Home Innovation RESEARCH LABS

National Green Building Standard™
2015 UPDATE

Substantiating Documents for Public Comments on 2015 NGBS Second Draft (October 9, 2015)

December 3, 2015

PC038 – Greg Johnson

PC038 & PC067 – Jack Karlin

PC067 – Greg Johnson

PC097 – Thomas Culp

H108(Held) – Carl Seville

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 15 or less inches per year and that the use of a water budget tool be used to establish turf limits for sites that average more than 15 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 water budget tool. Comments on point awards are within scope because the section requirements of draft 2 are proposed for modification; the two cannot be separated.

The positive environmental benefits that turfgrass can provide have been extensively documented for the committee previously in the process and again in a companion comment to Sec. 503.5 (5) addressing lot development. 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 .

As the pictures are reviewed keep in mind that the draft NGBS turf limitations for the development of sites are cumulative, on a percentage of vegetated area, meaning that for every 100 square feet of installed turf a minimum of 165 square feet of other vegetation must be provided to earn any points.

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 its needs.

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.

Proposed change:

403.6 Landscape plan. A plan for the lot is developed to limit water and energy use while preserving or enhancing the natural environment.	
	Points
(4) EPA WaterSense Water Budget Tool or equivalent is used when implementing the maximum percentage of turf areas.	~~2~~ <u>5</u>
(5) For landscaped vegetated areas <u>on sites receiving 15 or less inches of average annual precipitation</u>, 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

.

.

Turfgrass in the National Green Building Code

Unskewing the approach to turf in landscape

Turfgrass Water Conservation Alliance® public comment on the 2nd draft of the NAHB National Green Building Standard. Specifically focused on Chapters 4, 5 and 8.

Jack Karlin
Turfgrass Water Conservation Alliance®
Program Administrator
26th June 2015

Page left intentionally blank

Turfgrass Water Conservation Alliance®

Researching, Qualifying, and Promoting Water Conservation in the Turfgrass Industry

33725 Columbus St SE Albany OR 97322 tgwca.org phone: 541-971-4418 email: info@tgwca.org

The Turfgrass Water Conservation Alliance® (TWCA®) is a 501c3 nonprofit committed to water conservation and preserving the ecological services provided by turfgrass in the managed environment. Representing 93 members around the world in academia, government, and private sector, TWCA's coalition reaches beyond our industry members. TWCA® provides education based on scientific information which contradicts many of the opinions and much of the misinformation about turfgrass. Further, the TWCA® recognizes that water and plants are necessary to sustain life, and strive to protect the environment in which we live. Destruction of the environment by the removal of plant materials, including turfgrass is detrimental to the health and wellbeing of our society.

Turf serves as an important sink for Carbon; nationwide, single family detached homes with yards sequester enough carbon to take 44,000 cars off the road each year[1]. That is the same as every person in Coachella CA not driving for a year. Turf filters fine particulate and dust out of the air[2] improving air quality, reduces noise and glare[3] and cools the air to help mitigate the heat island effect caused by the ever expanding blanket of hard, impervious surfaces covering large swathes of the United States. Green spaces in general, and turf in particular, are linked to large scale improvements in the physical and mental health of the population[4] as well as attenuating the health gaps between the richest and poorest citizens of communities[5].

The removal of plant matter from any environment, managed or natural, should be considered long and with great care. Decisions made today to remove or limit turf may conserve water in the short term. It may take years or decades, even, for the long term negative consequences to be felt. However, when the consequences are felt it will be in the form of higher cooling costs, louder, dirtier cities, and shorter, less healthy, less happy lives.

Further, to treat turf as a monolith is to ignore the broad spectrum of genetic diversity represented by this classification of plants and discounts decades of research that have gone into reducing the water needs of turfgrasses[6,7]. TWCA's third party, peer review process has identified over 80 varieties that have demonstrated statistically significant water efficiencies over conventional varieties of the same species.

TWCA recognizes the importance of updating and revising the National Green Building Standard, hereinafter referred to as "this Standard", to continually improve the rule by which all our industries are measured. TWCA believes all improvements are rooted in good, sound science and are designed to maximize the efficiency and benefits of our managed environment. TWCA agrees with many of the landscape measure updates in this Standard, specifically, the addition of measures to protect and enhance pollinator habitat (§503.5.2), incentivizing the use of brownsville sites, and utilizing the Irrigation Association's Landscape Irrigation Best Management Practices as a design guide, however, in reviewing the proposed 2nd Draft of this Standard we have found the following areas requiring reconsideration:

The disconnect between stated goals in§403.5 and prescriptive turf limits in §403.6.5-
Infiltration rates on dense sodded slopes are more than three times the rates on bare soil [8]. This makes turf an excellent green stormwater management practice as it both promotes infiltration and

Turfgrass Water Conservation Alliance®

Researching, Qualifying, and Promoting Water Conservation in the Turfgrass Industry

33725 Columbus St SE Albany OR 97322 tgwca.org phone: 541-971-4418 email: info@tgwca.org

evapotranspiration to reduce discharge and runoff. Disproportionately encouraging the elimination of turf from landscapes, as proposed in §403.6.5, necessitates the use of more, and more expensive solutions to receive credits for §403.5.2 and 403.5.3. This will have the unfortunate side effect of driving the cost of environmentally conscious housing out of the affordable range for many Americans.

§403.6.4 - Only rewarding water budgeting when implementing the maximum percentage of turfgrass areas –

The key to long term outdoor water savings in residential development is education and engagement. Awarding points to landscapes that water budget for the maximum percentage of turf and not to landscapes using less than the maximum but more than zero (0) percent turf unfairly punishes developments that are making different, but responsible, choices about using turf in their landscapes.

TWCA proposes awarding points for using a Water Budgeting Tool to any landscape that utilizes turf to incentivize engagement with and understanding of the landscaped areas surrounding houses. We believe this engagement and understanding will significantly contribute to water savings over the life of the development.

§403.6.5 – Disproportionately targeting turf for removal from landscapes-

There are a number of issues with this portion of this Standard… Incentivizing the use of literally any other landscape plant for vegetated areas does not ensure responsible landscaping or water conservation and could actually result in an increase of the water requirements for a landscape depending on the landscape plants used. This system also ignores the broad range of demonstrated water efficiencies available in turfgrasses today.

An alternative point system endorsed by the TWCA uses the following scheme:

For vegetated areas, the maximum percentage of all turf areas is:

GREEN BUILDING PRACTICES	POINTS
403.6 Landscape plan. A landscape plan is developed to limit water and energy use in common areas while preserving or enhancing the natural environment utilizing one or more of the following:	
(4) EPA WaterSense Water Budget Tool or equivalent is used when implementing ~~the maximum~~ any percentage of turf areas.	2
(5) For landscaped vegetated areas, the maximum percentage of all turf areas is:	
(a) 0 percent	5
(b) Greater than 0 percent to less than 20 percent	4
(c) Using third party qualified water efficient grasses	3
(d) 20 percent to less than 40 percent	3
(e) Using third party qualified water efficient grasses	3
(f) 40 percent to 60 percent	2
(g) Using third party qualified water efficient grasses	3

Turfgrass Water Conservation Alliance®

Researching, Qualifying, and Promoting Water Conservation in the Turfgrass Industry

33725 Columbus St SE   Albany OR 97322   tgwca.org   phone: 541-971-4418   email: info@tgwca.org

Using such a point award scheme maintains the incentive to use turf in landscapes responsibly while incentivizing the selection of improved water efficient varieties and encouraging a real engagement with the plant selection process. This point system also eliminates the unfounded demonization of turf.

The disconnect between stated goals in§503.4 and prescriptive turf limits in §503.5.5-
As in prior comment, turf is an effective tool for mitigating or eliminating storm water runoff. Increased soil infiltration rates, evapotranspirative capacity, and slower overland flow decrease sediment loads and runoff. Disproportionately rewarding the elimination of turf from landscapes as proposed in §503.5.5, necessitates the use of more, and more expensive solutions to receive credits for §503.4.2 and §503.4.3.

§503.5.4 - Only rewarding water budgeting when implementing the maximum percentage of turfgrass areas –
As discussed in previous points, Engaging the green community during the plant selection process is an essential part of changing habits and shifting the landscaping approach away from wall to wall turf and toward a responsible, measured use of turf.

TWCA proposes awarding points for using a Water Budgeting Tool to any landscape that utilizes turf. Not only does this incentivize a broader range of choice for landscapes, but it encourages designers to take a more even handed approach to utilizing turf in a responsible, functional way. TWCA believes incentivizing greater understanding and engagement with landscapes in our managed environment is a key component of making water conservation the cultural norm.

§503.5.5 – Disproportionately targeting turf for removal from landscapes-
Similar to TWCA's prior discussion regarding §403.6.5, we believe the proposed points system not only takes an unbalanced approach to turf but also discounts the remarkable genetic diversity found within turfgrasses.

An alternative point system endorsed by the TWCA use the following scheme:

For vegetated areas, the maximum percentage of all turf areas is:

GREEN BUILDING PRACTICES	POINTS
(4) EPA WaterSense Water Budget Tool or equivalent is used when implementing ~~the maximum~~ any percentage of turf areas.	2
(5) For landscaped vegetated areas, the maximum percentage of all turf areas is:	
(a) 0 percent	5
(b) Greater than 0 percent to less than 20 percent	4
(c) Using third party qualified water efficient grasses	3
(d) 20 percent to less than 40 percent	3
(e) Using third party qualified water efficient grasses	3

Turfgrass Water Conservation Alliance®
Researching, Qualifying, and Promoting Water Conservation in the Turfgrass Industry

33725 Columbus St SE Albany OR 97322 tgwca.org phone: 541-971-4418 email: info@tgwca.org

(f) 40 percent to 60 percent	2
<u>(g) Using third party qualified water efficient grasses</u>	<u>3</u>

As discussed when addressing §403.6.5, our proposed point system fosters engagement, responsible use of functional turf and informed plant selections when designing and installing landscapes and developments.

§505.2 – Heat Island Mitigation-

Turfgrass' ability to attenuate the urban heat island (UHI) effect is well established[9]. To have an entire subsection of the code designated specifically to addressing this issue without awarding any points for implementing such an affordable, well known and well documented solution seems illogical.

We believe encouraging innovation also means encouraging innovative uses of existing methods and solutions. To this end, TWCA advocates for awarding points (based on percentage of hardscape replaced up to 50%) for using turfgrass pavers as a way to mitigate the UHI caused by new development.

§801.6 – Irrigation systems –

TWCA is dismayed to see the absence of points for using an MP-rotor system for overhead irrigation application. While we applaud incentivizing the use of subsurface drip irrigation we also recognize that it is not appropriate for all landscape application. Meanwhile, the conservation benefits of mp-rotor technology are well documented and readily available.

Maintaining this Standard to remain relevant to the rapidly evolving challenges and technologies of the modern world is a daunting task. We at the TWCA agree that proper design, planning and preparation in a landscape are essential to the water efficiency of any development or landscape installation. We know, as much as planning and preparation, selecting plant materials with proven water efficient properties is also crucial to achieving water efficiency. TWCA also knows that drought tolerant, water efficient turfgrasses exist and have proven that TWCA qualified grasses can use up to fifty (50) percent less water than conventional varieties, while continuing to provide the functional, recreational, and aesthetic benefits that we as a society have come to rely on.

It has become popular to portray turf as a wasteful and useless relic of a bygone era; or to say, "Green turf isn't green". The reality couldn't be further from the truth. Turf continues to cool our homes, lengthen and enrich our lives, and provide space for our children and pets to play in safety and comfort. Turf is not the problem. The reality is that over eighty seven (87) percent of Americans use water out doors at or below responsible levels (as determined by the ongoing project #4309 "Residential End Uses of Water Update" being conducted by the Water Research Foundation).

Turfgrass Water Conservation Alliance®

Researching, Qualifying, and Promoting Water Conservation in the Turfgrass Industry

33725 Columbus St SE Albany OR 97322 tgwca.org phone: 541-971-4418 email: info@tgwca.org

TWCA offers up our services to the National Association of Homebuilders (NAHB) to help craft regulations that encourage the healthy, responsible application of turf in a managed environment and to recommend appropriate, qualified grasses that demonstrate statistically significant water efficiencies over conventional varieties of the same species.

Finally, TWCA asks that NAHB not promulgate the notion that turfgrass is contrary to green development by codifying changes to this Standard reinforcing the perception of turf as a bad thing. Finally, we encourage the NAHB to hold fast to the foundations of science when updating this Standard and not be swayed by public opinion or the damaging popular trend of removing turf from the managed environment.

Regards,

Jack Karlin,
Program Administrator
jack.karlin@tgwca.org
(541) 971-4418

References:

1) R. Lal and B. Augustin (eds.) Carbon Sequestration in Urban Ecosystems, DOI 10.1007/978-94-007-2366-5_14 © Springer Science+Business Media B.V. 2012

2) Water Quality and Quantity Issues for Turfgrasses in Urban Landscapes, Council for Agricultural Science and Technology (CAST), Special Publication 27, 2006,Ch2.

3) Beard, J. B. and R. L. Green. 1994. The role of turfgrasses in environmental protection and their benefits to humans. J Environ Qual 23(9):452–460.

4) Jolanda Maas, Robert A Verheij, Sjerp de Vries, Peter Spreeuwenberg, Francois G Schellevis, Peter P Groenewegen. "Morbidity is related to a green living environment." J Epidemial Community Health. Published Online 15 October 2009. DOI:10.1136/jech.2008.079038

5) Richard Mitchell, Frank Popham "Effect of exposure to natural environment on health inequalities: an observational population study" *Lancet* 2008; 372: 1655-60

6) Karcher, D.E., Richardson, M.D., Hignight, K., and Rush, D. "Drought Tolerance of Tall Fescue Populations Selected for High Root/Shoot Ratios and Summer Survival" *Crop Science* 2008; v48 n2: 771-777

33725 Columbus St SE Albany OR 97322 tgwca.org phone: 541-971-4418 email: info@tgwca.org

7) Karcher, D., M. Richardson and J. Landreth. 2008. Drought tolerance of tall fescue and bluegrass cultivars. Arkansas Turfgrass Report 2007, Ark. Ag. Exp. Stn. Res. Ser. 557:17-20.

8) Roberts, E.C., and Roberts, B.C. Lawn and sports turf benefits. The Lawn Institute. Pleasant Hill, Tennessee. 31 pp.

9) Balling, Jr, R.C. and Lolk, N.K. "A developing cool island in the desert? The case of Palm Springs, CA". Journal of the Arizona-Nevada Academy of Science 23(2):93-96.

Continued incentives for the limitation of turfgrass for all sites regardless of climate, topography, and functional needs is at best informed by popular misconceptions. When building in more sensible and sustainable locations than the desert (less than 15 inches of annual precipitation), turfgrass provides many ecosystem services and should not be arbitrarily limited.

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.

For the 1st draft TG 2 also proposed eliminating the 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. It recognized that for most sites incentives to limit turf were counterproductive for environmental reasons.

In response to a strong lobby from the Southern Nevada Homebuilders Association and the Southern Nevada Water Authority, as a measure of compromise, TG 2 recommended restoring turf limits as an **alternate** to the use of a water budget tool for draft 2 of the NGBS. 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. Draft 2 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 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 draft 2 of the 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]

[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

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.

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 niversity 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

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

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

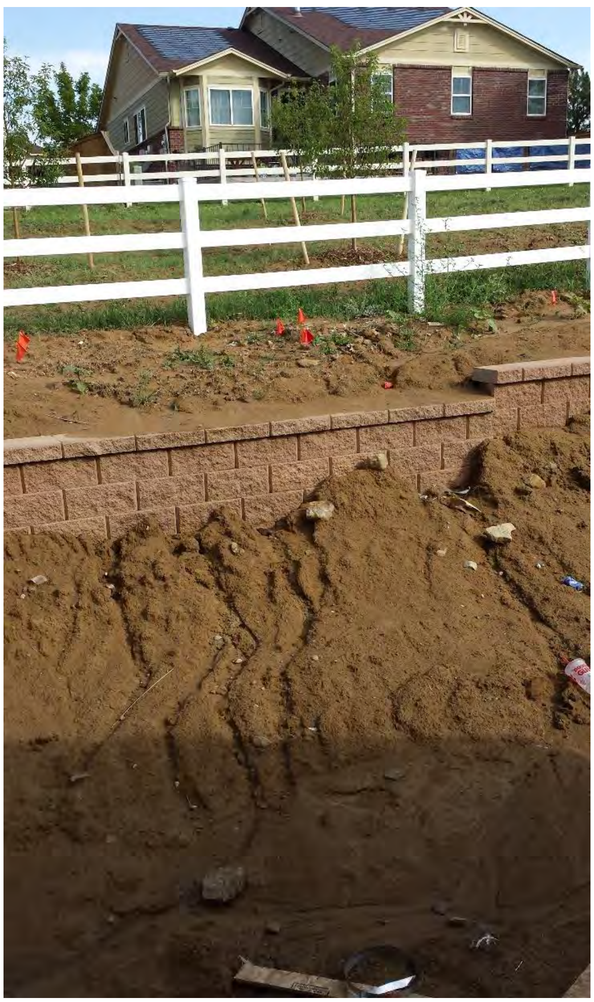
Sahu, R. (2008). *Technical Assessment of the Carbon Sequestration Potential of Managed Turfgrass in the United States.* Outdoor Power Equipment Institute (OPEI). Alexandria, VA

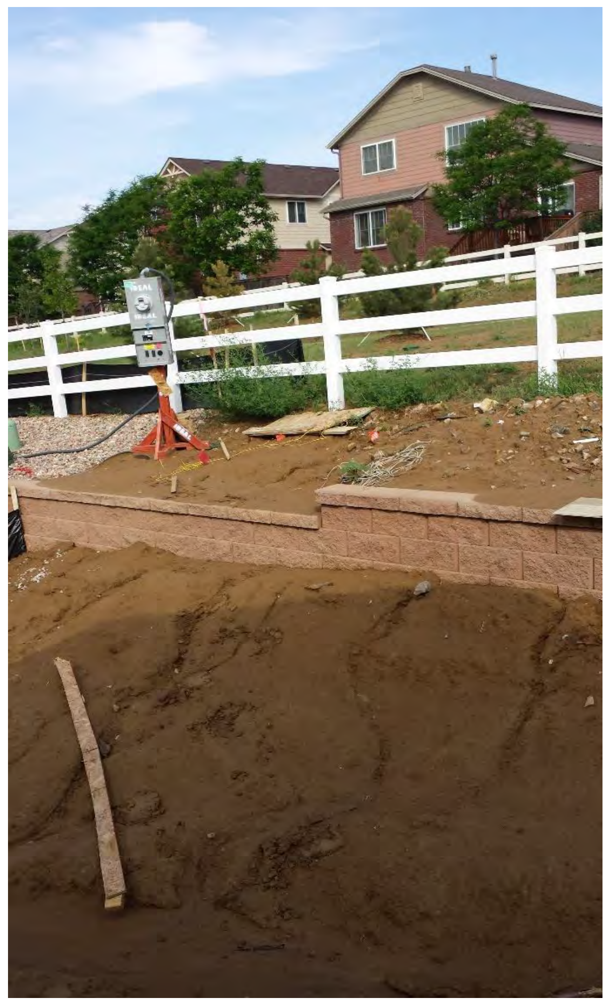
Selhorst, A.L. (2007). *Carbon Sequestration and Emissions due to Golf Course Turfgrass Development and Maintenance in Central Ohio* (Thesis, The Ohio State Univ. Columbus)

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.

