percent below 2005 levels by 2020,[19] Minnesota's goal to reduce emissions 30 percent below 2005 emissions by 2025 and 80 percent below 2005 emissions by 2050,[20] and California's goal to reduce GHG emissions by approximately 30 percent by 2020 and 80 percent by 2050.[21] Also of significance, EPA's 2015 Clean Power Plan is projected to achieve a 32 percent cut from 2005 emissions nationwide by 2030.[22] Renewable energy policies are similarly aggressive, with 37 states having adopted binding targets or voluntary goals, and the U.S. recently setting a goal of 20 percent non-hydro renewables by 2030, which would be up from 7 percent in 2014.[23] These goals will have an increasing and lasting impact on the carbon dioxide emission profile of the grid.

In designing policies for end-use equipment, it is important to consider both the grid as it operates today and longer-term trends due to the life expectancy of end-use equipment. For example, DOE estimates the average lifespan of a residential furnace is 22 years[24] and residential water heater is 13 years.[25] **Figure 1** shows the emissions profile of GHG emission rates of electric generation in the U.S. and the trend per federal policy goals through 2030, a timeframe within which most space and heating equipment purchased today will remain in operation. *Investments in a new end-use appliance that burns natural gas or other fossil fuel on-site will lock emissions from that source into future decades*. In contrast, the environmental performance of electric equipment will improve over the life of the product as the emissions from a changing power generation fuel mix decrease. Over their life, electric products can support the integration of renewable energy generators, could be powered by on-site

1040-6190/© 2015 Elsevier Inc. All rights reserved., http://dx.doi.org/10.1016/j.tej.2015.09.019

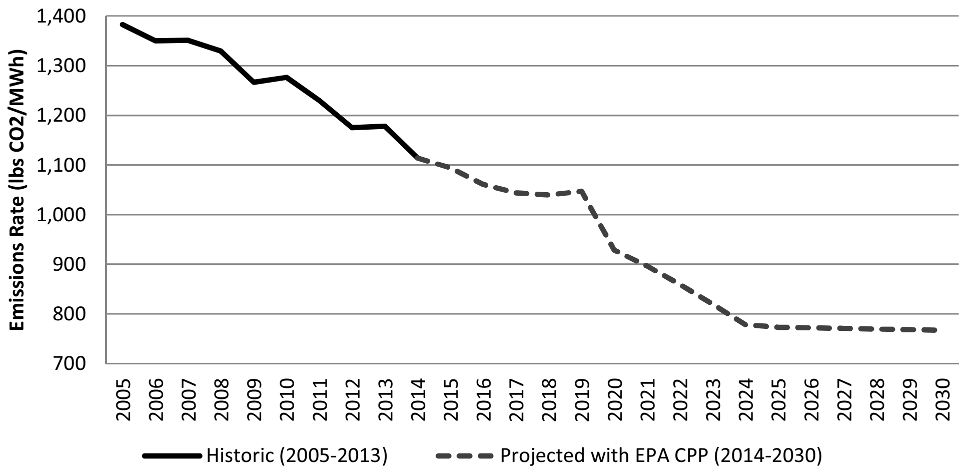


Figure 1: Carbon Intensity of US Electric Generation 2005–2030

renewable generation that has not yet been installed, and can participate in thermal storage programs. The same cannot be said of appliances that will require fossil fuel on-site through the duration of their useful life.

B. Increased availability and adoption of heat pump technology

As an example of key beneficial electrification potential, rapid advances and adoption of electric heat pump technology provide an important opportunity to reduce energy consumption in homes and businesses and to lower greenhouse gas emissions. Common air source heat pump space and water heating systems, which use a refrigeration cycle to extract heat from the air, are 200 to 300 percent efficient. In other words, for every unit of power used, the heat pump produces two or three times that amount by taking heat out of ambient air.[26] Using these systems cuts energy use and associated emissions of the system by a factor of two or three.[27] This heat pump technology is increasing in adoption. In 2014 air source heat pump space heating systems shipments were the highest on record with about 2.4 million shipments, up from 1.7 million in 2012.[28]