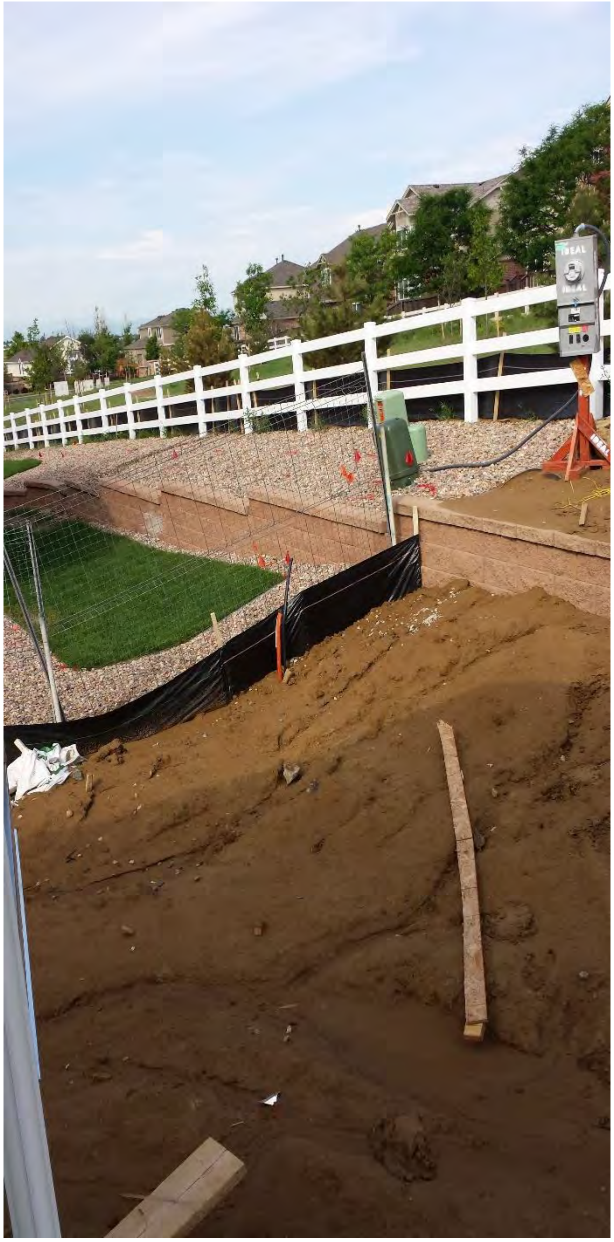
Climate change models indicate that that Northern and Eastern states will see sharply increased precipitation with storm events increasing both in frequency and intensity. The Midwest is projected to stay relatively wet. Sustainable landscapes in these regions will need to be able to mitigate the impacts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

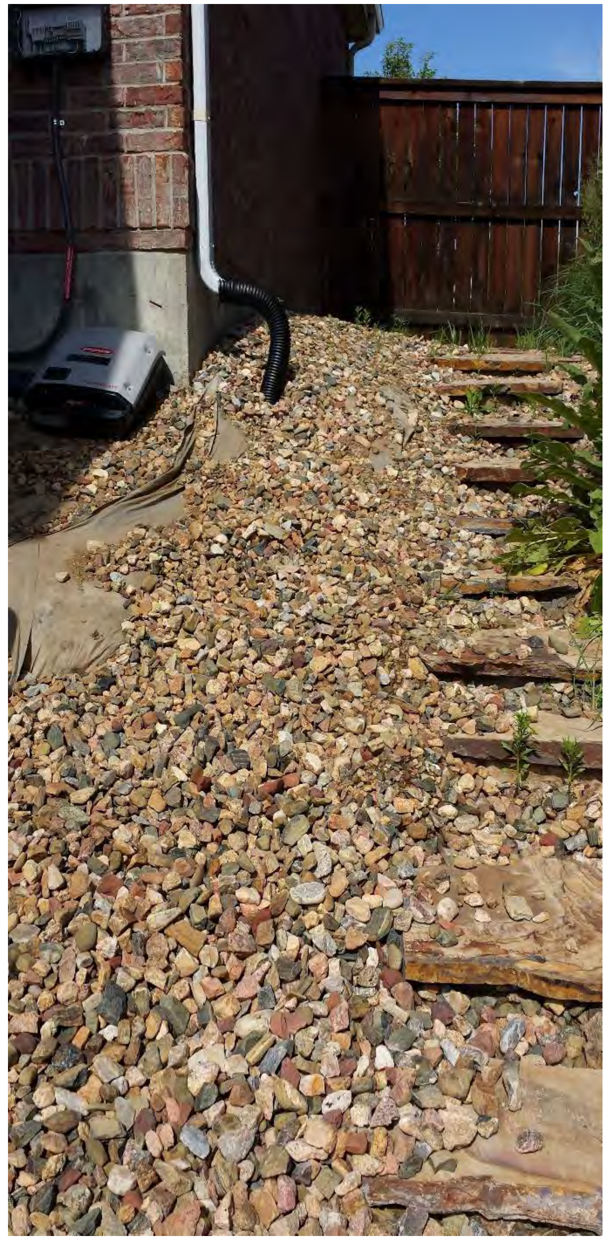




The area between the white fences appears to be common area for a community green belt; perhaps a utility easement. It also appears to have been seeded in addition to having trees planted there.

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





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 draft 2 of 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.

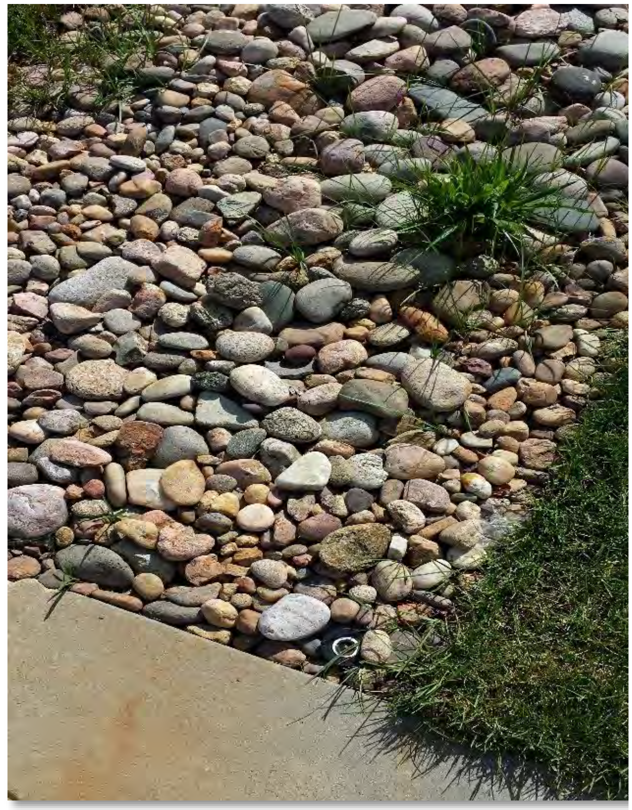
This is an area of rock mulch invaded by both weeds and spreading lawn grass; this was common at established sites in this jurisdiction. Deposits from water runoff and atmospheric soil deposition from wind erosion fill the interstitial spaces of the rock, creating a medium for unwanted plant growth.

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, we propose that points for turf limitations be awarded only where annual precipitation averages 15 or less inches per year and that the use of a WBT be used to establish turf limits for sites that average more than 15 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) EPA WaterSense Water Budget Tool or equivalent is used when implementing the maximum percentage of turf areas.	~~2~~ <u>5</u>
(5) For landscaped vegetated areas <u>on sites receiving 15 or less inches of average annual precipitation</u>, 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

HortScience 46(5):808–814. 2011.

Modeling Carbon Sequestration in Home Lawns

Gina Zirkle[1]

Carbon Management and Sequestration Center, The Ohio State University, 210 Kottman Hall, 2021 Coffey Road, Columbus OH 43210

Rattan Lal

Carbon Management and Sequestration Center, The Ohio State University, Columbus, OH 43210

Bruce Augustin

The Scotts Miracle-Gro Company, Marysville OH 43041

Additional index words. soil C sequestration, global warming, lawn management, turfgrass, hidden C costs

***Abstract*. Soil organic carbon (SOC) sequestration and the impact of carbon (C) cycling in urban soils are themes of increasing interest. A model was developed to investigate the potential of C sequestration in home lawns. The model contrasted gross C sequestered versus the hidden C costs (HCC) associated with typical lawn maintenance practices. The potential of SOC sequestration for U.S. home lawns was determined from SOC sequestration rates of turfgrass and grasslands. Net SOC sequestration in lawn soils was estimated using a simple mass balance model derived from typical homeowner lawn maintenance practices. The average SOC sequestration rate for U.S. lawns was 46.0 to 127.1 g C/m²/year. Additional C sequestration can result from biomass gains attributable to fertilizer and irrigation management. Hidden C costs are the amount of energy expended by typical lawn management practices in grams of carbon equivalents (CE)/m²/year and include practices including mowing, irrigating, fertilizing, and using pesticides. The net SOC sequestration rate was assessed by subtracting the HCC from gross SOC sequestration rate. Lawn maintenance practices ranged from low to high management. Low management with minimal input (MI) included mowing only, a net SOC sequestration rate of 25.4 to 114.2 g C/m²/year. The rate of SOC sequestration for do-it-yourself (DIY) management by homeowners was 80.6 to 183.0 g C/m²/year. High management, based on university and industry-standard best management recommendation practices (BMPs), had a net SOC sequestration rate of 51.7 to 204.3 g C/m²/year. Lawns can be a net sink for atmospheric CO_2 under all three evaluated levels of management practices with a national technical potential ranging from 25.4 to 204.3 g C/m²/year.**

Research on abrupt climate change and the C cycle have become major thematic foci since the 1990s. SOC sequestration is one of the strategies proposed to stabilize atmospheric carbon dioxide (CO_2) (Lal, 2004a; Smith et al., 2007b). The interest in urban soils is derived from the fact that 75% of the U.S. population lives in urban areas where individuals can potentially affect C sequestration in their home landscape (United States Census Bureau, 2010). Lawn grasses are the predominant plants in the urban landscape that are managed by the homeowner (Beard, 1973). A simple C footprint benchmark of home lawns can be developed from three components: the capacity of urban soils to store C, the capability of grass plants to fix and sequester C, and the C footprint of lawn maintenance practices.

Several studies have evaluated C sequestration potential of agricultural and urban soils as one of several options to stabilize atmospheric CO_2 abundance (Blanco-Canqui and Lal, 2004; Bruce et al., 1999; Lal, 2004a, 2008; Leified, 2006; Pataki et al., 2006; Pickett et al., 2008; Pouyat et al., 2002, 2006; Smith et al., 1993). SOC is comprised of the historic accumulation of humus in the soil. Long-term storage of SOC occurs when humus reaches a point of stability and gains exceed losses (Whitehead and Tinsley, 2006). Variations in the SOC pool occur in different ecosystems because of differences in the rate of soil organic matter decay through microbial decomposition, temperature fluctuations, and precipitation amounts and frequencies (Pouyat et al., 2002).

The SOC pool is important for soil structure maintenance and other ecosystem services (Lal, 2004a, 2009). It improves numerous soil properties and processes including soil tilth, aggregation, plant-available water and nutrient capacities, reduction in susceptibility to erosion, and filtering of pollutants (Blanco-Canqui and Lal, 2004). Soil organic carbon is depleted through soil cultivation and land use conversion (Lal, 2004a; Post and Kwon, 2000) and can be enhanced through those soil conservation and restoration practices, which add biomass C and influence the rate of its decomposition (Lal, 2004a). Common conservation and restoration practices include no-till (NT) agriculture, perennial plant cover, fertilization, irrigation, and organic amendments (Lal, 2004a; Post and Kwon, 2000; Post et al., 2004). Moreover, lawn grasses are a perennial plant cover and have the potential for long-term SOC sequestration (Pataki et al., 2006; Pouyat et al., 2006).

Urban lawns are potential C sinks and their prevalence in urban landscapes suggests that they can store a significant amount of C (Pataki et al., 2006; Pouyat et al., 2002, 2006). Urbanized land covers ≈40.6 million hectares (Mha) in the United States (United Nations, 2004a). The National Census Bureau estimates that 75% to 80% of North American population lives in urban areas (United Nations 2004b). Urban land use is 3.5% to 4.9% of the U.S. land area (National Association of Realtors, 2001; Nowak et al., 2001). As urbanization increases, the percentage of land converted into turfgrass is also increasing (Bandaranayake et al., 2003; Lorenz and Lal, 2009a; Milesi et al., 2005; Qian and Follett, 2002).

Approximately 41% of the U.S. urban area is under residential land use (Nowak et al., 1996, 2001). Turfgrasses cover 16 to 20 Mha in the United States, which includes residential, commercial, and institutional lawns; parks; golf courses; and athletic fields (Grounds Maintenance, 1996; Milesi et al., 2005). There are 80 million U.S. single-family detached homes with 6.4 Mha under lawns (Augustin, 2007; National Association of Realtors, 2001; National Gardening Association, 2004). The size of home lawns varies regionally (north to south and east to west) as well as locally (rural versus suburban). Home lot size differs from that of home lawn size (National Association of Realtors, 2001). Home lot size includes the house and land owned by the homeowners, where home lawn size includes the area covered by turfgrass. In this study, the average size of household lawns in the United States is 0.08 ha (Augustin, 2007; National Association of Realtors, 2001; Vinlove and Torla, 1995).

The estimated SOC pool in the U.S. urban soils is 77.0 ± 2.0 Mg·ha^{-1} (Pouyat et al., 2006). A compilation of research showing conversion of crop land into perennial grasses sequestered an average of 0.3 Mg C/ha/year (Post and Kwon, 2000), and the rate can be as high as 1.1 Mg C/ha/year with fertilizer and irrigation management (Contant et al., 2001; Gebhart et al., 1994; Qian and Follett, 2002). Qian and Follett (2002) modeled SOC sequestration with historic soil testing data from golf courses and reported that soils under golf course sequester SOC at a rate of 1.0 Mg C/ha/year. Land under the Conservation Reserve Program also sequesters SOC at a similar rate (Qian and Follett, 2002). Ohio farmland converted to golf courses sequesters SOC at an initial rate of 2.5 to 3.6 Mg C/ha/year as a result

Received for publication 11 Nov. 2010. Accepted for publication 4 Mar. 2011.

[1]To whom reprint requests should be addressed; e-mail gina.zirkle@gmail.com.

of permanent groundcover and increased management inputs of fertilizer and irrigation (Selhorst, 2007).

Although home lawns have potential to sequester C, information on SOC dynamics in urban lawns is limited (Pouyat et al., 2006), yet the technical potential for urban lawns to sequester SOC is high as a result of perennial turfgrass cover and improved management. Lawns provide a perennial groundcover and the soils beneath established grasses are relatively undisturbed. Therefore, the lawn ecosystem has been compared with perennial grasslands and NT agricultural systems (Falk, 1976, 1980; Follett et al., 2009; Qian and Follett, 2002). Lawns have the capacity to produce biomass at a rate similar to those of managed crops such as corn (*Zea mays*), wheat (*Triticum aestuvum*), and prairie grasses (Falk, 1976, 1980; Qian and Follett, 2002). A complete turfgrass C cycle accounting for turfgrass maintenance practices of mowing, irrigating, fertilizing, and applying pesticides must be completed to determine net C sequestration rates (Bandaranayake et al., 2003; Pickett et al., 2008; Pouyat et al., 2006).

In general, fertilizer and irrigation practices can increase the rate of SOC sequestration (Campbell and Zenter, 1993; Glendining and Powlson, 1991; Gregorich et al., 1996; Lal, 2003; Paustian et al., 1997). Thus, use of fertilizers and irrigation as lawn maintenance practices could increase plant biomass and enhance the SOC pool. An increase in input of plant biomass also increases the rate of humification (Duiker and Lal, 2000; Puget et al., 2005).

A wide range of techniques exist for estimating the technical potential of SOC sequestration (Bruce et al., 1999; Rickman et al., 2001; Smith et al., 1993, 2008). Changes in the SOC pool can be measured directly over time (Bruce et al., 1999). Direct measurements are an efficient technique for a small scale (plot scale) but can be complicated by spatial and temporal differences in soils for large regional scales (Bruce et al., 1999; Qian et al., 2003; Smith et al., 1993). Mathematical modeling of SOC is well developed and is widely used to study SOC dynamics under a range of environmental conditions at regional scales (Bruce et al., 1999; Lal, 2004a; Post et al., 2004; Qian et al., 2003; Smith et al., 1993, 2008). Modeling has been used extensively to estimate changes in the SOC pool resulting from management practices (Blanco-Canqui and Lal, 2004; Bruce et al., 1999; Lal, 2004a, 2004b).

Although atmospheric enrichment of CO_2 is cited as a principal driver of climate change, N_2O and CH_4 are other green house gases (GHGs) of concern. The global warming potential (GWP) of N_2O and CH_4 can be expressed in terms of CO_2-C equivalents by knowing their radiative forcing and residence time. Radiative forcing is the difference in the amount of radiation energy entering and exiting the earth's atmosphere. On a 100-year time scale, one unit of N_2O has the same GWP as 310 units of CO_2 and one unit of CH_4 has the same GWP as 21 units of CO_2 (Intergovernmental Panel on Climate Change, 2001).

Soil emissions of CO_2, methane (CH_4), and nitrous oxide (N_2O) are highly impacted by soil properties and climate (Kaye et al., 2005; Khan et al., 2007; Maggiotto et al., 2000; Smith et al., 2007a). Carbon dioxide represents over 98% of the soil GHG flux and is accounted for by NPP estimates in the basic model (Phillips et al., 2009). Emissions of CH_4 are formed from anaerobic fermentation of organic matter under conditions typical of flooded rice paddies but not of typical home lawn ecosystem conditions. Normal well-drained soils tend to act as a sink for CH_4 (Janssen et al., 2009; Phillips et al., 2009). Soil emissions of N_2O are less than 1% of the GHG soil flux and result from soil microbial activity (Kaye et al., 2005; Phillips et al., 2009). Soil N_2O emissions are increased under saturated soil conditions (Eichner, 1990; Smith et al., 2007a). Average soil N_2O flux is comprised of 65% to 77% background emissions and 23% to 35% fertilizer-induced emissions (Snyder et al., 2007). Significant potential exists for the mitigation of these GHG fluxes from soils by management practices according to the Intergovernmental Panel on Climate Change (Smith et al., 2007b).

Determining N losses from turfgrass and soil ecosystems is a useful strategy for developing an appropriate fertilization program that promotes healthy turfgrass as well as addressing the environmental concerns associated with N losses. Losses of N from turfgrass occur through denitrification, leaching, volatilization, runoff, and in some cases by erosion (Baird et al., 2000; Foth and Ellis, 1997; Petrovic, 1990; Tinsdale et al., 1985).

Groffman et al. (2009) reported few differences in N_2O fluxes above four urban grassland and eight forested ecosystems. The flux of N_2O from intensively fertilized grasslands did not exceed that from forest ecosystems, indicating that N cycling in urban lands is a complex process. The data by Groffman and colleagues also suggests that N retention may be significant in these ecosystems. Denitrification losses are most likely low for many turfgrass/soil conditions (Carrow et al., 2001). Some conditions such as soils compacted with poor drainage and algae covered surfaces may be conducive to denitrification. Kaye et al. (2004) studied the fluxes of CH_4 and N_2O from urban soils and compared these with those from non-urban ecosystems.