Heat pumps have been criticized for poor performance in cold climate conditions. However, cold climate technology is improving and some new systems can operate effectively at subzero temperatures without the need for any backup resistance or fossil fuel heating.[29] Additionally, dual fuel heat pump technology has advanced in popularity and provides a solution with multiple benefits. These dual fuel systems switch to a fossil fuel, such as propane or natural gas, when the temperature is too cold to operate the heat pump effectively or when the overall electric system has high demand. This switching capability can make the best use of the heat pump technology to lower energy use, and also avoids creating a system peak where electricity may have to be generated using less efficient power generators. While electric heat pumps have greater potential for efficiency gains as the technology advances, fossil fuel end-use products are more limited with no path towards efficiencies of 100 percent or above. Energy Star gas water heaters systems, for example, are only 67 percent efficient whereas their electric counterparts are 200 percent efficient on-site.[30]

With heat pump technology, the old rule of thumb is now obsolete. The onsite unit efficiency of over 200 percent negates any efficiency that would be achieved by combusting fossil fuel on-site rather than at a fossil-fuel-based electric generator providing remote electrification to the unit. For example, analysis from the Vermont Public Interest Research Group (VPIRG) shows

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Baseline Fuel	New Heating Fuel	
	Natural Gas	Electric Heat Pump
Oil	27%	34%
Propane	16%	26%

Figure 2: Carbon Emission Reductions from Fuel Switching to Gas or Cold Climate Heat Pump in Vermont
Note: Chris Neme, Supra note 32 at 7.

''a fuel switch to a cold climate ductless heat pump would also result in greater carbon dioxide emission reductions than a fuel switch to natural gas.''[31] The analysis, the results of which are shown in **Figure 2**, shows that using an electric heat pump reduces carbon dioxide emissions more than a high-efficiency natural gas system in Vermont. These findings incorporate the current marginal emission profile of electric power in Vermont; it does not account for future changes and probable emission reductions resulting from new federal policies and technology developments.[32] Similar studies by non-profit groups such as Environment Northeast show similar results. As emissions in the grid decline in the future, the case will only be more compelling all across the country.[33]

C. The need to manage electric end-use load to fit the supply availability of renewable energy

Traditionally, utilities have used a combination of baseload, intermediate, and peaking power plants to supply the necessary electrical power at the time it is needed. Traditional electric power can be scheduled. In order to integrate variable renewable electricity generation, utilities must find a way to integrate that power when it is available, which often does not coincide with periods of greatest end-use demand. Utilities need to manage load to meet available energy supply, creating a paradigm shift for the industry. Matching energy demand to energy supply can be assisted greatly by an often forgotten thermal storage device that is located in every home in the country – the water heater.[34] Energy storage is traditionally related with high-tech, expensive, and exciting battery technology. However, the simple technology of water heaters offers tremendous value through the ability to store energy taken from the grid at times when overall energy demand is low and energy is readily available and cheap—including energy generated by intermittent renewable resources, such as wind, solar, and hydro.[35]

Over 250 electric cooperatives in 34 states conduct demand response programs using electric resistance water heaters that are able to lower system peaks by over 500 MW.[36] While traditional end-use demand response simply lowers energy demand in times of short energy supply through load shedding, the thermal storage properties of water heaters enable both the demand reduction and the ability to increase load during times of excess energy supply. Such oversupply situations occur when the wind is blowing at night while people are sleeping, or when the sun is shining in the day while people are at work. This is the difference between load shedding and intelligent load control shown in **Figure 3**. Since a water heater can store energy until it is needed for a shower or dish or hand washing, consumers' hot water service will not be affected by delay in time between when the water is heated and subsequently used. The benefits of this ''electric thermal storage'' technology enabled by residential electric storage water heaters includes improved grid efficiency, reduced operating costs, and cost savings to consumers.[37]

While electric water heaters have long been a key asset for demand response programs, the technology is positioned for even greater value as the renewables market continues to mature. Using water heaters to store renewable energy can prevent it from being curtailed or spilled to maintain system reliability during periods of low load. This is one of the strategies put forth by the Regulatory Assistance Project (RAP) in its

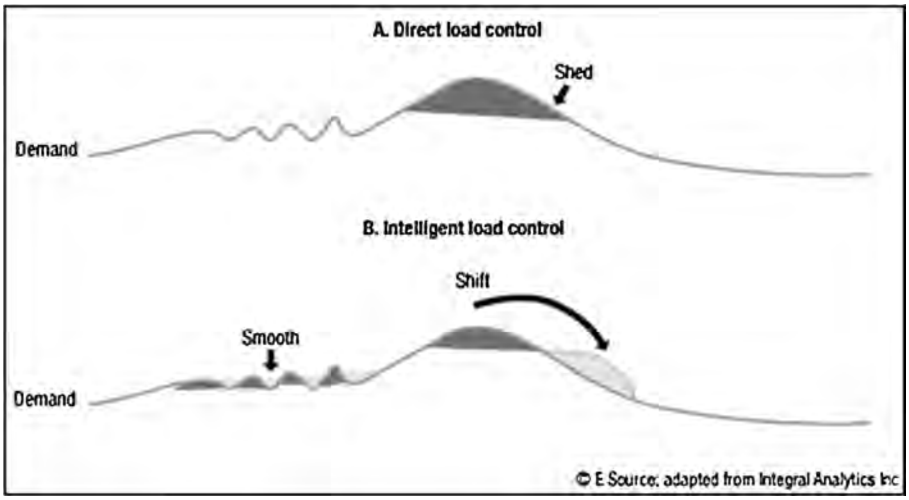


Figure 3: Using Water Heaters for Intelligent Load Control (David Podorson. 2014. Battery Killers: How Water Heaters Have Evolved into Grid-Scale Energy-Storage Devices)
Note: An E Source White Paper.

paper ''Teaching the Duck to Fly''[38] to help solve the challenges faced in California as solar ramps up and down daily on its grid, a phenomenon illustrated by the rather infamous ''Duck Curve.'' According to RAP's analysis, implementation of water heater controls on 100,000 electric water heaters would enable the utility to add about 450 MW at any single hour, and to shift a total of about 1,000 MWh of energy between periods of the day.[39] PJM has found that water heaters are the most cost-effective form of energy storage available and a resource with a combined energy storage capacity on par with today's pumped storage hydro fleet.[40]

IV. Policy Considerations

Effectively implementing energy policy can be challenging, especially when the policies rely on consumers to make certain choices. Policymakers often provide consumers with tools and incentives to help them make choices that align with policy goals. These tools range from direct rebate incentives on certain equipment, minimum appliance standards, energy ''scores'' that rate the performance of their home, or Energy Star labels. These tools depend on technical analysis that must be periodically updated as technology changes or the policies incentivize the wrong choices, leading to sub-optimal outcomes. A period of rapid technology change makes updating these tools all the more urgent.

A. Revisiting the 'source' energy metric

The use of ''source'' energy estimates in expressing the relative energy performance of buildings and homes has become a practice in some programs and policies aimed at reducing end-use energy consumption, improving energy security, and reducing pollution. The idea behind the ''source'' energy metric is to represent the total amount of raw fuel that is required to operate the building. It incorporates all transmission, delivery, and production losses associated with energy use in buildings, as illustrated in Figure 4.

Among the high-profile programs that use source estimates are the EPA-DOE Energy Star program, DOE's Home Energy Score and Commercial Building Asset Rating programs, and DOE's proposed rules on reducing fossil fuel use at federal buildings.[41] Table 1 presents a

Table 1: Use of Flawed Source Energy Metric in Building Codes and Standards.

US EPA Energy Star for Commercial Buildings (Portfolio Manager)
US DOE Appliance Standards Program
California Title 24 Compliance Procedure
US DOE Home Energy Score
2012 International Green Construction Code
2012 International Energy Conservation Code
ASHRAE Standards
US Green Building Council LEED® 2014
Legislated Benchmarking and Reporting Requirements such as New York City Local Law 84
Federal building energy reporting requirements
DOE's Definition of Zero Energy Buildings