The ecosystems studied consisted of urban lawn, native shortgrass steppe, dryland wheat fallow, and flood-irrigated corn. The urban lawn fluxes of CH_4 and N_2O were comparable to those from irrigated corn (*Zea mays*) but were more than those from wheat (*Triticum aestivum*) fallow or native grasslands. Limited information is available for field comparisons of soil–atmosphere exchange on N_2O and CH_4 fluxes from turfgrass/soil ecosystems.

Although this model did not account for CH_4 and N_2O, future modeling scenarios should consider inclusion of soil GHG when dictated by specific climate, soil conditions, or management practices known to greatly influence GHG fluxes (Groffman et al., 2009; Lorenz and Lal, 2009b; Neeta et al., 2008; Raciti et al., 2008).

The objective of this research was to investigate a simple mass balance model that compares the rate of SOC sequestration under a range of management scenarios for single-family home lawns practiced in diverse ecoregions of the United States. This article specifically explains methods to estimate the net pool of SOC sequestration under MI, medium input determined as DIY homes based on average current practices, and high input determined as homes using BMPs. Net SOC sequestration rates of each category were determined by subtracting the HCC from gross SOC sequestration.

Materials and Methods

Soil organic carbon sequestration rates for U.S. home lawns were modeled using data available from published literature. All data for SOC sequestration rates were compiled for the 0- to 15-cm soil layer. The net SOC sequestration rate was the amount of gross C accumulated minus the HCC of lawn maintenance practices expressed as C equivalents.

Home lawns are cared with a number of agronomic and maintenance inputs with the majority including mowing, use of fertilizers and pesticides, and irrigation. Forty million home lawns use a MI system (mowing only), 30 million lawns are maintained by the homeowner, and 10 million use a lawn care service or apply fertilizer multiple times a year (Augustin, 2007).

Do-It-Yourself lawn practices focus on average current lawn maintenance practices to calculate average net SOC sequestration rate in U.S. home lawns. Estimates of lawn maintenance practices for MI and BMPs are calculated to benchmark C sequestration of low- to high-range lawn maintenance regimes. These ranges also provide an estimate of lawn management practices under a wide range of regional environmental conditions. The parameters, data, and assumptions used in the model are summarized in Table 1. This equation is expressed in units of g/m^2/year (Eq. [1]).

$$\text{Net C sequestration rate} = \text{Gross SOC sequestration rate} - \text{HCC} \quad [1]$$

Soil organic carbon sequestration. The net rates of SOC sequestration were compiled from published literature on NPP and SOC dynamics (Tables 2 and 3). Data on net primary productivity (NPP) were used to estimate the average rate of SOC sequestration after the humification of plant material (Smith et al., 1993). The only data sets selected for use in this study consisted of gross primary productivity minus the respiration using both the belowground (root) and aboveground (shoot) growth rate for U.S. grasslands and turfgrasses (Table 2). The grassland sites ranged widely in geography and climate across the United States. The NPP data used in this model included direct measurements of dry plant biomass over 12 different sites. The average range of NPP was 5.89 to 12.71 Mg dry matter/ha/year. Each year, ≈10% of the biomass added to the soil may be humified (Duiker and Lal, 2000;

Table 1. Summary of parameters, data, and assumptions used in the model development.

Lawns category	No. of lawns (millions)	Mowings/year	No. of irrigated lawns (millions)	Fertilizer use	Pesticide use
MI	40	28	None	None	None
DIY	30	28	3–4.5	9.07×10^5 Mg fertilizer sold/year (The Scotts Miracle-Gro Company, 2006)	EPA reported pesticide use estimations in Mg/year (United States Environmental Protection Agency, 2004)
			(10% to 15%)	2.63×10^5 nitrogen 2.70×10^4 phosphorus 3.60×10^4 potassium	5.9×10^3 Mg herbicide 1.4×10^3 Mg insecticide
BMPs	10	28	10	Industry-standard recommendations in kg/ha/year 147–250 nitrogen 30–50 phosphorus 60–100 potassium	Industry-standard recommendations in kg/ha/year 1 pre-emergent herbicide at 1.77 1 post-emergence herbicide combo at 2.54 1 insect control at 0.09

MI = minimal input; DIY = do-it-yourself; BMPs = best management practices.

Table 2. Annual net primary productivity of dry plant weight (roots and shoots) of grasslands in the United States.

Biomass/region	Dry plant wt (Mg/ha/year)	Reference
Desert grasslands	2.00–3.00	Woodwell and Whittaker (1968)
Desert grasslands	2.25–3.79	Sims and Singh (1978)
Mountain grassland	8.00–9.20	Sims and Singh (1978)
Shortgrass prairies	5.70–13.00	Sims and Singh (1978)
Mixed prairies	5.20–14.25	Sims and Singh (1978)
Tallgrass prairie	7.00–13.53	Sims and Singh (1978)
Tallgrass prairie	9.92–11.32	Kucera et al. (1967)
Tropical grasslands	2.00–20.00	Leith (1975)
Tropical grasslands	15.00–30.00	Woodwell and Whittaker (1968)
Temperate grassland	6.76	Van Hook (1971)
Temperate grasslands	1.00–15.00	Leith (1975)
Average biomass	5.89 ± 1.26^z to 12.71 ± 2.30^z	

[z]The mean of each range is followed by the SE.

Table 3. Annual soil organic carbon accumulation rates of grasslands in the United States.

Land use/management	Avg SOC accumulation (Mg C/ha/year)	References
Cultivated reseeded to grass	0.80	Bruce et al. (1999)
Low–high grassland management	0.54	Contant et al. (2001)
Cultivated to wheatgrass	0.189	White et al. (1976)
Cultivated to Russian wild rye	0.069	White et al. (1976)
Cultivated to abandoned grassland	0.031	Burke et al. (1995)
Cultivated to perennial grasslands	1.10	Gebhart et al. (1994)
Average SOC accumulation	0.46 ± 0.18^z	

[z]The mean of each range is followed by the SE.
SOC = soil organic carbon; C = carbon.

Puget et al., 2005; Schimel et al., 1994). This is the amount of plant material left as SOC after detrital and microbial turnover (Schimel et al., 1994). Thus, the rate of SOC sequestration was estimated at 0.6 to 1.3 Mg C/ha/year after adjusting for the humification efficiency.

Data on SOC sequestration included U.S. grasslands and lands converted to grasslands or turfgrass (Table 3). The sites chosen ranged widely in geography and climate across the United States. The data on SOC sequestration consisted of direct soil measurements or a combination of direct soil measurements and modeling techniques. SOC sequestration rates in grassland and prairie sites were similar to those from perennial turfgrass systems found in the literature (Pouyat et al., 2002; Qian and Follett, 2002). The average rate of SOC sequestration was 0.46 Mg C/ha/year (Table 3).

Soil organic carbon sequestration models are often developed using the NPP data (Smith et al., 2008). The present model uses NPP and SOC dynamic studies for grasslands specifically selected to compare two different approaches. Both NPP and SOC sequestration rates are comparable and support the conclusion that SOC sequestration values obtained could be representative of U.S. home lawns. The average rate of SOC sequestration ranged from 0.5 to 1.3 Mg C/ha/year for the United States (Tables 2 and 3), equivalent to 46.0 to 127.1 g C/m²/year.

Influence of fertilizer and irrigation on soil organic carbon sequestration. Fertilizer and irrigation practices can increase the SOC pool by increasing the amount of biomass production (Lal et al., 1999). The proposed model uses experimental data relating the rate of biomass production to N application. Grasslands receiving fertilizer produced 7% to 298% more dry biomass than unfertilized grassland (Beaty et al., 1960; Graber and Ream, 1931; Harrison, 1934; Juska et al., 1955; Juska and Hanson, 1969; Lovvorn, 1945; Madison, 1961; Sullivan, 1961; Warnes and Newell, 1968). The rate of increase in the SOC pool by irrigation is estimated at 50 to 100 kg C/ha/year, an equivalent of 5 to 10 g C/m²/year (Lal et al., 1999). Each set of SOC sequestration data is summed to attain the net cumulative SOC sequestration rate. Each term is expressed in units of g C/m²/year (Eq. [2]).

$$\text{Net SOC Sequestration rate} = \text{SOC by humification} + \text{Fertilizer SOC} + \text{Irrigation SOC} \quad [2]$$

Hidden carbon costs. Lawn management practices of mowing, irrigating, fertilizing, and using pesticides are derived from energy-based inputs. The HCCs are the amount of energy expended by different lawn maintenance practices from manufacturing to the amount used in lawn care. The HCCs of turfgrass operations are not well documented. Therefore, farm operation energy conversions were used in this model. Turfgrass operations were assumed to be similar to farm land operations in terms gasoline emissions from maintenance equipment, supplemental irrigation, and fertilizer and pesticide production and transportation. Lal (2004b) converted energy use from farm operations into units of CEs expressed as g CE/m²/year. Inputs from turfgrass management practices are converted into kilograms CE and are summed for each maintenance practice to estimate the HCC (Eq. [3]).

$$\text{HCC} = \text{CE Mowing} + \text{CE Irrigation} + \text{CE Fertilizer} + \text{CE Pesticides} \quad [3]$$

Hidden carbon costs of the inputs are used in the model to compute net SOC sequestration rates. The HCC of mowing is based on typical homeowner practices of mowing once per week from April to October for a total of 28 mowings/year (Augustin, 2007). The number of mowings is similar to a 900-person survey taken by students of Eastern Illinois University who found the average number of mowings was 30 times per year. However, the average in the university study was extremely variable as a result of the inclusion of other yard maintenance practices (Quigly, 2001). University recommendations for lawn management practices include leaving the clippings on the lawn after mowing (McKinley, 2005; Thurn et al., 1994). Recycling clippings is a common practice in a home lawn situation as a result of landfill restrictions on yard waste (Qian et al., 2003). Therefore, it is assumed homeowners leave clippings on the lawn after mowing.

Over 50% of homeowner lawnmowers are walk-behind with a 2.2 to 3.7 kilowatt gasoline-powered motor (Quigley, 2001). Mowers in this category consume 12.7 to 20.4 mL gasoline/min (Priest et al., 2000). The CE of gasoline developed by Lal (2004b) was a compilation of a wide range of fuel sources used in farm operations and averages 0.8 g CE/g gasoline. Mowing time for an average-sized lawn is estimated at an average walking speed of 4.0 $km \cdot h^{-1}$ for mowing a 0.5 m × 1509.5-m (0.08 ha) strip and doubling the time for making mower turns (Tudor-Locke, 2003; Weil, 2009). Therefore, mowing produces 12.9 to 20.6 g CE/m^2/year. Riding mowers may emit more fuel than walk-behind mowers but take less time to mow. Therefore, this rate was standardized for all management levels.

Rates of turfgrass water use and evapotranspiration (ET) are well established and vary among turfgrass species (Kenna, 2006). The rates of water use for turfgrasses range from 3.0 to 8.0 $mm \cdot d^{-1}$ and of ET from 3.0 to 12.0 $mm \cdot d^{-1}$ (Beard, 1973; Kenna, 2006). In general, BMPs suggest irrigating turfgrass when rainfall volume is less than that of ET (McKindey, 2005; Osmond and Bruneau, 1999; Thurn et al., 1994; Trenholm et al., 2002).

In areas of the United States receiving enough rainfall to supply water to the grass, lawns can survive without any irrigation (Bormann et al., 1993). In arid areas of the United States, irrigation may be required for turfgrass survival (Bormann et al., 1993). The CE of irrigation was derived from the amount of energy required to pump water and is variable as a result of the difference in system pressure, water lift, pipe friction, water flow rate, and efficiency (Lal, 2004b). The majority of homeowners participating in irrigation practices use hose-end sprinklers (Powell and Witt, 2003). Therefore, the hand-moved sprinkler conversion from farm operations was used and consisted of 1.6 g CE/m^2/year (Lal, 2004b).

The CE conversions for fertilizers and pesticides were derived from a compilation of production, packaging, storage, and distribution requirements for fertilizer and pesticide a.i. (Lal, 2004b) and vary based on the lawn management category. The CE conversion of fertilizer was 0.9 to 1.8 g CE/g nitrogen, 0.1 to 0.3 g CE/g of phosphorus, and 0.1 to 0.2 g CE/g of potassium (Lal, 2004b). The CE conversion for pesticides was 1.7 to 12.6 g CE/g herbicide and 1.2 to 8.1 g CE/g insecticide (Lal, 2004b).

Results

Minimal input management. Minimal input lawns, comprising of 40 million homes, are defined as mowing once a week without irrigation, fertilizer, or pesticide use (Augustin, 2007). The net SOC sequestration model for MI is based on the gross SOC minus the HCC.

The SOC sequestration rate was 46.0 to 127.1 g C/m^2/year (Table 2 and 3). Carbon equivalents for mowing, used to estimate the total HCC for MI, were 12.9 to 20.6 g CE/m^2/year. Thus, total net SOC sequestration rate per MI home lawn was 25.4 to 114.2 g C/m^2/year (Table 4) or a total of 0.8 to 3.6 Teragrams (Tg)/year for the United States.

Do-it-yourself management. The rate of SOC sequestration per DIY home lawn was 46.0 to 127.1 g C/m^2/year (Tables 2 and 3). The rate of SOC sequestration from nitrogen (N) fertilization was based on 2.63 × 10^5 Mg of N/year applied to all DIY lawns divided by 30 million lawns. Thus, DIY lawns apply ≈10.9 $g \cdot m^2$/year N and produce an estimated 980 g biomass/m^2/year (Beaty et al., 1960; Graber and Ream, 1931; Harrison, 1934; Juska et al., 1955; Juska and Hanson, 1969; Lovvorn, 1945; Madison, 1961; Sullivan, 1961; Warnes and Newell, 1968). The rate of biomass produced in a DIY lawn was 780 g/m^2/year more than unfertilized lawns (Beaty et al., 1960; Graber and Ream, 1931; Harrison, 1934; Juska et al., 1955; Juska and Hanson, 1969; Lovvorn, 1945; Madison, 1961; Sullivan, 1961; Warnes and Newell, 1968). After accounting for humification efficacy, the rate of SOC sequestration in each DIY lawn was 78.0 g C/m^2/year from fertilization.

Only 10% to 15% (3 to 4.5 million) of DIY lawns irrigate (National Agriculture Statistics Service, 2002, 2004), and the rate of SOC sequestration aided by irrigation was 5 to 10 g of C/m^2/year (Lal, 2004b). Therefore, total SOC sequestration for 3 to 4.5 million irrigated home lawns was 12,000 to 36,000 Mg C/year.

The CE values for mowing, irrigating, and applying fertilizers and pesticides were summed to obtain the total HCC for DIY. The CE for mowing was 12.9 to 20.6 g CE/m^2/year and that for irrigation is an average of the 10% to 15% of the households that irrigate. The CE conversion for hand-moved sprinklers (16.3 kg CE/ha/year) was multiplied by 3 to 4.5 million home lawns. This total was divided by 30 million DIY lawns for an average of 0.1 to 0.3 g CE/m^2/year.

Fertilizer use for DIY lawns in the United States was 9.07 × 10^5 Mg of fertilizer sold to the DIY category on a yearly basis (The Scotts Miracle-Gro Company, 2006). A typical lawn fertilizer analysis by weight is 29% N, 3% phosphorus (P), and 4% potassium (K) (The Scotts Miracle-Gro Company, 2006). This amounts to 2.63 × 10^5 Mg of N/year, 2.70 × 10^4 Mg of P/year, and 3.60 × 10^4 Mg of K/year. The CE conversions for fertilizer (0.9 to 1.8 g CE/g N, 0.1 to 0.3 g CE/g of P, and 0.1 to 0.2 g CE/g of K) were multiplied by the appropriate fertilizer component to obtain an average of 10.1 to 20.4 g CE/m^2/year.

Pesticide use for the lawn and garden category in the United States is estimated at 11,800 Mg herbicides and 2,800 Mg insecticides/year (United States Environmental Protection Agency, 2004). Because this report includes lawns, gardens, landscaping beds, pesticides used indoors, and pesticides used on pets, the pesticide rate was assumed to be divided among the categories. Therefore, it was assumed half of the consumption was on lawns and the other half was on landscape, garden, indoor, and pet pesticides. This number also fell in the same range as proprietary sales data given by The Scotts Miracle-Gro Company. Therefore, lawn herbicides are estimated at 5900 Mg/year and pesticides at 1400 Mg/year. The CE conversion for pesticide a.i. (1.7 to 12.6 g CE/g herbicide and 1.2 to 8.1 g CE/g insecticide) was divided among the 30 million DIY lawns for an average of 0.4 to 2.6 g CE/m^2/year.

The gross SOC sequestration for the average DIY lawn was 124.5 to 206.6 g C/m^2/year with a HCC of 23.6 to 43.9 g CE/m^2/year. Thus, the total net SOC sequestration rate for a DIY home lawn was 80.6 to 183.0 g C/m^2/year (Table 4) or at total of 1.9 to 4.4 Tg/year for the United States.

Best management practices. Home lawns following BMPs are comprised of 10 million homes, which use a lawn care service or engage in multiple fertilizer applications in a given year (Augustin, 2007). Lawn care services adopt university BMPs as a management program. This program is defined as mowing once per week, fertilizing four times a year with pest prevention, and irrigating regularly when rainfall is insufficient for healthy grass growth (Carrow et al., 2001; Fipps et al., 2005; Heckman and Murphy, 2003; Landschoot, 2005; Louisiana State University, 2008; McKinley, 2005; Osmond and Bruneau, 1999; Reicher and Throssell, 1998; Rieke and Lyman, 2002; Sartain, 2000; Street and White, 2006; Thurn et al., 1994; Trenholm et al.,

Table 4. U.S. grassland annual soil organic carbon accumulation rate.

	Minimal input lawns	Do-it-yourself lawns	Best management practices lawns
		(g/m^2/year)	
SOC	46.0–127.1	46.0–127.1	46.0–127.1
Fertilizer SOC	0	78.0	78.0–98.0
Irrigation SOC	0	0.5–1.5	5.0–10.0
Gross SOC	46.0–127.1	124.5–206.6	129.0–235.1
Mowing HCC	12.9–20.6	12.9–20.6	12.9–20.6
Irrigation HCC	0	0.1–0.3	1.6
Fertilizer HCC	0	10.1–20.4	15.5–49.5
Pesticide HCC	0	0.4–2.6	0.8–5.6
Gross HCC	12.9–20.6	23.6–43.9	30.8–77.3
Total net sequestration	25.4–114.2	80.6–183.0	51.7–204.3
Total net sequestration per lawn	20,320–91,360	64,480–146,400	41,360–163,440

SOC = soil organic carbon; HCC = hidden carbon cost.

2002). The net SOC sequestration model for BMPs was also based on subtracting the HCC from gross rate of SOC sequestration.

The rate of SOC sequestration was 80.0 kg C/lawn/year (Tables 2 and 3) based on industry standards of BMPs for fertilizing turfgrass 14.7 to 25.0 g N/m^2/year (Carrow et al., 2001; Fipps et al., 2005; Heckman and Murphy, 2003; Landschoot, 2005; Louisiana State University, 2008; McKinley, 2005; Osmond and Bruneau, 1999; Reicher and Throssell, 1998; Rieke and Lyman, 2002; Sartain, 2000; Street and White, 2006; Thurn et al., 1994; Trenholm et al., 2002; University of Florida, 2004). This range is based on regional area and species type variations. The BMP rate of fertilizer application produced 780 to 980 g more biomass/m^2/year than unfertilized grass (Beaty et al., 1960; Graber and Ream, 1931; Harrison, 1934; Juska et al., 1955; Juska and Hanson, 1969; Lovvorn, 1945; Madison, 1961; Sullivan, 1961; Warnes and Newell, 1968). Accounting for 10% humification efficiency, SOC sequestered through BMP rates of N fertilization was 78.0 to 98.0 g C/m^2/year. The SOC sequestered from irrigation was calculated at 5.0 to 10.0 g C/m^2/year.