 1040-6190/ http://dx.doi.org/10.1016/j.tej.2015.09.019

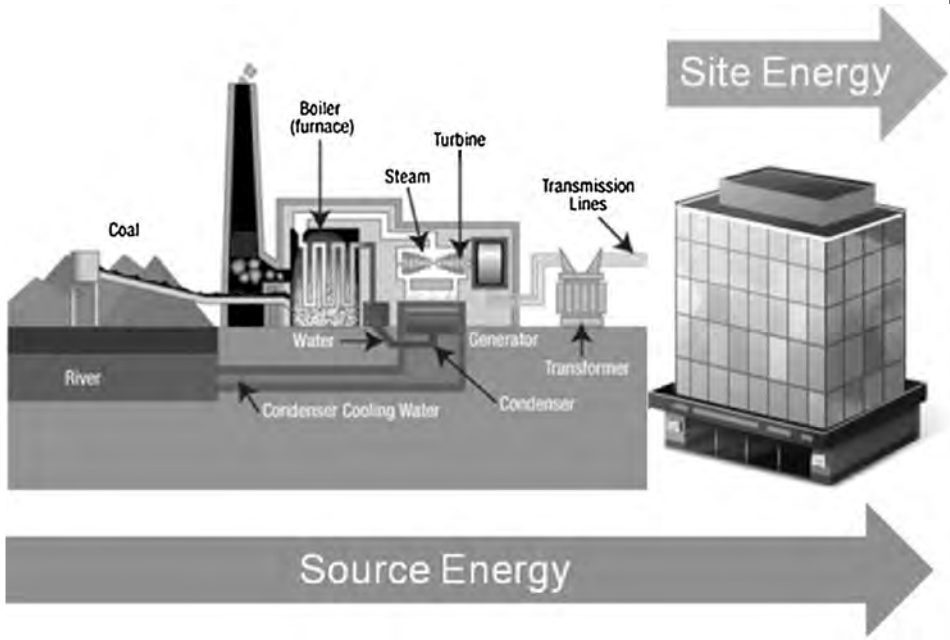


Figure 4: The Concept of 'Site' and 'Source' Energy Metrics
Note: www.energystar.gov

Table 2: EPA and DOE Source-Site Ratios[a]

Energy Type	U.S. Ratio
Electricity (Grid Purchase)	3.14
Electricity (on-Site Solar or Wind Installation)	1.00
Natural Gas	1.05
Fuel Oil	1.01
Propane & Liquid Propane	1.01

[a] For basic information, see: https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf

partial list of programs and policies inappropriately affected by the use of this metric.

With so much at stake, society needs and deserves estimates based on a technically sound and accurate methodology. The methodology used to calculate the source energy conversion lumps non-fossil electric generation in with fossil-fuel based generation, ignoring the fact that more than 30 percent of electric power is generated using non-emitting power sources. As a result, EPA, DOE and others treat electricity delivered to a home as if it is less than one-third as efficient as fossil fuel delivered to a home or business, which is technically unsound and ultimately leads to sub-optimal environmental end-use energy decisions. Correcting the flaws in the source energy metric is a priority on which environmental advocates and the electric industry can agree. Notably, in comments on a DOE appliance standard, the National Resource Defense Council (NRDC) commented ''the source conversion factors that EIA adopts have serious deficiencies for the purpose of setting a product standard; they're simply not the right numbers to inform good standards decisions.''[42]

The source-site ratios used by DOE, EPA and others are presented in **Table 2**. In order to calculate the ''source'' energy use of a building or home, EPA and DOE tools convert the energy delivered to the site into ''source'' energy using these ratios. For a home that receives electrical, natural gas, and propane service, for example, electricity use in British thermal units (Btu)[43] will be multiplied by 3.14, natural gas by 1.05, propane by 1.01. These values will be added together to determine overall ''source'' energy use for the building.

The ''source'' energy metrics used to gauge the relative performance of electric generation are based on EIA methodologies established before reducing carbon dioxide emissions was a policy objective and before renewable energy generation was a significant contribution to the electric grid. As NREL notes in their report of source energy metrics, the source-site ratios are ''based on the assumption that most of the electricity was produced from thermal electric power plants. The result tells nothing of the fuel types consumed or the emissions from the electricity production.''[44] This means that before even taking into account the efficiency of an electric appliance itself, the electricity from the grid used to power the device has already been determined by energy efficiency tools and policies to be less than one-third as efficient as on-site fossil fuel, no matter how it was generated.

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Table 3: Approximate Heat Rates for Electricity New Generation Calculations Used by EIA in Energy Flow.