The CE for mowing, irrigating, and applying fertilizers and pesticides was summed to compute the total HCC for BMPs. The HCC was 12.9 to 20.6 g CE/m^2/year for mowing. It was assumed that irrigation was practiced by all BMP lawns. The total amount of land under irrigation for the BMP category was 0.8 Mha. Using the hand-moved sprinkler conversion, BMP lawns used 1.6 g CE/m^2/year for irrigation.

Fertilizer use as modeled from university recommendations was based on applying 14.7 to 25.0 g N/m^2/year. A common lawn fertilizer ratio is 5–1–2. Therefore, P was calculated at 3.0 to 5.0 g P/m^2/year and K was calculated at 6.0 to 10.0 g K/m^2/year. The amount of N, P, and K was multiplied by the appropriate fertilizer component CE for a total of 15.5 to 49.5 g CE/m^2/year.

Pesticide use for BMPs is modeled on the basis of one application for each pre-emergence herbicide, post-emergence herbicide, and insect control per year (Louisiana State University, 2008; McKinley, 2005). All pesticide controls were based on common lawn granular fertilizer plus pest control combination products using percent a.i. of each pesticide (Scotts Training Institute, 2007). The pre-emergence control involved use of pendimethalin ($C_{13}H_{19}N_3O_4$) at a rate of 0.17 g·m^{-2}. The post-emergence control involved a combination of 2,4-dichlorophenoxyyacetic acid ($C_8H_6Cl_2O_3$) at 0.17 g·m^{-2} and Mecoprop-P ($C_{10}H_{11}ClO_3$) at 0.08 g·m^{-2}. Insect control involved the insecticide bifenthrin ($C_{23}H_{22}ClF_3O_2$) at 0.01 g·m^{-2}. Using the CE conversion for herbicide (1.70 to 12.60 g CE/g herbicide) and insecticide (1.2 to 8.1 g CE/g insecticide), the total amount of each pesticide was multiplied by the appropriate pesticide CE for a total of 0.8 to 5.6 g CE/m^2/year.

The average BMP home lawn has a gross SOC sequestration rate of 129.0 to 235.1 g C/m^2/year, HCC of 30.8 to 77.3 g CE/m^2/year, and net SOC sequestration rate of 51.7 to 96.3 g C/m^2/year (Table 4) or a total of 0.4 to 0.8 Tg/year for the United States.

Discussion

The proposed model is a national scale assessment of the net SOC sequestration potential of existing home lawns in the United States. The model indicated the rates of SOC sequestration estimated from NPP compare well with those from grassland and turfgrass SOC sequestration rates reported in published data. These rates are also similar to some cropland ecosystems. The rates of SOC sequestration are similar to the national average rates for other land uses.

An average size home lawn in the United States has the potential to sequester 20.3 to 163.4 kg C/lawn/year (Table 4). The largest increase in C sequestration occurs when management practices increase from MI to DIY. BMPs can increase the rate of SOC sequestration even further. At a high level of management, however, the HCC can offset the benefit of C sequestration. For example, a lawn in the arid southwest under a BMP lawn program has more HCC and a lower net rate of SOC sequestration. In contrast, a lawn in the northeast under a DIY program requires less HCC to maintain a healthy lawn and has a higher rate of SOC sequestration.

Total single-family home lawn area of 6.4 Mha covers ≈5% of the total land under cropland (138 Mha) in the United States (United States Census Bureau, 2010). From the model, the rate of SOC sequestered in home lawns is 0.5 to 1.5 Mg C/ha/year, which is more than an average rate for U.S. cropland of 0.3 Mg C/ha/year (Lal and Follett, 2009). The rate of SOC sequestration for home lawns also falls in a rate similar to that for the world grasslands of 0.6 to 1.9 Mg C/ha/year (Bruce et al., 1999).

The rate of SOC sequestration depends on the antecedent SOC level, climate, profile characteristics, and management (Lal et al., 1999). The net rate of SOC sequestration for a specific land use (i.e., home lawns) eventually attains a steady state and the net rate approaches zero (Lal et al., 1999). The point of SOC saturation for home lawns is unknown and may vary widely among regions. Historical soil data on home lawns is limited as a result of the lack of continuity of lawn care maintenance practices.

The scope of the model can be further broadened to account for specific climate, soil types, lawn management practices, and soil gas flux. Validation through long-term field sampling of SOC is needed to determine the extent and limits to which urban lawn soils can sequester C. Direct measurements and future research will increase the precision and accuracy of this model to a local or regional scale.

Literature Cited

Augustin, B.J. 2007. Perception vs. reality: How much nitrogen do homeowners put on their lawn. Am. Soc. of Agron. 269-6 (abstr.).

Baird, J.H., N.T. Basta, R.L. Huhnke, G.V. Johnson, M.E. Payton, D.E. Storm, C.A. Wilson, M.D. Smolen, D.L. Martin, and J.T. Cole. 2000. Best management practices to reduce pesticide and nutrient runoff from turf, p. 268–293. In: Clark, J.M. and M.P. Kenna (eds.). Fate and management of turfgrass chemicals. Am. Chem. Soc. Symp. Ser. 743, Washington, DC.

Bandaranayake, W., Y.L. Quian, W.J. Parton, D.S. Ojima, and R.F. Follet. 2003. Estimation of soil organic carbon changes in turfgrass systems using the CENTURY model. Agron. J. 95:558–563.

Beard, J.B. 1973. The turfgrass environment, p. 179–380. In: Turfgrass science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beaty, E.R., R.A. McCreery, and J.D. Powell. 1960. Responses of Pensacola Bahiagrass to nitrogen fertilization. Agron. J. 52:453–455.

Blanco-Canqui, H. and R. Lal. 2004. Mechanisms of carbon sequestration in soil aggregates. Crit. Rev. Plant Sci. 23:481–504.

Bormann, F.H., D. Balmori, and G.T. Geballe. 1993. Redesigning the American lawn. Yale University Press, New Haven, CT, and London, UK.

Bruce, J.P., M. Frome, E. Haites, H. Janzen, R. Lal, and K. Paustian. 1999. Carbon sequestration in soils. J. Soil Water Conserv. 54:382–390.

Burke, I.C., W.K. Lauenroth, and D.P. Coffin. 1995. Soil organic matter recovery in semiarid grasslands: Implications for the Conservation Reserve Program. Ecol. Monogr. 5:793–801.

Campbell, C.A. and R.P. Zenter. 1993. Soil organic matter as influenced by crop rotation and fertilization. Soil Sci. Soc. Amer. J. 57:1034–1040.

Carrow, R.N., D.V. Waddington, and P.E. Rieke. 2001. Developing fertilizer programs, p. 339–346. In: Turfgrass soil fertility and chemical problems Wiley, Hoboken, NJ.

Contant, R.T., K. Paustian, and E.T. Elliott. 2001. Grassland management and conversion into grassland: Effects on soil carbon. Appl. Ecol. 11:343–355.

Duiker, S. and R. Lal. 2000. Carbon budget study using CO_2 flux measurements from a no-till system in central Ohio. Soil Tillage Res. 54:21–30.

Eichner, M.J. 1990. Nitrous oxide emissions from fertilized soils: Summary of available data. J. Environ. Qual. 19:272–280.

Falk, J.H. 1976. Energetics of a suburban lawn ecosystem. Ecology 57:141–150.

Falk, J.H. 1980. The primary productivity of lawns in an urban environment. J. Appl. Ecol. 17:689–696.

Fipps, G., J. McAfee, and D. Smith. 2005. Turf irrigation and nutrient management reference manual. Texas A&M Coop. Ext. Bul. B-6165.

Follett, R.F., G.E. Varvel, J.M. Kimble, and K.P. Vogal. 2009. No-Till corn after bromegrass: Effect on soil carbon and soil aggregates. Agron. J. 101:261–268.

Foth, H.D. and B.G. Ellis. 1997. Soil fertility. 2nd Ed. CRC Press, Inc., Boca Raton, FL.

Gebhart, D.L., H.B. Johnson, H.S. Mayeux, and H.W. Polley. 1994. The CRP increases soil organic carbon. J. Soil Water Conserv. 49:488–492.

Glendining, M.J. and D.S. Powlson. 1991. The effect of long-term applications of inorganic nitrogen fertilizer on soil organic nitrogen, p. 329–338. In: Wilson, W.S. (ed.). Advances in soil organic matter research: The impact of agriculture and the environment Ambridge, UK.

Graber, L.F. and H.W. Ream. 1931. Growth of bluegrass with various defoliations and abundant nitrogen supply. J. Amer. Soc. Agron. 23:938–945.

Gregorich, E.G., B.H. Ellert, C.F. Drury, and B.C. Lang. 1996. Turnover of soil organic matter and storage of corn residue carbon estimated from natural ^{13}C abundance. Can. J. Soil Sci. 60:161–167.

Groffman, P.M., C.O. Williams, R.V. Pouyat, L.E. Band, and I.D. Yesilonis. 2009. Nitrate leaching and nitrous oxide flux in urban forests and grasslands. J. Environ. Qual. 38:1848–1860.

Grounds Maintenance. 1996. Turf acrage. Grounds Maint. 31:10.

Harrison, C.M. 1934. Responses of Kentucky bluegrass to variations in temperature, light, cutting, and fertilizing. Agron. J. 9:83–106.

Heckman, J. and J. Murphy. 2003. Fertilizing the home lawn. Rutgers Coop. Res. and Ext. Bul. FS633.

Intergovernmental Panel on Climate Change. 2001. Climate change 2001—The scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. In: Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. Van derLinden, X. Dai, K. Maskell, and C.A. Johnson (eds.). Cambridge University Press, Cambridge, UK.

Janssen, I.A., E.D. Schulze, S. Luyssaert, P. Ciais, and A. Freibauer. 2009. Importance of methane and nitrous oxide for Europe's terrestrial greenhouse-gas balance. Nat. Geosci. 2:842–850.

Juska, F.V. and A.A. Hanson. 1969. Nutritional requirements of *Poa annua* L. Agron. J. 61:466–468.

Juska, F.V., J. Tyson, and C.M. Harrison. 1955. The competitive relationship of merion bluegrass as influenced by various mixtures, cutting heights, and levels of nitrogen. Agron. J. 47:513–518.

Kaye, J.P., I.C. Burke, A.R. Mosier, and J.P. Guerschman. 2004. Methane and nitrous oxide fluxes from urban soils to the atmosphere. Ecol. Appl. 14:975–981.

Kaye, J.P., R.L. McCulley, and I.C. Burke. 2005. Carbon fluxes, nitrogen cycling, and soil microbial communities in adjacent urban, native and agricultural ecosystems. Glob. Change Biol. 11:575–587.

Kenna, M.P. 2006. Turfgrass and the environment, p. 65–90. In: Beard, J.B. and M.P. Kenna (eds.). Water quality and quantity issues for turfgrasses in urban landscapes. Council for Agr. Sci. and Tech Ames, IA.

Khan, S.A., T.R. Mulvaney, T.R. Ellsworth, and C.W. Boast. 2007. The myth of nitrogen fertilization for soil carbon sequestration. J. Environ. Qual. 36:1821–1832.

Kucera, C.L., R.C. Dahlman, and M.R. Koelling. 1967. Total net productivity and turnover on an energy basis for tallgrass prairie. Ecology 48:1–24.

Lal, R. 2003. Offsetting global CO_2 emissions by restoration of degraded and intensification of world agriculture and forestry. Land Degrad. and Dev. 14:309–322.

Lal, R. 2004a. Soil carbon sequestration to mitigate climate change. Geoderma 123:1–22.

Lal, R. 2004b. Carbon emissions from farm operations. Environ. Int. 30:981–990.

Lal, R. 2008. Promise and limitations of soils to minimize climate change. J. Soil Water Conserv. 63:113–118.

Lal, R. 2009. Sequestering atmospheric carbon dioxide. Crit. Rev. Plant Sci. 28:90–96.

Lal, R. and R. Follett. 2009. Soils and climate change, p. xxi–1. In: Lal, R. and R.F. Follett (eds.). Soil carbon sequestration and the greenhouse effect. 2nd Ed. Soil Sci. Soc. of Amer., Madison, WI.

Lal, R., R.F. Follet, J.M. Kimble, and C.V. Cole. 1999. Managing U.S. cropland to sequester carbon in soil. J. Soil Water Conserv. 54:374–381.

Landschoot, P.J. 2005. Turfgrass fertilization basics. Penn. State Univ. Coop. Ext. University Park, PA, 4 Oct. 2005. <http://turfgrassmanagement.psu.edu/turfgrassfertilizationbasics.cfm>.

Leified, J. 2006. Soils as sources and sinks of greenhouse gases. Geological Soc. Special Pub. 266:23–44.

Leith, H. 1975. Primary productivity of the major vegetational units of the world, p. 203–216. Leith, H. and R.H. Whittaker. Primary Productivity of the Bisphere. Springer, NY.

Lorenz, K. and R. Lal. 2009a. Carbon dynamics in urban soils, p. 393–400. In: Lal, R. and R.F. Follett (eds.). Soil carbon sequestration and the greenhouse effect. 2nd Ed. Soil Sci. Soc. of Amer., Madison, WI.

Lorenz, K. and R. Lal. 2009b. Biogeochemical C and N cycles in urban soils. Environ. Int. 35:1–8.

Louisiana State University. 2008. Louisiana lawns best management practices. Louisiana Agr. Ctr. Bul. 2940.

Lovvorn, R.L. 1945. The effect of defoliation, soil fertility, temperature, and length of day on the growth of some perennial grasses. J. Amer. Soc. Agron. 37:570–581.

Madison, J.H. 1961. Turfgrass ecology, effects of mowing, irrigation, and nitrogen treatments of Agrostis palustris Huds., 'Seaside' and Agrostis tenuis Sibth., 'Highland' on population, yield, rooting, and cover. Agron. J. 53:407–412.

Maggiotto, S.R., J.A. Webb, C. Wagner-Riddle, and G.W. Thurtell. 2000. Nitrous and nitrous oxide fluxes from turfgrass receiving different forms of nitrogen fertilizer. J. Environ. Qual. 29:621–630.

McKinley. 2005. Ortho's all about lawns. Meredith Books, Des Moines, IA.

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 turfgrasses in the United States. Environ. Manage. 36:426–438.

National Agricultural Statistics Service. 2002. Michigan turfgrass survey. Mich. Agric. Stat. Serv., Lansing, MI.

National Agricultural Statistics Service. 2004. New York Agric. Stat. Serv., Albany, NY.

National Association of Realtors. 2001. Land use and land loss in the United States: The impact of land use trends on real estate development. The Res. Div. of the Natl. Assn. of Realtors, Washington, D.C.

National Gardening Association. 2004. Natl. gardening survey. Burlington, VT.

Neeta, S., C. Bijoor, I. Czimczik, and E. Pataki. 2008. Effects of temperature and fertilization on nitrogen cycling and community composition of an urban lawn. Glob. Change Biol. 14:2119–2131.

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.

Nowak, D.J., R.A. Rowntree, E.G. McPherson, S.M. Sisinni, E.R. Kerkmann, and J.C. Stevens. 1996. Measuring and analyzing urban tree cover. Landsc. Urban Plan. 36:49–57.

Osmond, D.L., and A.H. Bruneau. 1999. Caring for your lawn and the environment. North Carolina State Coop. Ext. Publ. E99-35386.

Pataki, D.E., R.J. Alig, A.S. Fung, N.E. Golubiewski, C.A. Kennedy, E.G. McPherson, D.J. Norwalk, R.V. Pouyat, and P.R. Lankao. 2006. Urban ecosystems and the North American carbon cycle. Glob. Change Biol. 12:1–11.

Paustian, K., O. Andren, H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Van Norrdwijk, and P. Woomer. 1997. Agricultural soil as a C sink to offset CO_2 emissions. Soil Use Manage. 13:230–244.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1–14.

Phillips, R.L., D.L. Tanaka, D.W. Archer, and J.D. Hanson. 2009. Fertilizer application timing influences greenhouse gas fluxes over a growing season. J. Environ. Qual. 38:1569–1579.

Pickett, S.T.A., M.L. Cadenasso, J.M. Grove, P.M. Groffman, L.E. Band, C.G. Boone, and W.R. Burch, Jr., C.S.B. Grimmond, J. Hom, J.C. Jenkins, N.L. Law, C.H. Nilon, R.V. Pouyat, K. Szlavecz, P.S. Warren, and M.A. Wilson. 2008. Beyond urban legends: An emerging framework of urban ecology, as illustrated by the Baltimore ecosystem study. Bioscience 58:1–12.

Post, W.M., C. Izaurralde, J.D. Jastrow, B.A. McCarl, J.E. Amonette, V.L. Bailey, P.M. Jardine, T.O. West, and J. Zhou. 2004. Enhancement of carbon sequestration in US soils. Bioscience 54:895–908.

Post, W.M. and K.C. Kwon. 2000. Soil carbon sequestration and land-use change: Processes and potential. Glob. Clim. Biol. 6:317–328.

Priest, M.W., D.J. Williams, and H.A. Brigman. 2000. Emissions from in-use lawn-mowers in Australia. Atmos. Environ. 34:657–664.

Pouyat, R., P. Groffman, I. Yesilonis, and L. Hernandez. 2002. Soil carbon pools and fluxes in urban ecosystems. Environ. Pollut. 116:S107–S118.

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

Powell, A.J. and M.L. Witt. 2003. Home lawn irrigation. Univ. of Kentucky College of Agr. Bul. ID-79.

Puget, P., R. Lal, C. Izaurralde, M. Post, and L. Owens. 2005. Stock and distribution of total and corn-derived soil organic carbon in aggregate and primary particle fractions for different land use and soil management practices. Soil Sci. 170:256–279.

Qian, Y., W. Bandaranayake, W.J. Parton, B. Mecham, M.A. Harivandi, and A.R. Mosier. 2003. Long-term effects of clipping and nitrogen management in turfgrass on soil organic carbon and nitrogen dynamics: The CENTURY model simulation. J. Environ. Qual. 32:1694–1700.

Qian, Y. and R.F. Follett. 2002. Assessing soil carbon sequestration in turfgrass systems using long-term soil testing data. Agron. J. 94:930–935.

Quigley, M.F. 2001. Ornamental plants annual reports and research reviews 2000. The Ohio State Univ. Special Circular 177-01.

Raciti, S.M., P.M. Groffman, and T.J. Fahey. 2008. Nitrogen retention in urban lawns and forests. Ecol. Appl. 18:1615–1626.

Reicher, Z. and C. Throssell. 1998. Fertilizing established lawns. Purdue Univ. Coop. Ext. Serv. Bul. AY-22.

Rickman, R.W., C.L. Douglas Jr., S.L. Albrech, L.G. Bundy, and J.L. Berc. 2001. CQUESTER: A model to estimate carbon sequestration in agricultural soils. J. Soil Water Conserv. 56: 237–243.

Rieke, P.E. and G.T. Lyman. 2002. Lawn fertilization. Mich. State Univ. Ext. Bul. E05TURF.

Sartain, J.B. 2000. General recommendations for fertilization of turfgrasses on Florida soils. Univ. of Florida Ext. Bul. SL21.