		Approx Heat Rates
Fossil Fuels	Coal	10,498
	Petroleum	10,991
	Natural Gas	8,039
	Total Fossil Fuel	9,516
Non-Emitting Generation	Nuclear	10,479
	Noncombustable Renewable Energy	9,516

The EIA Electricity Flow chart (**Figure 5**), upon which the source energy metric is based, is designed to illustrate the relative contribution of energy by fuel type into the electrical system. In order to illustrate the relative portion of non-fossil fuel in the grid, an artificial conversion for electricity generated by non-fossil fuels is used. For renewable energy, for example, a fossil fuel heat rate above the average for natural gas plants is used, as shown in **Table 3**. However, those artificial conversions are not appropriate for the purposes of illustrating relative resource efficiency or environmental performance of the various non-fossil fuels. The conversions are not based on any practical science and are contradictory to the policy objectives that the source energy metric is designed to address.

Using these heat rates to calculate source-site energy ratios makes the ratio insensitive to changes in the grid mix. In fact, adding renewable energy generation to the electric grid would have the same effect on the ratio as adding the average fossil fuel generation using EIA's methodology. Adding nuclear generation would actually increase the source-site ratio for electricity, which would signal consumers to invest in more on-site fossil fuel combustion as the grid lowers emissions. This is the opposite of policy objectives, is not understood by even the most informed consumers,[45] and is likely an unintended flaw in the methodology of the ratio that is just coming to light as use of the metric increases.

A Power Systems Engineering study replicating the EIA's methodology under various hypothetical scenarios demonstrates the flaws in the way the source energy metric is

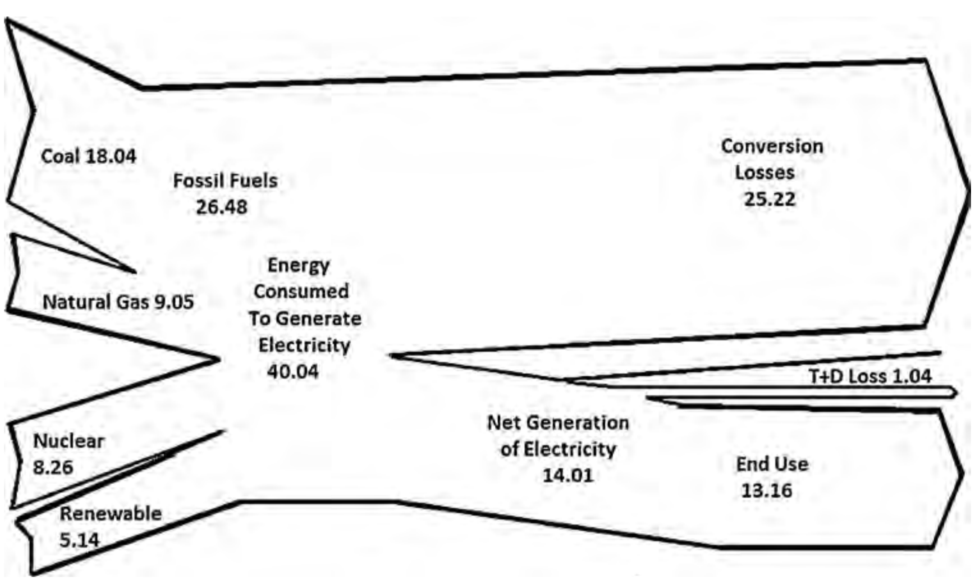


Figure 5: 2011 Electricity Flow (in Quadrillion Btu)
Note: EIA. Electricity Flow 2011. Modified for better display.

  http://dx.doi.org/10.1016/j.tej.2015.09.019

Table 4: Source-Site Ratios Using EPA/DOE Methodology[a]

	Source-Site Ratio
All Coal Switched to Gas	2.81
All Coal Switched to Renewable	2.99

[a] David Williams. 2014. *Source-Site Ratios.* Power Systems Engineering. http://www.nreca.coop/wp-content/uploads/2015/04/sourcesite_ratios_final_022015.pdf

Table 5: Sample Calculation of a 'Fossil Source' Energy Metric.

Sample Calculation of Current ''Source'' Energy Conversion Factor Using 2011 Data
Energy Consumed to Generated Electricity/(Gross Generation of Electricity – T&D Losses)=
40.04/(14.01 – 1.04) = **3.09**
Sample Calculation of Proposed ''Fossil Source'' Energy Conversion Factor Using 2011 Data
Fossil Fuels/(Gross Generation of Electricity – T&D Losses)=
26.48/(14.01 – 1.04) = **2.04**

currently calculated. The analysis shows that a switch of all coal-fired power in the country to renewable energy would result in a source-site ratio of 2.99 (Table 4). Under this scenario, despite using non-emitting sources to provide 71 percent of the grid's power, consumers would still be incentivized three to one to have gas end uses rather than electric.

Of critical concern, and driving the need to fix this metric, is that a myriad of energy policy tools are built on this flawed source energy metric. Output from these policy tools, for example, forms the basis for deciding whether homeowners and businesses should be provided or denied incentives based on the energy performance of their homes and buildings. These consumers are given inaccurate signals from the government and are improperly incentivized due to the flaws in this metric. This is in contrast to the intent of the tools, which is to help consumers to be better informed market participants.[46]

As the nation moves forward in an effort to curb carbon dioxide emissions, use of this metric in policy runs counter to those goals – especially in the context of EPA's Clean Power Plan (CPP). Under the CPP or other policies that cap emissions in the electric sector, there could be a significant and unintended incentive to switch consumers from a more environmentally beneficial electric system to one that burns fossil fuel on-site. The emissions from this one-site combustion would not be subject to the electric sector cap, so the switch from electricity to on-site gas would simply shift the emissions to sectors not covered under the cap. Use of source metrics in combination with other climate policies could thus lead to compliance of the electric-sector GHG rules while simultaneously significantly increasing GHG emissions of the country overall.

With new grid-connected combined cycle natural gas plants that are over 60 percent efficient, increasing new renewable electric generation on the grid, and large contributions of non-fossil hydro and nuclear power, it is inaccurate and inappropriate to characterize electricity as one-third as efficient as site-delivered fossil fuel. Since these metrics are subject to debate in many forums, from code hearings and appliance standards proceedings to legislation, there is an opportunity for utilities, environmental advocates, and policy makers to work to fix this issue. One proposal would be to simply replace the current ''source'' energy metric with a ''fossil source'' energy metric using data from the same EIA chart. A sample calculation with this simple change to the calculation used to derive the current metric is presented in Table 5.[47] This solution would better align the source energy metric with its intent of reducing primary fossil fuel use and its associated emissions. In addition to correcting the flawed treatment of renewable resources, NRDC's comments to DOE also include a proposal to use a ''marginal source'' value to better reflect the types of generation that power new appliances.[48]

B. Applying a systems approach to end-use efficiency

When considering an issue as broad as end-use energy efficiency it is important to take a

Table 6: Household Site End-Use Consumption by Fuel in the U.S., Averages, 2009[a]

	Electricity	Natural Gas	Propane/LPG	Fuel Oil
Water Heating (Million Btu)	9.1	21.0	18.9	18.6

[a] EIA. 2009. Residential Energy Consumption Survey. Table 4.6.

system-wide approach and viewpoint. This systems approach to efficiency has historically been lacking throughout the end-use efficiency community, but is critical to understanding the topic and implementing environmentally and economically optimal end-use strategies. In order for technology to work, it must be cost-effective. There is no ''one size fits all'' solution to end use and the simple existence of a technology with a higher efficiency rating does not mean that its use will be the optimal or most efficient fit for every application. Maximizing efficiency ratings of end-use appliances does not necessarily maximize the economic or environmental performance of our energy *systems* as a whole.

The optimal end-use energy policy should consider the adoption of heat pump technology as a tool where appropriate to meet goals, but not the whole solution itself. Indeed, there are many cases in which more traditional electric resistance technology is the most beneficial option. Electric resistance space and water heaters have a negative reputation in the efficiency community. However, it must to be recognized that in some cases this technology is the best economic and environmental choice when you take a systems approach. While space and water heating efficiency standards measure the ''energy efficiency factor'' of the specific end-use appliance, they do not capture the whole picture related to the application of the technology within the broader energy system, such as the home or business in which it is operating.