Schimel, D.S., B.H. Braswell, E.A. Holland, R. McKeown, D.S. Ojima, T.H. Painter, W.J. Parton, and A.R. Townsend. 1994. Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils. Global Biogeochem. Cycles 8:279–293.

Scotts Training Institute. 2007. 2008 product guide. Marysville, OH.

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.

Sims, P.L. and J.S. Singh. 1978. The structure and function of ten western North American grasslands III. Net primary production, turnover, and efficiencies of energy capture and water use. J. Ecol. 66:573–597.

Smith, P., P. Falloon, U. Franko, M. Korschens, R. Lal, K. Paustian, D. Powlson, V. Romanenkov, L. Shevtsova, and J. Smith. 2007a. Greenhouse gas mitigation potential in agricultural soils, p. 227–236. In: Canadell, J.G., D.E. Pataki, and L.F. Pitelka (eds.). Terrestrial ecosystems in a changing world. Springer, Heidelberg, Germany.

Smith, R.D., D. Martino, Z. Cai, D. Gwery, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholeo, and O. Sirotnko. 2007b. Agriculture, p. 499–532. In: Metz, B., O.R. Davidson, P.R. Boach, R. Dave, and L.A. Meyers (eds.). Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Smith, P., C. Fang, J.J.C. Dawson, and J.B. Moncrieff. 2008. Impact of global warming on soil organic carbon. Adv. Agron. 97:1–43.

Smith, T.M., W.P. Cramer, R.K. Dixon, R. Leemans, R.P. Neilson, and A.M. Solomon. 1993. The global terrestrial carbon cycle. Water Air Soil Pollut. 70:19–37.

Snyder, C.S., T.W. Bruulsema, and T.L. Jensen. 2007. Greenhouse gas emissions from cropping systems and the influence of fertilizer management—A literature review. International Plant Nutrition Institute, Norcross, GA.

Street, J.R., and S.K. White. 2006. Fertilization of lawns. The Ohio State Univ. Ext. Fact Sheet HYG-4006.

Sullivan, E.F. 1961. Effects of soil reaction, clipping height, and nitrogen fertilization on the productivity of kentucky bluegrass sod transplants in pot culture. Agron. J. 53:261–263.

The Scotts Miracle-Gro Company. 2006. Corporate responsibility report: Product usage monitoring protocols. Marysville, OH.

Thurn, M.C., N.W. Hummel, and A.M. Petrovic. 1994. Home lawn establishment and maintenance. Cornell Coop. Ext. Bul. 185.

Tinsdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers. 4th Ed. Maccmillan Co., New York, NY.

Trenholm, L.E., E.F. Gilman, G.W. Knox, and R.J. Black. 2002. Fertilization and irrigation needs for Florida lawns and landscapes, Univ. of Florida Ext. Publ. ENH860.

Tudor-Locke, C. 2003. Watch your step: Pedometers and physical activity. Alberta Sport, Recreation, Parks, and the Wildlife Foundation, Edmonton, Alberta, Canada.

Quigly, M.F. 2001. Ornamental plants annual reports and research reviews 2000. The Ohio State Unvi. Special Circular 177-01.

United Nations. 2004a. World population monitoring 2003: Population, education, and development. United Nations Department of Economic and Social Affairs, Population Division, Washington, DC.

United Nations. 2004b. World urbanization prospects: The 2003 revision. United Nations Department of Economic and Social Affairs, Population Division, Washington, DC.

United States Census Bureau. 2010. Urban and rural population. 2 Jan. 2010. <http://www.census.gov/population/censusdata/urpop0090.txt>.

United States Environmental Protection Agency. 2004. Pesticide Industry sales and usage 2000 and 2001 market estimates. Washington, DC.

University of Florida. 2004. Homeowner best management practices for the home lawn. Institute of Food and Agr. Sci. Publ. ENH979.

Van Hook, R.I. 1971. Energy and nutrient dynamics of a spider and orthopeteron populations in a grassland ecosystem. Ecol. Monogr. 41:1–26.

Vinlove, F.K. and R.F. Torla. 1995. Comparative estimations of U.S. home lawn area. J. Turfgrass Manag. 1:83–97.

Warnes, D.D. and L.C. Newell. 1968. Establishment and yield responses of warm-season grass strains to fertilization. Grass Establ. 11:235–240.

Weil, R. 2004. Walking speed. MedicineNet. 6 Mar. 2009. <http://www.medicinenet.com/walking/page5.htm>.

White, E.M., C.R. Crueger, and R.A. Moore. 1976. Changes in total nitrogen, organic matter, available P, and bulk densities of a cultivated soil 8 years after tame pastures were established. Agron. J. 68:581–583.

Whitehead, D.C. and J. Tinsley. 2006. The biochemistry of humus formation. J. Sci. Food Agr. 14:849–857.

Woodwell, G.M. and R.H. Whittaker. 1968. Primary production in terrestrial ecosystems. Am. Zool. 8:19–30.

Comment on 703.2.6.2

Thomas D. Culp, Ph.D. on behalf of the Aluminum Extruders Council
culp@birchpointconsulting.com

Strike as follows:

~~(Points for multifamily buildings four or more stories in height are awarded at 3 times the point value listed in Table 703.2.6.2(c))~~

Reason:

While sections 703.2.6.1 and 703.2.6.2 are very appropriate for lowrise residential, they are still incorrect for highrise residential. In fact, by referring to U-factors that originate from the residential chapter of the IECC and the Energy Star program for Windows, they are already inconsistent with Sections 703.1.1.1, 703.1.1.2, and 703.2.1 which properly refer to Table C402.4 as the baseline for windows in buildings that fall under the commercial IECC, including multifamily four stories and above. (Note: The Energy Star program for Windows is applicable only to windows in residential buildings three stories or less in height, and specifically excludes windows intended to be installed in buildings four stories or higher – see "Energy Star Product Specification Residential Windows, Doors, and Skylights, Eligibility Criteria Version 6.0", sections 2A, 2B, and 1M. Attached at end.)

Corrections have been made to other parts of Section 703 to accommodate highrise multifamily, but not here. While we recognize the process may not allow changes to the main criteria in sections 703.2.6.1 and 703.2.6.2 at this time, the NGBS should certainly not give extra points (especially a multiple of 3x) in buildings four stories or higher until this section is corrected to remove the technical inconsistencies.

If it is possible to make corrections to the other parts of these sections now or in the future, the most glaring aspect is the technical inconsistency between the two mandatory baselines for windows in 703.1.1.2 (which refers to Table C402.4 of the 2015 IECC) and 703.2.6.1 (which refers to U-factors from Table R402.1.4 of the 2015 IECC). Simply inserting the proper reference will correct this, as follows:

> **703.2.6.1** NFRC-certified (or equivalent) U-factor and SHGC of windows, exterior doors, skylights, and tubular daylighting devices (TDDs) on an area-weighted average basis do not exceed the values in Table 703.2.6.1 <u>or Table C402.4 where applicable</u>.

The enhanced criteria in Section 706.2.6.2 also need revision based on the correct baseline from the commercial IECC, but we are willing to overlook this until the next edition. It is most important to correct the flaw in the mandatory baseline for windows. Not only will this improve technical consistency and usability of the NGBS for highrise residential (think 10, 20, 30 stories, not just 4), but it will also make it more attractive for adoption into standards such as ASHRAE 189.1.

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·°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

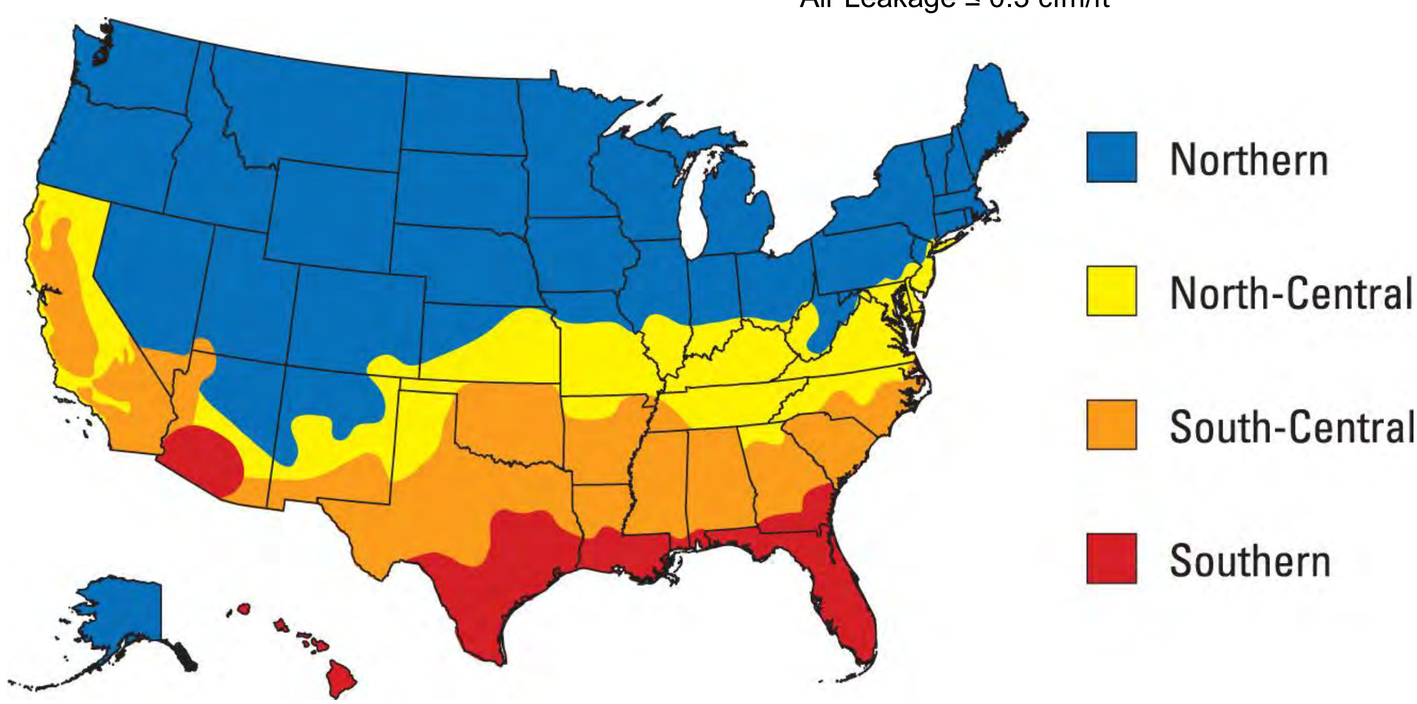
Glazing Level	U-Factor[1]	SHGC[2]	
Opaque	≤ 0.17	No Rating	
≤ ½-Lite	≤ 0.25	≤ 0.25	
> ½-Lite	≤ 0.30	Northern North-Central	≤ 0.40
		Southern South-Central	≤ 0.25

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.

H108 (HELD) - Carl Seville

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Challenges of Achieving 2012 IECC Air Sealing Requirements in Multifamily Dwellings

S. Klocke, O. Faakye, and S. Puttagunta
Consortium for Advanced Residential Buildings

October 2014

Building America
U.S. Department of Energy

NOTICE

Available electronically at http://www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

H108 (HELD) - Carl Seville

Challenges of Achieving 2012 IECC Air Sealing Requirements in Multifamily Dwellings

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

Golden, CO 80401

NREL Contract No. DE-AC36-08GO28308

Prepared by:

Steve Klocke, Omari Faakye, and Srikanth Puttagunta

Steven Winter Associates, Inc.

of the

Consortium for Advanced Residential Buildings (CARB)

61 Washington Street

Norwalk, CT 06854

NREL Technical Monitor: Stacey Rothgeb

Prepared under Subcontract No. KNDJ-0-40342-04

October 2014

The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

Contents

List of Figures

Unless otherwise noted, all figures were created by CARB.

List of Tables

Unless otherwise noted, all tables were created by CARB.

Definitions

ACH	Air Changes per Hour
ACH_{50}	Air Changes per Hour at 50 Pascal
AERC	Annualized Energy-Related Cost
CARB	Consortium for Advanced Residential Buildings
ccSPF	Closed Cell Spray Polyurethane Foam
CV	Coburg Village
HV	Housing Visions
IECC	International Energy Conservation Code
ocSPF	Open Cell Spray Polyurethane Foam
SH	Sharker 4
SWA	Steven Winter Associates

Executive Summary

While previous versions of the International Energy Conservation Code (IECC) have included provisions to improve the airtightness of dwellings, for the first time, the 2012 IECC mandates compliance verification through blower door testing. Simply completing the Air Barrier and Insulation Installation Checklist through visual inspection is no longer sufficient by itself. In addition, the 2012 IECC mandates a significantly stricter air sealing requirement. In climate zones 3–8, air leakage may not exceed 3 ACH_{50}, which is a significant reduction from the 2009 IECC requirement of 7 ACH_{50}. This requirement is for all residential buildings, which includes detached one- and two-family dwellings and multiple single-family dwellings (townhouses) as well as Group R-2 (apartment dwellings), R-3, and R-4 buildings three stories or less in height above-grade plane. While this air leakage rate requirement is an important component to achieving an efficient building thermal envelope, currently, the code language doesn't explicitly address differences between single-family and multifamily applications.

In addition, the 2012 IECC does not explicitly provide an option to sample dwellings for larger multifamily buildings, so compliance would have to be verified on every unit. According to Sydney Roberts, program manager at Southface Home Services, "The size and complexity of a multifamily building makes it challenging to measure air leakage between individually occupied units, and between a unit and the outside."

Given the 2012 IECC air leakage requirements on the horizon, several of the Consortium for Advanced Residential Buildings' (CARB) multifamily builder partners are evaluating how best to comply with the 2012 IECC air leakage requirements. Builders are not sure whether it is more practical or beneficial to simply pay for guarded testing or to revise their air sealing strategies to improve compartmentalization to comply with code requirements based on unguarded blower door testing.

CARB conducted research to assess the feasibility of meeting the 2012 IECC air leakage requirements with unguarded blower door testing. By analyzing testing results from numerous dwellings within three multifamily projects, CARB compared performance based on several variables, including construction details (insulation, framing, etc.) and design characteristics (dwelling layout, location within the building, etc.). Additional analysis was performed to explore the cost effectiveness of various air sealing techniques.

Based on these findings, CARB created an air sealing guideline in low rise, wood construction multifamily buildings. This guide will provide builders/developers/contractors the critical details needed to comply with the air leakage requirements of the 2012 IECC. Still, achieving an unguarded 3 ACH_{50} in multifamily dwellings is not easy. In addition to applying the strategies detailed in the air sealing guide provided in the Appendix, the following items were determined to be critical for compliance with the 2012 IECC air leakage requirement in multifamily dwellings:

- Reducing air leakage starts during the design development process; design teams must make decisions that allow for the air leakage requirement to be met.

- Construction teams must understand the design teams' intent while incorporating their experiences from previous successes and failures. Implementation is crucial; subcontractors will not meet their air leakage reduction goals without heightened awareness, support and oversight.
- Until design and construction teams become familiar and comfortable with the tasks required to meet the air leakage requirement, construction schedules will be slowed down and implementation costs will be high.

While CARB believes the goals of the 2012 IECC air leakage requirement are desirable, there is concern that this requirement is geared toward single-family construction only and doesn't address the nuances of multifamily construction. Rather than quantifying air leakage based on a dwelling's volume, one might argue that air leakage should be quantified based on how much of a dwelling's enclosure area is exposed to ambient conditions. This idea has implications for both attached and detached dwellings. In any dwelling, energy loss occurs at the exterior enclosure, and the relationship between the dwelling's enclosure and its volume is not constant. For example, a dwelling with an elongated plan will have a larger enclosure area than a square-shaped dwelling of the same floor area. The discrepancy in exterior enclosure area is even greater when comparing attached and detached dwellings. CARB believes that an exception for testing multifamily buildings (a building containing multiple dwelling units) based on a metric of cubic feet per minute per square foot of enclosure area (all six sides of the dwelling unit) would be beneficial to the construction industry while maintaining the goal/intent of the code requirement. In addition, a methodology for test sampling is needed.

1 Introduction

While previous versions of the International Energy Conservation Code (IECC) have included provisions to improve the airtightness of dwellings, for the first time, the 2012 IECC mandates compliance verification through blower door testing. Simply completing the Air Barrier and Insulation Installation Checklist through visual inspection is no longer sufficient by itself. In addition, the 2012 IECC mandates a significantly stricter air sealing requirement. In climate zones 3–8, air leakage may not exceed 3 ACH_{50}, which is a significant reduction from the 2009 IECC requirement of 7 ACH_{50}. ACH_{50} refers to the air changes per hour when testing is conducted with a blower door at a pressure of 0.2 in. w.g. (50 Pascal). This requirement is for all residential buildings, which includes detached one- and two-family dwellings and multiple single-family dwellings (townhouses) as well as Group R-2 (apartment dwellings), R-3, and R-4 buildings three stories or less in height above grade plane. While this air leakage rate requirement is an intrinsic component to achieving an efficient building thermal envelope, currently, the code language doesn't explicitly address differences between single-family and multifamily applications (IECC 2009, 2012).

The air leakage requirements were established for single-family detached homes. The intent of the blower door test is to determine the amount of air leakage to outdoors, as this would be associated with an energy penalty. In attached housing, some of the air leakage will be to neighboring units. To achieve an equivalent metric in attached housing, a guarded blower door test needs to be performed. Unfortunately, there is no standard test method similar to the ASTM E1827 and E779 ("Standard Test Methods for Determining Air Tightness/Leakage in Detached Units") that can be readily applied to attached housing. The Energy Conservatory and Camroden Associates released a *Blower Door Application Guide: Beyond Single Family Residential* (Brennan et al. 2014) that provides guidance on multifamily buildings and large facilities, but the focus was primarily for whole-building infiltration testing.

In addition, the 2012 IECC does not provide an option to sample dwellings for larger multifamily buildings, so compliance would have to be verified on every unit. According to Sydney Roberts, program manager at Southface Home Services, "The size and complexity of a multifamily building makes it challenging to measure air leakage between individually occupied units, and between a unit and the outside."[1] Therefore, several multifamily builder partners of the Consortium for Advanced Residential Buildings (CARB), a Building America research team led by Steven Winter Associates, Inc. (SWA), requested assistance with evaluating how to comply with the 2012 IECC air leakage requirements if adopted by their state code. As testing fees and construction costs vary widely, the builders were not sure whether it would be more practical/beneficial to simply pay for guarded testing or to revise their air sealing strategies to improve compartmentalization to comply with code requirements based on unguarded blower door testing. As 2012 IECC air leakage rates weren't mandatory for these projects, these field demonstrations were used more as learning labs for the builders and their contractors to see the performance of the current construction specifications and what additional changes may be needed for future projects.

[1] http://www.southface.org/sfjournal/summer_2012/files/assets/seo/page11.html

2 Background

Before trying to determine how to meet the IECC air leakage requirement in multifamily buildings, it is important to understand the unique characteristics of multifamily construction.

2.1 What Makes Multifamily Enclosures Different From Single-Family Enclosures?

Detached dwellings are enclosed primarily by exterior surfaces, whereas the enclosure of attached dwellings incorporates interior surfaces (Figure 1). These interior surfaces are typically dealt with as adiabatic surfaces. Heat is not transferred through adiabatic surfaces because the spaces on both sides of the surface are conditioned to a comparable degree; examples of adiabatic surfaces include demising walls between units, corridor walls, ceilings/floors above/below other units or non-unit areas, and other surfaces between two conditioned areas.