Take, for example, electric resistance water heating. Unlike gas water heaters, electric water heaters are extremely flexible in application because they do not need to be vented to the outside to exhaust combustion fumes. A gas water heater, on the other hand, necessitates the creation of a hole in a home's thermal envelope that would bring in external air at the outdoor temperature, decreasing the efficiency of the home. Electric resistance water heaters come in all shapes and sizes and can be tucked into closets near showers and sinks, reducing piping and distribution system loses. They also are superior products for use in electric thermal storage programs. Similarly, electric resistance space heaters can be used for ''zone'' heating and can be placed in basements and play rooms for use only during cold periods or periods when the area is being used. The flexible nature of electric resistance heating can negate the need to duct a central heating system or to operate a whole house HVAC system just to heat a specific space in a building. This enables overall energy savings in the building. Data collected by the EIA in its 2009 Residential Energy Consumption Survey shows that the *actual, field-observed* efficiency advantage for electric resistance water heaters over fossil-fuel-fired water heaters is dramatic (Table 6). The site energy use of an electric water heater in 2009, before the heat pumps would have registered in the survey, shows that an electric resistance water heater uses only 43 percent as much energy on-site as a gas water heater. This in part due to the energy savings associated with the flexibility of locating the electric resistance water heater near the point of water use without the need for long pipes or outdoor air venting, which is not accounted for in ''efficiency'' ratings of the products. However, the savings are confirmed in the surveys of actual installations.

In the final analysis, an environmentally beneficial choice is not always going to be a heat pump or the most ''efficient'' product as indicated by the product's label. Society needs metrics that will incentivize any technology where it makes cost-effective sense and more traditional electric technology where it is the best fit in order to

  http://dx.doi.org/10.1016/j.tej.2015.09.019

maximize the benefits of the decreasing grid emissions moving forward.

V. Conclusion

Incentivizing beneficial electrification with appliances and technologies available today would immediately reduce carbon dioxide emissions. Failure to do so will result in locking in technologies for many years that are net negative relative to greenhouse emissions reduction objectives. Given the current and future policies to lower grid emissions, the increasing popularity of heat pump technology, and the challenge of matching renewable energy supply with demand, end-use electrification will become a more and more attractive and useful option to improve the environmental performance of homes and businesses across the country. Due to the long life of end-use appliances, it is important that we get the policy incentives right now so that the investments made today align with the goals we hope to achieve tomorrow.

Climate goals cannot be met by widespread burning of fossil fuels in home appliances. Cost-effective electrification of end-use of electric appliances and vehicles will need to be a big part of any strategy designed to meet these types of policy objectives. It is now not a matter of whether electrification will be the obvious choice for end-use, it is a matter of when we reach the tipping point where electricity is *the* choice.■

Endnotes:

1. Constable, George; Somerville, Bob. 2003. A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives.

2. World Bank Independent Evaluation Group. 2008. *The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits.*

3. Amber Mahone et al. 2015. *California PATHWAYS: GHG Scenario Results*. Energy and Environmental Economics.

4. LBNL. 2013. California's Carbon Challenge Phase II Volume I: Non-Electricity Sectors and Overall Scenario

5. For example, Jeffrey Sachs (Five Questions for Jeffrey Sachs On Decarbonizing the Economy. July 15th, 2014) and Bill Nye (Chris Smith. 2015. *Watch Bill Nye Explain Climate Change with Emoji*. BGR News).

6. While it could be argued that the idea that on-site fossil fuel combustion is environmentally preferred to on-site use of electricity has never been accurate in geographic locations where the local grid is supplied by low- or non-carbon dioxide emitting sources such as nuclear or hydro, this idea is quickly becoming outdated throughout the entire nation.

7. 75 FR 20112.

8. This is a simplified example for illustrative purposes and does not take into account losses in the overall energy system of the house associated with gas systems as discussed in Section IV(b) herein.

9. John Siciliano. Climate Daily News. Gas Utilities To Remain Neutral In 2015 Fight to Impede EPA Climate Rule. Posted: Dec. 19, 2014.

10. LBNL. 2013. *Scenarios for Deep Carbon Emission Reductions from Electricity by 2025 in Western North America Using the Switch Electric Power Sector Planning Model*. California's Carbon Challenge Phase II Volume II.

11. California Energy Commission. Residential Compliance Manual for the 2013 Building Energy Efficiency Standards. June 2014.

12. This article focuses on end-use space and water heating appliances. There are similar opportunities for electrification of vehicles, diesel agricultural pumps, and small internal combustion engines like lawnmowers and commercial blowers.

13. EIA. 2015. Electric Power Monthly. Table 1.1.

14. EIA. 2015. What is U.S. electricity generation by energy source?

15. FERC Office of Energy Projects Energy Infrastructure Update, May 2015.

16. Tim Shear. EIA. 2015. Scheduled 2015 capacity additions mostly wind and natural gas; retirements mostly coal. Today in Energy.