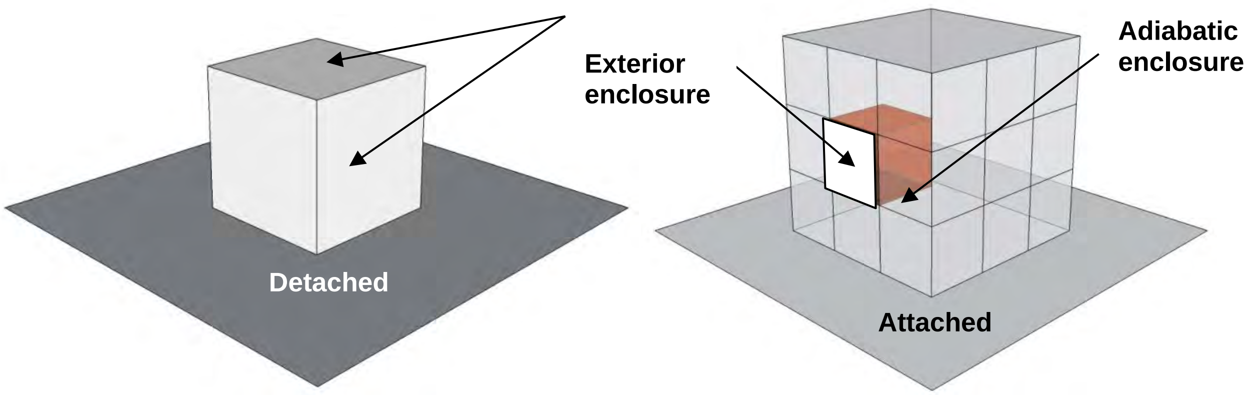


Figure 1. Detached versus attached dwelling enclosures

In multifamily construction, adiabatic surfaces are usually treated differently than exterior surfaces. Air leakage at the adiabatic surfaces in an attached dwelling tends to have minimal impact on energy performance when analyzing an individual dwelling unit because the air in the adjacent spaces is assumed to be at nearly the same temperature and therefore, does not require additional conditioning. Still, there is the potential for an interior surface to be connected to the exterior conditions through indirect pathways. In addition, permanent seals are needed at all large exterior openings of chases and framing edges to roof/wall joints, to floor/wall joints, party wall edges, rooftop mechanical openings, crawlspaces, mechanical rooms, loading docks and garages. These interior bypasses, along with bypasses directly to outdoors, increase overall building air leakage due to stack effect acting over a larger height (Lstiburek 2005). Yet, for design and modeling purposes, these interior walls are generally treated as adiabatic.

Most builders are familiar with the various strategies for reducing air leakage at exterior assemblies, whereas the typical scope of work at adiabatic surfaces focuses on fire-stopping and acoustic insulation for sound attenuation. Reducing interior air leakage in an attached dwelling is referred to as *compartmentalization*.

2.2 How Much Air Leaks Through Exterior Surfaces Versus Adiabatic Surfaces?

The standard method for testing air leakage includes one set of equipment, a blower door (or duct blaster for small units), set up in the entry door of dwelling being tested. The blower door depressurizes or pressurizes the unit to a given pressure differential and the rate at which air is being drawn out of or into the dwelling is recorded. A ±50 Pascal pressure differential is the standard testing criteria to allow for universal comparison of air leakage in buildings between verifiers; it does not represent actual air leakage under natural operating conditions.

In attached dwellings, an alternative method for testing air leakage, called "guarded" testing, includes additional blower doors being set up in the conditioned spaces adjacent to the unit being tested (can alternatively be done by using a fan or multiple fans to pressure the rest of the floor or building). The additional blower doors are adjusted to neutralize the pressure differential between the adjoining surfaces to the main unit being evaluated, resulting in a leakage value that can be attributed primarily to air movement at the exterior surfaces, thus impacting energy performance. A preliminary finding of a 2006 study by Lawrence Berkeley National Laboratory found that multifamily dwellings are 1.5–2 times as leaky per unit surface area as single-family detached homes (Gadgil et al. 2006).

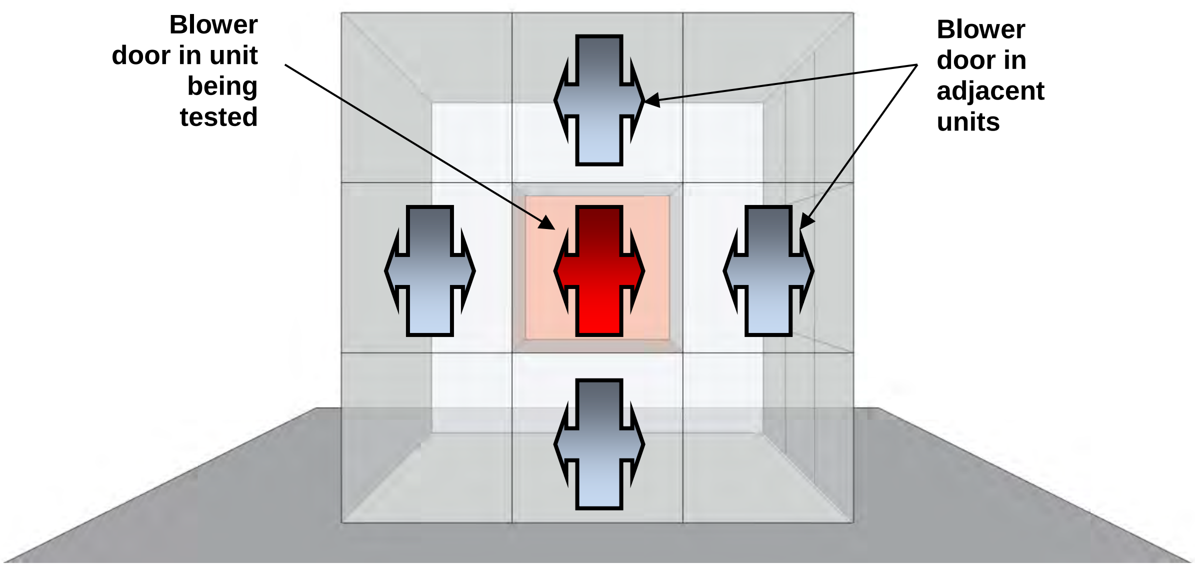


Figure 2. Guarded blower door testing

A handful of other studies have been performed to compare guarded and unguarded testing results. The New River Center for Energy Research & Training presented a study in 2012 that showed a 22% reduction when changing from unguarded to guarded air leakage testing.[2] Similarly, the Center for Energy and Environment presented findings in 2012 that showed that 27% of air leakage was occurring at demising walls.[3] Using blower door test data available from numerous multifamily projects, CARB has also developed a framework for a simple algorithm

[2] http://www.energyoutwest.org/eow_library/__past_confs/EOW_2012_Presentations/Air%20Tightness%20Testing%20of%20Multifamily%20Buildings%20-%20Anthony%20Cox.pdf
[3] http://www.slideshare.net/mnceeInEx/mf-sealing-and-ventilation-bb-il-2012-v5-dlb

based on unguarded blower door tests and a few basic dwelling unit characteristics (Faakye et al. 2013). Results for the new construction multifamily apartments in that dataset suggest an average air leakage reduction of ~30% with guarded blower door testing.

2.3 What Reference Resources Are Currently Available That Discuss Strategies for Reducing Air Leakage?

The U.S. Department of Energy's Building Energy Codes Program has published the "Air Leakage Guide: Meeting the Air Leakage Requirements of the 2012 IECC" (BECP 2011). This guide primarily discusses the details of *Table R402.4.1.1 Air Barrier and Insulation Installation Checklist* of the 2012 IECC. These specifications were developed and vetted through the U.S. Department of Energy's Building America program and have become a key component of the U.S. Environmental Protection Agency's ENERGY STAR® Certified New Homes Program (through the Thermal Enclosure System Rater Checklist). This resource is geared toward single-family dwellings and generally does not address the issues of air sealing and testing multifamily dwelling units.

There are several Building America resources that address multifamily air sealing. In 2012, CARB completed a measure guideline on air sealing attics and roof assemblies in multifamily buildings (Otis and Maxwell 2012). This guideline explains why air sealing is desirable, explores related health and safety issues, and identifies common air leakage points in multifamily building attics. In addition, it also gives an overview of materials and techniques typically used to perform air sealing work. While a useful resource, it is geared more to existing building applications.

Another Building America team, Advanced Residential Integrated Energy Solutions, provides air sealing instructions in Appendix E of its technical report, *Air Leakage Testing and Air Sealing in Existing Multifamily Units* (Dentz and Conlin 2012). A key finding of this study was that sealing air pathways in the attic and basement, and not just individual dwellings, can affect air leakage in many units. Still this was again more focused on existing multifamily buildings.

The Building America Solution Center does have some new construction guidance, but this content focuses on air sealing multifamily party walls,[4] which is geared more toward compartmentalization air sealing. This guidance was provided to specifically address sealing multifamily party walls, which is not address within the 2012 IECC *Table R402.4.1.1 Air Barrier and Insulation Installation Checklist.*

Using lessons learned on numerous past multifamily projects, SWA has developed air sealing guides specific to several multifamily construction types (wood,[5] masonry,[6] and garden style[7]) that include details specifically geared toward compartmentalization. SWA's builder partners have successfully used these guides to assemble comprehensive, cost-effective air sealing packages to achieve their air leakage reduction goals of less than 0.25 cfm_{50}/ft^2 of enclosure area (Figure 3), which roughly equates to 4.5–5.5 ACH_{50} for typical size apartment dwellings.

[4] https://basc.pnnl.gov/resource-guides/multifamily-party-walls#block-views-guide-static-blocks-block-1
[5] http://carb-swa.com/Collateral/Documents/CARB-SWA/Details/SWA-MultifamilyAirSealingGuide-Wood.pdf
[6] http://carb-swa.com/Collateral/Documents/CARB-SWA/Details/SWA-MultifamilyAirSealingGuide-Masonry.pdf
[7] http://carb-swa.com/Collateral/Documents/CARB-SWA/Details/Air%20Sealing%20Guide%20Garden%20Style%20_Version1.pdf

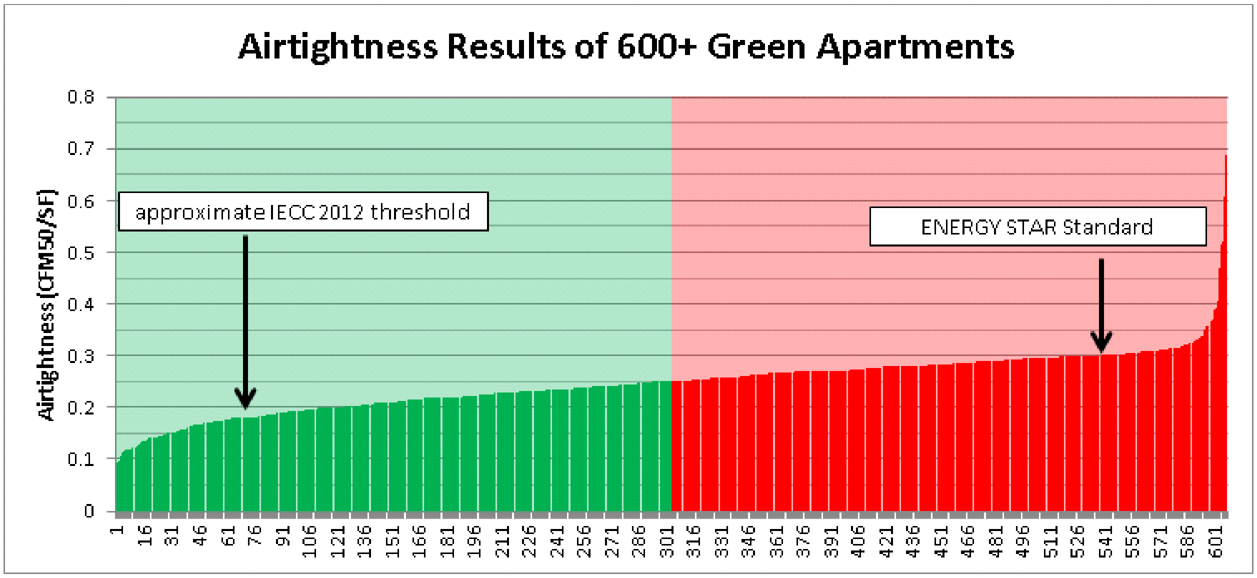


Figure 3. Airtightness results of 600+ green apartments (green denotes apartments that achieved < 0.25 cfm50/ft^2 of enclosure area, while red denotes apartments that exceeded this goal)

CARB and other researchers have found that 0.25 cfm_{50}/ft^2 of enclosure area is a reasonable ratio that scales with all sizes of individual units and whole building enclosures. It is also consistent with the 2012 IECC commercial (four-story and taller buildings) air leakage ratio of 0.40 cfm_{75}/ft^2 of enclosure area.

3 Research Focus

This project sought to create a well documented design and implementation strategy for air sealing in low-rise multifamily buildings which would assist in compliance with the building infiltration requirements of the 2012 IECC as it is adopted across the country, without having to go through the potential added expense of guarded blower door testing.

The following research questions were pursued:

- How achievable is the IECC climate zone 3–8 infiltration value of 3 ACH_{50} in multifamily dwellings when accounting for unguarded blower door testing?
- What insulation and air sealing strategies help dwellings achieve the 2012 IECC ACH_{50} values with an unguarded blower door test?
- What lessons can be learned from the air sealing/insulating techniques employed in these projects?

4 Technical Approach

CARB analyzed construction details and air leakage test results from three projects (Figure 4) in upstate New York, listed in order of final completion (all during 2013):

1. Coburg Village (CV): 78 units located in Rexford, New York (climate zone 5A)
2. Shaker 4 (SH): 69 units located in Watervliet, New York (climate zone 5A)
3. Housing Visions (HV): 50 units located in Syracuse, New York (climate zone 5A).

The same construction team was used at CV and SH; an entirely different construction team was used at HV. All projects achieved ENERGY STAR version 3 and LEED for Homes certification.

Figure 4. The three low-rise multifamily projects that were evaluated: CV (left), SH (top right), and HV (bottom right)

CARB performed unguarded blower door testing using the Residential Energy Network's sampling protocol in each of these buildings. The insulation and air sealing strategies were inspected and documented at the pre-drywall stage of construction and upon completion of construction. CARB also solicited feedback from the builders regarding challenges during construction and lessons learned after project completion.

Why unguarded blower door testing?
Guarded blower door testing was previously performed on two units at the earlier Shaker 3 project by SWA. The staggered layout of these units resulted in a total of seven blower doors being needed to test a single unit (the unit of interest, two adjoining units on same floor, common hall, unit directly above, and the two units below due to staggered a layout). Equipment setup, coordination between verifiers, and coordination with building crew members took more than an hour per unit. When testing began, CARB found that the sequence in which the blower doors were ramped up had varying results, which could lead to a further divergence in test results between verifiers. This issue can be minimized through the use of computer software to bring all doors up to speed at the same rate.

In addition, the transport of pollutants, smoke/fire, and odors between apartments may have health and safety consequences, so there is an added benefit of achieving air leakage compliance through compartmentalization. Only focusing on sealing exterior air leakage without reducing the internal transport of air between dwelling units may exacerbate indoor air quality problems (Gadgil 2006). The builder wanted a more sound construction solution to ensure repeatable compliance with code air leakage requirements and enhanced living conditions.

5 Analysis

CARB analyzed several factors that potentially affect air leakage as well as the cost effectiveness of air leakage reduction. The buildings were compared to each other in regard to differences in construction details, including framing, insulation and air sealing details, and the location of dwellings within each building was analyzed on a building-by-building basis. Cost effectiveness was evaluated using modeling software as well as data provided by the builders.

5.1 Construction Details

While CV and HV implemented site-built wood framing, HV utilized some advanced framing techniques and simplified floor plan configurations (one-bedroom units in an L-shaped plan versus two-bedroom units in a winding floor plan). HV framing plans were simplified by having ceiling joists running from corridor to exterior walls. Whether by design or implementation, the framing at HV was significantly neater with fewer framing members, which allowed connections between framing members to be tighter. This allowed for easier air sealing, rater inspections, and seems to have fostered pride for construction site cleanliness (Figure 5).

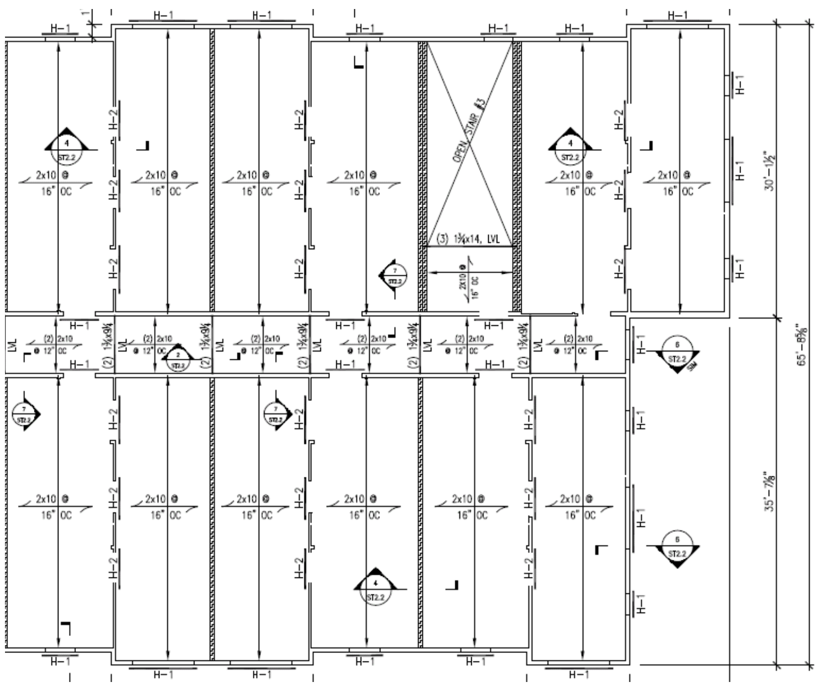


Figure 5. Framing plans at HV were well implemented by framers and set up the air sealing crew for success

(courtesy of Holmes King Kallquist & Associates, LLP)

As shown in Table 1, the three projects utilized a variety of air sealing details at the exterior and adiabatic surfaces. Closed-cell spray polyurethane foam (ccSPF) insulation was initially used at the exterior walls at CV, but the builder switched to elastomeric sealant and blown-in fiberglass batts due to fire-rated assembly requirements (Figure 6); discrepancies in air leakage and cost were negligible between these two specifications. This later specification was also used at SH. At HV, ccSPF insulation was used on all exterior walls (Figure 7), which was allowed because this building was classified as a different construction type.

Table 1. Overview of Construction Details

Detail	CV	SH	HV
Framing	Site-built wood; open-web floor trusses; resilient channels at demising and corridor walls	Panelized wood; open-web floor trusses; resilient channels at corridor walls	Site-built wood; advanced framing techniques; solid wood floor framing
Exterior Insulation/Air Sealing	ccSPF (in 2 of 9 building sections); elastomeric sealant and blown-in fiberglass (in remainder of building)	Elastomeric sealant and blown-in fiberglass	ccSPF
Interior Air Sealing (at Demising/ Corridor Walls)	Fire-stopping; acoustic sealant; caulk at electrical boxes; foam at pipe penetrations	Fire-stopping; acoustic sealant; caulk at electrical boxes; foam at pipe penetrations; tape at ducts	Fire-stopping; acoustic sealant; open cell spray polyurethane foam (ocSPF)

Figure 6. Exterior wall air sealing and insulation used at CV and SH

Figure 7. Exterior wall air sealing used at HV

Air sealing at the demising walls varied considerably between the three buildings. CV implemented a plywood smoke curtain between the trusses above the demising walls (Figure 8); whereas the smoke curtain at the demising walls at SH was constructed by extending the demising wall sheetrock between the floor joists (Figure 9). At HV the solid floor joists aligned with the demising walls (Figure 10), so a smoke curtain was not necessary (though sealing of wood to wood joints and seams was still needed).

Figure 8. Air sealed plywood smoke curtain used at demising wall of CV

Figure 9. Air sealed sheetrock smoke curtain used at demising wall of SH

Figure 10. Air sealed structural framing used at demising wall of HV

The builder of CV and SH increased the air sealing scope of work in the SH project due to leakier than expected test results at CV; air sealing in both cases consisted mostly of caulk and expanding foam. The builder at HV has found that ocSPF insulation reliably addresses compartmentalization issues (Figure 11), while providing additional benefits as discussed previously. The increased first cost of the sealing method was offset by reduced labor to air seal and improved quality control, so this sealing strategy is being used at all HV multifamily projects moving forward.

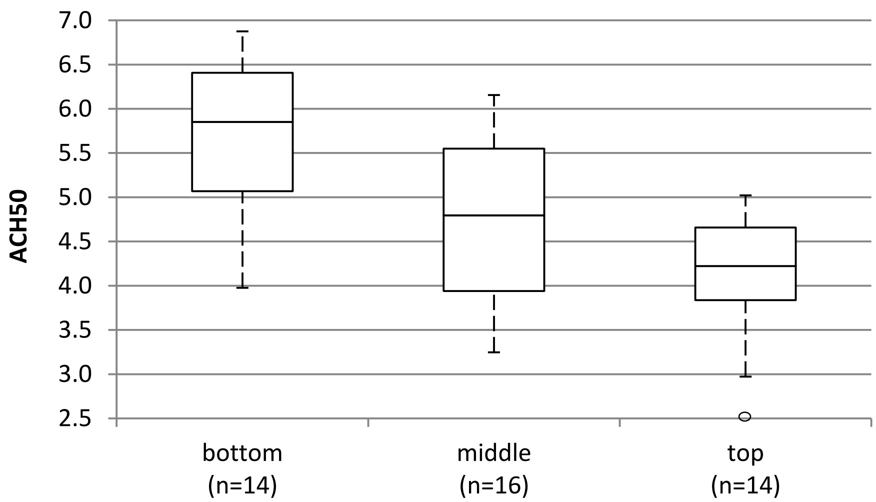
Figure 11. Demising wall air sealing at HV

A common issue with air sealing of walls is compliance with fire code and rated wall assemblies. According to the builder, in compliance with their local jurisdiction, ocSPF is an approved material for use in a rated bearing wall construction. The design is similar to UL#U311, with the ocSPF used in lieu of batt insulation. An ICC-ES Evaluation report released in 2010 reviewed and allowed the use ocSPF in a rated wall, provided it was enclosed on both sides of the stud wall with minimum ½ in. thick gypsum wall board, attached to the studs with metal fasteners as shown in UL #311. In this project, ⅝ in. thick gypsum wall board was installed. This method of air sealing dwellings has become the norm in this local region.

5.2 Dwelling Characteristics

CARB investigated potential connections between air leakage and various characteristics of the dwellings in each project. The first dwelling characteristic to be analyzed was whether the floor level had an impact on the air leakage rate. Bottom level units have a unit above and a slab below; middle level units have a unit or common area above and below; and top level units have a roof above and a unit below. Figure 12 summarizes this data in a box-and-whisker diagram. The box defines the middle half of data points bounded by the upper quartile and lower quartile. All whiskers represent the greatest and least data value excluding outliers. The circles represent the minimum and maximum outliers. Minimum, maximum, mean, and median ACH_{50} values are listed below each plot. The percent outliers describe the percentage of the data collected that lies outside the whiskers.

Opposite of what one might anticipate, testing at CV and SH showed that air leakage was highest on the bottom level and lowest on the top level. In addition, there was a lower variation (tighter distribution) of the test results on the top level units.

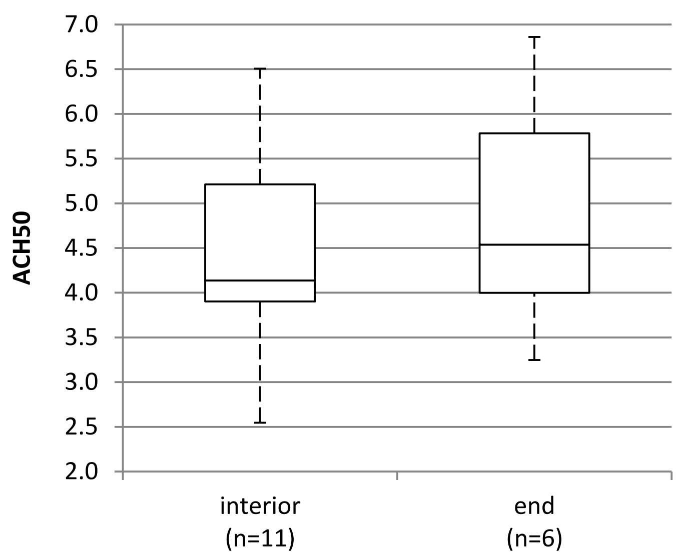


Min	3.98	3.25	2.97
Max	6.87	6.16	5.02
Mean	5.76	4.80	4.11
Median	5.85	4.80	4.22
% Outliers	0%	0%	7%

Figure 12. Unguarded ACH_{50} values by unit level at CV and SH

At CV, the air sealing crews started at the top of the building and worked their way down through the building. Unfortunately, they were rushed for time by the time they got to the lower levels and the quality control of the air sealing efforts suffered. It is unclear why SH showed this same trend, as the air sealing crew was not rushed for time for this building. The top level being the tightest is likely a result of all the buildings paying special attention to the critical air sealing of the ceiling plane. CV has a sheetrock ceiling for mechanical, electrical, and plumbing, then another layer of sheetrock before the blown cellulose in attics. SH did not have the double sheetrock ceiling, but did air sealing at attic penetrations before blown cellulose. Both are rigid on the flat roof sections where equipment sits.

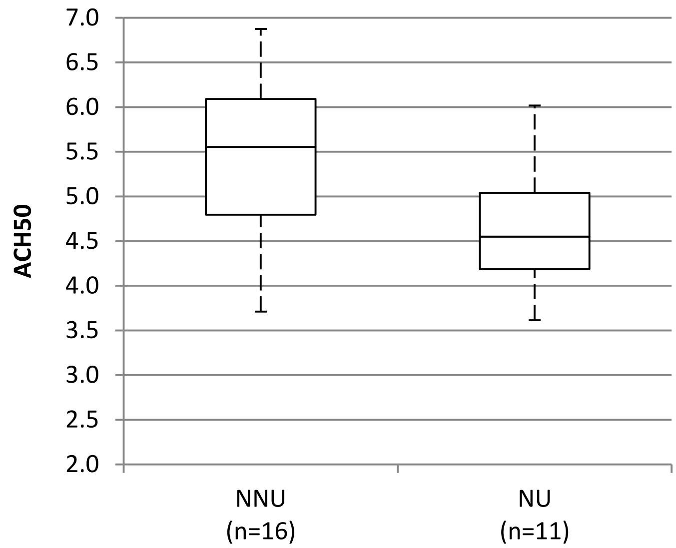
Another dwelling characteristic, the location of a dwelling within the footprint of a building, was anticipated to have a noticeable impact on air leakage, as the characteristics of the exterior surfaces typically differ from the characteristics of the adiabatic surfaces. However, from this small sample set, the impact on air leakage was not significant. Figure 13 shows the relationship between dwellings located toward the interior of the building and dwellings located at the ends of the SH building. The end dwellings had a slightly higher mean air leakage value as well as a larger variation in test results, even though these dwellings were considerably outnumbered by the interior dwellings.



Min	2.55	3.25
Max	6.51	6.86
Mean	4.36	4.83
Median	4.14	4.54
% Outliers	0%	0%

Figure 13. Unguarded ACH_{50} values by location at SH

The CV building showed a noticeable difference in air leakage between units that are neighbored by other units versus units neighbored by non-unit areas such as amenity areas, chases, and shafts. This analysis was done in the horizontal plane only (i.e., across walls rather than ceilings or floors). At walls between two units, both sides of the wall are most likely air sealed, whereas only one side is typically sealed at walls between units and non-unit spaces, resulting in a reduction in air leakage as shown in Figure 14 (NNU = units neighbored by non-unit areas; NU = units neighbored by other units).



Min	3.71	3.61
Max	6.87	6.02
Mean	5.42	4.65
Median	5.55	4.55
% Outliers	0%	0%

Figure 14. Unguarded ACH_{50} values by unit location at CV

5.3 Cost Effectiveness

BEopt™ software (Building Energy Optimization version 2.1) evaluates residential building designs and identifies cost-optimal efficiency packages at various levels of whole-house energy savings. The annual energy-related cost (AERC) can be obtained by annualizing the energy-related cash flows (mortgage payments and utility bills) over an analysis period of 30 years. Inputs for the various economic variables, as defined by the *Addendum to the Building America House Simulation Protocols* (Metzger et al. 2012), are shown in Table 2.

Table 2. Inputs of Economic Analysis

Economic Variables	Modeling Inputs
Project Analysis Period	30 years
Inflation Rate	2.4%
Discount Rate (Real)	3.0%
Loan Period	30 years
Loan Interest Rate	4.0%
Marginal Income Tax Rate (Federal/State)	28%/0%
Electricity Rate*	$0.14/kilowatt-hour
Natural Gas Rate*	$1.03/therm
Fuel Escalation Rate	0.0%

* Twelve-month average for upstate New York

CARB modeled a middle-floor, 1,120-ft^2 end unit in climate zone 5 according to IECC 2012 as shown in Table 3. Benchmark defaults as outlined in the *Addendum to the Building America Housing Simulation Protocols* (Metzger et al. 2012) were used for options not mandated by the 2012 IECC. The dwelling unit was modeled at eight varying air leakage levels ranging from 7 to 0.5 ACH50 to investigate the effects of air leakage on energy and cost. BEopt uses the Alberta air infiltration model (AIM-2) to determine hourly, weather-dependent infiltration rates. Still, this energy simulation is geared for modeling of a single dwelling unit and doesn't account for the multifamily building interactions (air leakage between units, stack effects, etc.), so there are significant limitations that need to considered when drawing conclusions from this analysis.

Table 3. Model Home Options

Category	Description
Walls	R-13 fiberglass batts, grade I, 2 × 4 studs @ 16 in. on center
Wall Sheathing	oriented strand board, R-5 extruded polystyrene
Windows	Double-pane, high gain low-emissivity, insulated frame, air filled U = 0.29, solar heat gain coefficient = 0.56
Air Leakage	3.0 ACH_{50}
Ventilation	Exhaust only, 100% ASHRAE 62.2-2010
Appliances, Lighting	Benchmark
Cooling System	Seasonal energy efficiency ratio 13
Heating System	Gas furnace, 78% annual fuel utilization efficiency
Ducts	15% leakage, R-8
Water Heater	Gas benchmark

The AERC for the modeled home at each infiltration level is shown Figure 15. As expected, decreasing ACH_{50} values correlate with lower annualized energy-related cost, while capital costs increase. The estimated annualized energy-related cost savings from 7 ACH_{50} (IECC 2009 code) to 3ACH_{50} (IECC 2012 ACH_{50}) decreases by 2.8% ($35/year), but this comes with a 0.35% ($150) increase in capital costs. Base on cost information from the National Residential Efficiency Measures Database, the energy modeling analysis suggests that the additional savings benefit in AERC decreases beyond 3 ACH_{50}, while the capital costs to achieve the lower air leakage value continue to rise.

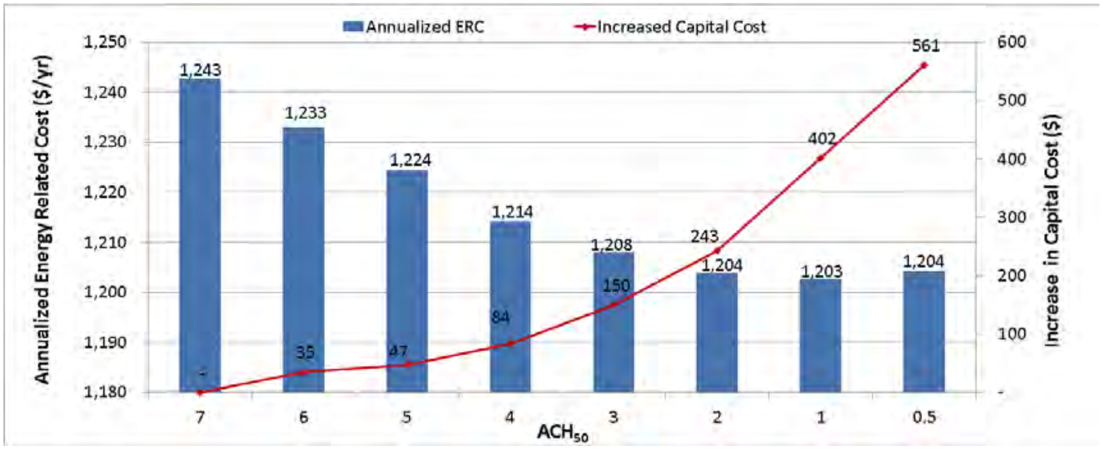


Figure 15. Annualized energy-related cost at decreasing ACH_{50} values

Actual capital costs for air leakage reduction were not available; however, CARB attained whole-building insulation and air sealing costs for each project, as shown in Table 4. By utilizing the same crew and making minor adjustments to the insulation and air sealing strategies, the construction team for CV and SH was able to decrease air leakage at a lower cost at the second building. In contrast, the insulation and air sealing costs are considerably higher at HV (due to use of ccSPF), but the resulting air leakage is significantly lower.

Table 4. Insulation/Air Sealing Cost per Unit Versus Mean ACH_{50}

	CV	SH	HV
Mean ACH_{50}	5.1	4.5	3.0
Estimated $/Unit	$2,371	$1,376	$2,910

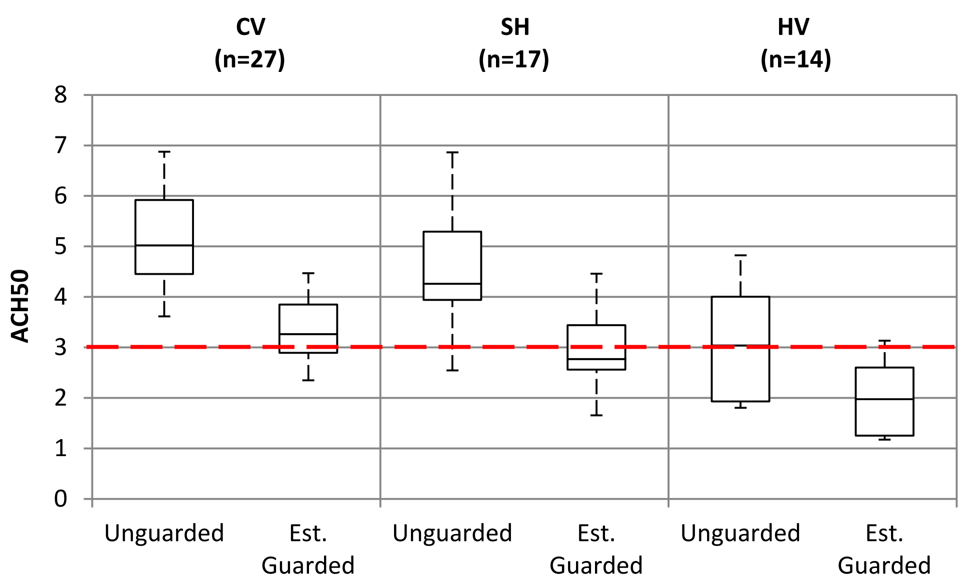
The question comes down to whether it is more advantageous for the builders to spend money on compartmentalization or guarded blower door testing of each unit. Community Housing Partners out of Virginia are one of the most experienced companies performing larger scale guarded blower door testing on attached homes and multifamily dwellings. According to Community Housing Partners, testing every unit of a ~100 unit building would cost $300–$350/unit and take roughly a week to test straight through utilizing up to nine blower doors at a time. This assumes that Community Housing Partners could go straight through without interference from others (builder, contractors, etc.), which is not typically possible in new construction buildings.

6 Results

6.1 How Achievable Is the 2012 IECC Climate Zone 3–8 Infiltration Value of 3 ACH_{50} in Multifamily Dwellings When Accounting for Unguarded Blower Door Testing?

HV had the highest percentage of units (50%) that met the 2012 IECC air leakage requirement of 3 ACH_{50} based on unguarded blower door testing. Twelve percent of units at SH met the requirement, and none of the units at CV met the requirement.

Figure 16 shows box plots of the distribution of ACH_{50} values for each project using a 30% air leakage reduction for estimated guarded values (based on the literature search, which showed a 20%–30% reduction from unguarded to guarded testing). Out of the 58 test apartments, only 11 units met the 2012 IECC 3 ACH_{50} requirement via unguarded testing. An additional 23 units passed when the estimated guarded value was applied. That still leaves roughly 40% of the units failing the airtightness requirement of the 2012 IECC. Based on the current language of the 2012 IECC, it is likely that a combination of enhanced air sealing and guarded blower door testing may be required. This suggests that specific air leakage requirements for multifamily dwellings may be worth consideration.



Min	3.61	2.35	2.55	1.65	1.80	1.17
Max	6.87	4.47	6.86	4.46	4.82	3.13
Mean	5.11	3.32	4.53	2.94	3.05	1.98
Median	5.02	3.26	4.26	2.77	3.04	1.97
% Outliers	0%	0%	0%	0%	0%	0%

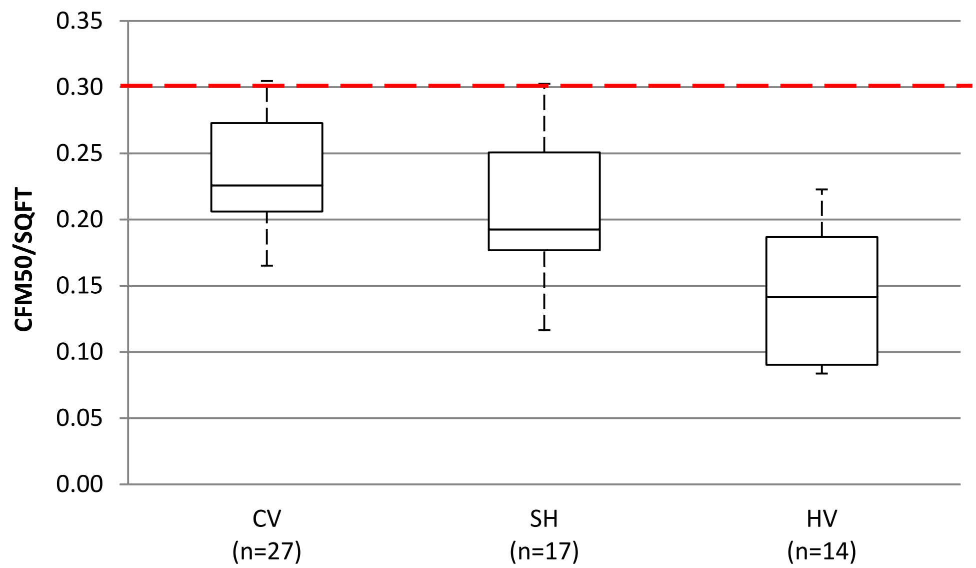
Figure 16. ACH values from both unguarded and estimated guarded testing

While the builders were interested in evaluating the level of effort required to achieve 3 ACH_{50} in these dwelling, it is important to note that none of the projects were required to achieve 3 ACH50. These projects were enrolled in the New York State Energy Research and

Development Authority Low-rise Residential New Construction Program (PON 2309). This program includes an air leakage requirement based on the surface area of each apartment rather than the volume of each apartment. Though not utilized by IECC for homes, this CFM_{50}/ft^2 of enclosure surface area is CARB's preferred metric, as the goal is to seal air leaks through all the surfaces that make up a building's shell and not within the entire volume of a home.