17. EIA. 2014. AEO2014 projects more coal-fired power plant retirements by 2016 than have been scheduled.

18. U.S. EPA. 2014. Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants. pp. 3–26.

  http://dx.doi.org/10.1016/j.tej.2015.09.019

19. Executive Office of the President. 2013. *The President's Climate Action Plan.*

20. Anne Claflin. 2015. *Greenhouse Gas Emissions Reduction: Biennial Report to the Minnesota Legislature. Minnesota Pollution Control Agency: Minnesota Department of Commerce. p. 1.*

21. California Environmental Protection Agency: Air Resources Board. *Climate Change Programs*. 2015.

22. The White House. 2015. *Fact Sheet: President Obama to Announce Historic Carbon Pollution Standards for Power Plants*.

23. The White House. 2015. *U.S.-Brazil Joint Statement On Climate Change.*

24. 80 FR 13122.

25. 73 FR 20159.

26. Geothermal heat pump systems reach efficiencies of well over 400%, but have less mainstream market potential.

27. US DOE. www.energy.gov

28. AHRI market data.

29. Jack Newsham. 2014. As electricity costs rise, market for heat pumps takes off. The Boston Globe.

30. US EPA ENERGY STAR® Product Specification for Residential Water Heaters V. 3.0.

31. Vermont Public Interest Research Group (VIRG). 2014. *Prefiled Testimony of Chris Neme.* Docket No. 8180. p. 4.

32. Chris Neme, Energy Futures Group.2014. *Comparative Analysis of Fuel-Switching from Oil or Propane to Gas or Advanced Electric Heat Pumps in Vermont Homes*. Docket 8180 Neme Attachment B. p. 8.

33. Environment Northeast Inc. 2014. *An EnergyVision Pathway to a Modern, Sustainable Low Carbon Economic and Environmental Future.*

34. This same strategy can potentially be done in the future with electric vehicles.

35. Alice Clamp. NRECA. Water Heaters for Thermal Storage: Major Cost Benefits but Wider Grid Use Faces Challenges. March 2015.

36. *Id.*

37. In April 2015, with wide-ranging support from efficiency and environmental groups, manufacturers, and utilities, new legislation was signed into law to create a new classification of grid-enabled water heaters, or large electric resistance water heaters designed for use in electric thermal storage programs. Public Law No. 114-11.

38. Jim Lazar. 2014. Teaching the ''Duck'' to Fly. RAP.

39. *Id.*

40. Terry Boston. April 7, 2014. *Urgent Action on Energy Conservation Standards for Residential Water Heaters*. DOE Docket # EERE-2012-BT-STD-0022.

41. DOE Docket # EERE-2010-BT-STD-0031.

42. NRDC Comments to DOE Docket: EERE-2014–BT–STD–0031. July 2015 at 7.

43. The electricity will first be converted to Btu using a value of 3,412 Btu/kWh.

44. M. Deru, P. Torcellini. 2007 Source Energy and Emission Factors for Energy Use in Buildings. NREL. p. 4.

45. For example, BSD-151: Understanding Primary/Source and Site Energy, by Kohta Ueno and John Straube, states: ''Of course, over time, the fraction of renewable energy is expected to increase, making the grid 'greener.' With the retirement of old coal, the addition of wind, high efficiency gas, biomass, tidal, or even nuclear, the carbon intensity of producing electricity will drop, and the source-site ratio will drop.'' The idea put forth by these experts is not accurate as increasing use of these fuels will not significantly affect the source-site ratio. This highlights the level of confusion around the source metric and the technical details of how it is calculated.

46. Dennis, K., 2006. The compatibility of economic theory and proactive energy efficiency policy. Electr. J. 19(7), 61.

47. This would replace the use of the 40.04 quads listed as ''energy consumed to generate electricity'' with the 26.48 quads of fossil fuel used to generate electricity in source calculations. The result would indicate the grid fossil source portion of the electric grid is currently approximately 50 percent, or the ''fossil source-site'' ratio is approximately 2.

48. NRDC Comments to DOE 2015 Supra note 42.

  http://dx.doi.org/10.1016/j.tej.2015.09.019