The passing threshold, ≤ 0.3 CFM50/ft^2 of enclosure surface area, takes into account the fact that attached dwelling enclosures include adiabatic AND exterior surfaces, and a portion of air leakage through the enclosure may have a relatively small effect on energy performance. Using the surface area-based air leakage metric and target, all dwellings units tested in these three projects met this criterion (Figure 17).

While a direct correlation between the volume-based metric (ACH_{50}) and the enclosure-based metric (CFM_{50}/ft^2 of enclosure surface area) cannot be made due to the unique characteristics of each apartment, for the apartments in this study, 0.3 CFM50/ft^2 was approximately equivalent to 6–7 ACH50.



Min	0.17	0.12	0.08
Max	0.30	0.30	0.22
Mean	0.24	0.20	0.14
Median	0.23	0.19	0.14
% Outliers	0%	0%	0%

Figure 17. Unguarded CFM_{50}/ft^2 of enclosure area

6.2 What Insulation/Air Sealing Strategies Help Buildings Achieve the 2012 IECC Air Leakage Requirement?

Due to the number of variables between the characteristics of each of the buildings, distinct strategies for achieving the 2012 IECC air leakage requirement cannot be directly identified.

However, the sequential improvement in testing results provides some insight into identifying the strategies for reducing air leakage.

The use of spray polyurethane foam insulation at HV clearly resulted in lower air leakage values; CARB believes that the greatest benefit from this material may be earned by using it at adiabatic walls in addition to exterior walls. The downside to using this material, however, includes increased costs and construction scheduling conflicts. Regardless, the HV builder has found that the benefits of spray polyurethane foam insulation, including those in addition to air sealing, warrant using this material for all of its multifamily projects.

The additional air sealing tasks performed at SH (compared to CV) definitely resulted in lower air leakage results. These tasks primarily applied to penetrations in the drywall, such as at piping and ductwork.

The characteristics of the units within each building had a modest effect on air leakage.

- In regard to building level, the top floor units performed better than bottom floor units, which may be attributed to the exposure of the horizontal surfaces above and below the units.
- A building with a generic rectangular plan will have fewer end units than a building with several corners, which would likely reduce air leakage due to minimized exposed area.
- Dwellings neighbored by non-unit areas, such as amenity areas, chases, and shafts, tended to not be as airtight. Sealing the walls of non-unit areas similar to dwellings could potentially reduce air leakage.

6.3 What Lessons Can Be Learned From the Air Sealing/Insulating Techniques Employed in These Projects?

The builder and Home Energy Rating Systems rater for CV and SH agree that the improvement in air leakage values at SH is rooted in lessons learned at CV.

- Due to unsatisfactory test results at CV, the construction team made air sealing a priority at SH; the various subcontractors were given additional time to perform the air sealing tasks, and the builder and rater provided additional oversight and support.
- In addition, the insulation subcontractor at SH was given full responsibility for all air sealing, whereas multiple subcontractors were responsible for air sealing at CV.

Unfortunately this additional effort is not easily quantified; regardless, CARB believes that a heightened level of awareness led to better results at the second building.

From an architectural standpoint, design decisions can be made to help reduce air leakage throughout the development process.

- As mentioned above, the layout of the units (exposed surface area) within a building can affect air leakage.

- The architect should also be familiar with a variety of air sealing techniques; incidentally, a large number of techniques in SWA's air sealing guides were not implemented in any of the projects in this study.
- Adding air leakage thresholds and responsibilities to the contract documents will make bidders more aware of air sealing expectations.

7 Discussion

7.1 What Other Techniques Could Have Been Used To Reduce Air Leakage?

Builders choose to implement various air leakage reduction techniques based on feasibility, cost, and experience. Some techniques, such as making access panels airtight (Figure 21), are relatively low in cost and easy to do; since this task can be completed at any time, however, builders will commonly wait to perform this task until after its necessity has been determined. Other techniques, such as separating wall cavities with a layer of drywall (Figure 20), are often rejected by design teams due to structural constraints. Generally, builders will not incorporate new or unfamiliar techniques until they are required to do so. SWA's air sealing guides include several strategies not implemented in these projects, as described below. An updated air sealing guide for wood construction multifamily projects is included as the Appendix.

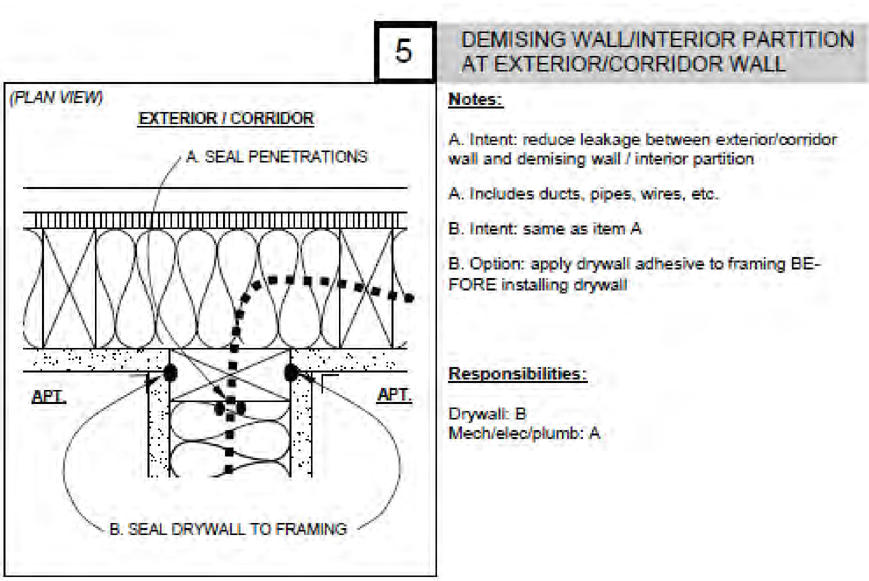


Figure 18. Air sealing detail—seal drywall to framing at wall intersections

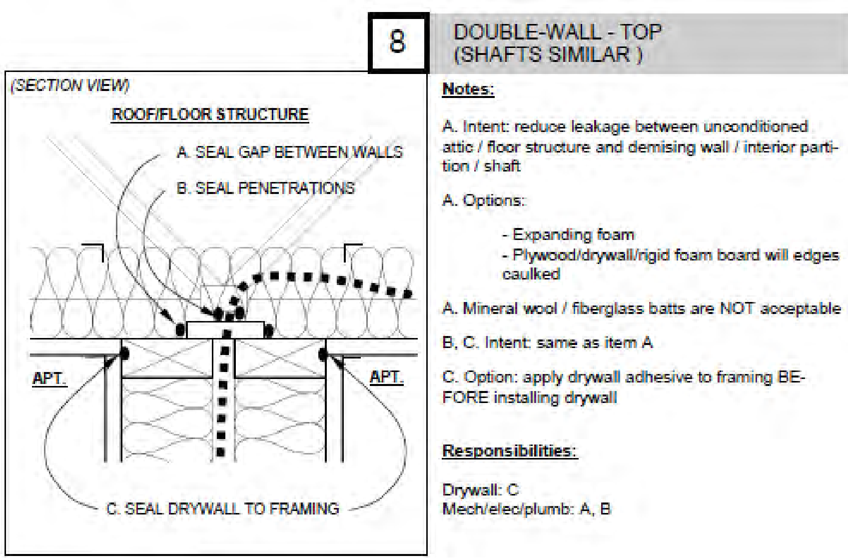


Figure 19. Air sealing detail—seal top of double-framed walls

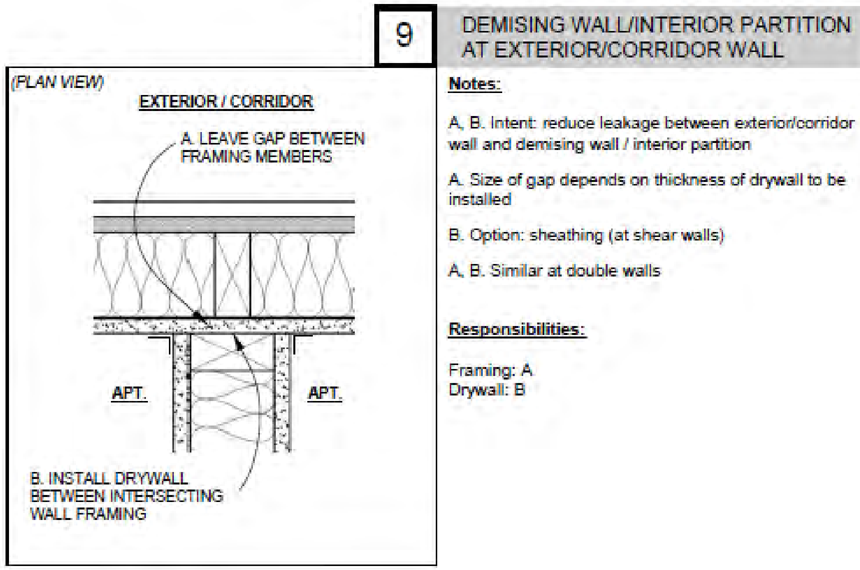


Figure 20. Air sealing detail—separate framing cavities with drywall

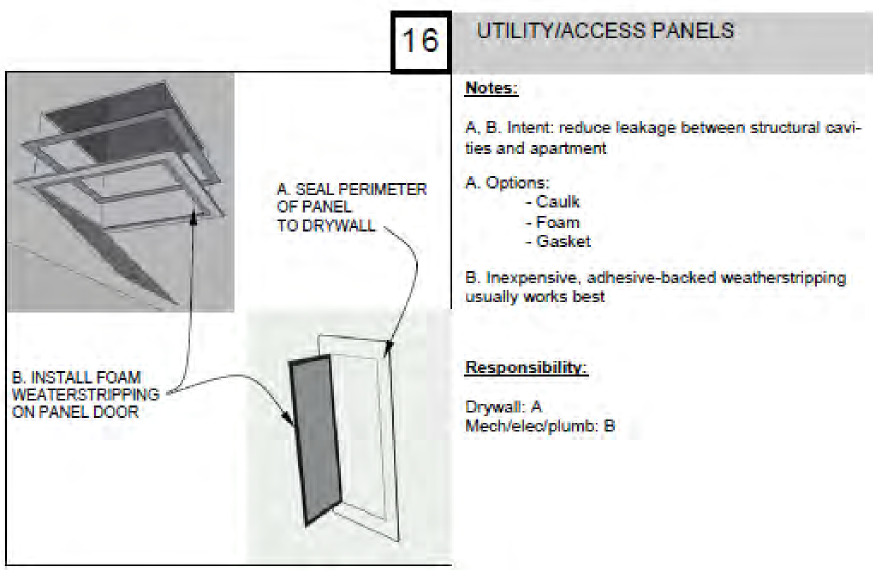


Figure 21. Air sealing detail—seal access panels

7.2 To Meet the 2012 IECC Air Leakage Requirement, Should Builders Spend Money on Air Sealing or Guarded Testing?

Based on CARB's findings, meeting the 2012 IECC air leakage requirement will require builders to put more effort toward reducing air leakage in multifamily dwellings. The responsibility for this effort could be focused in two possible directions: improving the air sealing scope of work (thereby reducing air leakage), or employing alternative testing techniques (guarded blower door testing).

Reducing air leakage between spaces in a multifamily building has several ancillary benefits:

- Increased smoke/fire control
- Increased occupant comfort, including reduced odors, drafts, and sound transmission
- Greater control and effectiveness of heating, ventilation, and air conditioning systems
- Increased overall building performance (reduced air leakage within the building helps reduce pressure differentials and therefore heat loss due to stack effect, wind, etc.).

The difference in testing results between CV/SH and HV could easily be attributed to the exclusive use of sprayed polyurethane foam insulation; obviously this reduction in air leakage comes at considerable cost. Other less expensive techniques may achieve similar results; however, these techniques (as outlined in Section 7.1) were not implemented, and the associated construction costs are not available.

From the builder's standpoint, employing alternative testing techniques may seem like a better approach. Instead of adding more tasks to the subcontractors' already substantial scope of work, the responsibility would fall to the rater to confirm the requirements after the majority of work has been completed.

In regard to construction costs, the builder would be required to weigh hard costs (improving the air sealing scope of work) against soft costs (paying the rater to perform more tests). Due to the multitude of air sealing techniques and testing costs, this comparison can only be done on a case-by-case basis.

It should be noted that in addition to the loss of ancillary benefits mentioned above, relying on guarded blower door testing is not a fail-safe strategy. Depending on assembly techniques, depressurizing all of the spaces adjacent to the apartment being tested may be unfeasible; these spaces include non-apartment spaces such as corridors and assembly areas, as well as interstitial spaces such as contiguous truss cavities.

7.3 Should the IECC Air Leakage Requirement Be Based on Enclosure Area Rather Than Volume?

While CARB believes the goals of the 2012 IECC air leakage requirement are desirable, there is concern that this requirement is geared toward single-family construction only and doesn't address the nuances of multifamily construction. Rather than quantifying air leakage based on a dwelling's volume, one might argue that air leakage should be quantified based on how much of a dwelling's enclosure area is exposed to ambient conditions. This idea has implications for both attached and detached dwellings.

In any dwelling, energy loss occurs at the exterior enclosure, and the relationship between the dwelling's enclosure and its volume is not constant. For example, a dwelling with an elongated plan will have a larger enclosure area than a square-shaped dwelling of the same floor area (Figure 22).

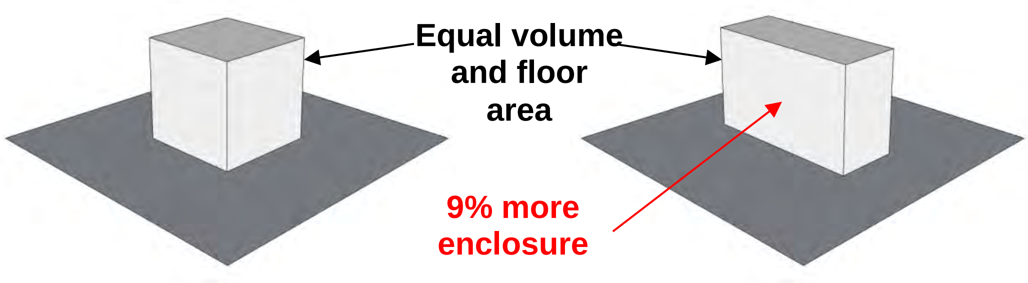


Figure 22. Comparison of dwelling volume and area

The discrepancy in exterior enclosure area is even greater when comparing attached and detached dwellings. Assuming the abstract dwellings shown earlier in Figure 1 have the same shape and volume, the exterior enclosure of the attached dwelling is a small fraction of the exterior enclosure of the detached dwelling.

CARB proposes the following exception for multifamily buildings (a building containing multiple dwelling units), which also includes an option for test sampling:

> *Exception: For low-rise multifamily buildings, dwelling units shall be tested and verified as having a leakage rate of not exceeding 0.25 cubic feet per minute (cfm) per square foot of enclosure area (all six sides of the dwelling unit) in Climate Zone 1 through 8. Testing shall be conducted with an unguarded blower door at a pressure of 0.2 inches w.g. (50 Pascal). If guarded blower door testing (a test with one or more adjacent units pressurized, which should eliminate any leakage between units) is being performed, this exception is not allowed and the standard testing requirements of Section 402.4.1.2 apply. Where required by the code official, testing shall be conducted by an approved third party. For buildings with more than 7 units, a sampling protocol is allowed by an approved third party. The sampling protocol requires the first seven units to be tested without any failures. Upon successful testing of those initial seven units, remaining units can be sampled at a rate of 1 in 7. If any sampled unit fails compliance with the maximum allowable air leakage rate, two additional units in the same sample set must be tested. If additional failures occur, all units in the sample set must be tested. In addition, all units in the next sample set must be tested for compliance before sampling of further units can be continued.*

The same requirement is being proposed for all climates for simplicity as the metric is shifting from air leakage to outside to compartmentalization. In addition, the 0.25 cfm_{50}/ft^2 of enclosure area roughly equates to 4.5–5.5 ACH_{50} for typical size apartment dwellings, which is similar to the airtightness rate currently specified by the 2012 IECC for climate zones 1–3.

8 Conclusion

Achieving an unguarded 3 ACH_{50} in multifamily dwellings is not easy.

- Reducing air leakage starts during the design development process; design teams must make decisions that allow for the air leakage requirement to be met.
- Construction teams must understand the design teams' intent while incorporating their experiences from previous successes and failures. Implementation is crucial; subcontractors will not meet their air leakage reduction goals without heightened awareness, support and oversight.
- Until design and construction teams become familiar and comfortable with the tasks required to meet the air leakage requirement, construction costs will almost certainly increase.

However, achieving 3 ACH_{50} is not impossible. With the right combination of design, investment and implementation, meeting the 2012 IECC requirement for air leakage is definitely feasible.

References

BECP (2011). *Air Leakage Guide: Meeting the Air Leakage Requirements of the 2012 IECC.* U.S. Department of Energy's Building Energy Codes. PNNL-SA-82900. Accessed December 23, 2013: http://www.energycodes.gov/sites/default/files/documents/BECP_Buidling%20Energy%20Code%20Resource%20Guide%20Air%20Leakage%20Guide_Sept2011_v00_lores.pdf.

Brennan, T.; Clarkin, M.; Nelson, G., Olson, C.; Morin, P. (2014). *Blower Door Applications Guide: Beyond Single Family Residential*. Minneapolis, MN: The Energy Conservatory. Edition 1.0. Accessed April 22, 2014: http://www.energyconservatory.com/sites/default/files/documents/blower_door_applications_guide_-_beyond_single_family_residential_ver_1-0_0.pdf.

Dentz, J.; Conlin, F. (2012). *Air Leakage Testing and Air Sealing in Existing Multifamily Units*. Advanced Residential Integrated Energy Solutions. DOE/GO-102012-3583. Accessed April 24, 2012: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/air_sealing_multifamily.pdf.

Faakye, O.; Arena, L.; Griffiths, D. (2013) *Predicting Envelope Leakage in Attached Dwellings.* Consortium for Advanced Residential Buildings. DOE/GO-102013-3939. July 2013. Accessed December 19, 2013: http://carb-swa.com/Collateral/Documents/CARB-SWA/Research/Predicting_Envelope_Leakage.pdf.

Gadgil, A.; Price, P.N.; Shehabi, A.; Chan, R. (2006). *Indoor-Outdoor Air Leakage of Apartments and Commercial Buildings*. CEC-500-2006-111. Berkeley, CA: Lawrence Berkeley National Laboratory. Accessed April 24, 2014: http://www.energy.ca.gov/2006publications/CEC-500-2006-111/CEC-500-2006-111.PDF.

IECC (2009). 2009 International Energy Conservation Code, Section 402.4 "Air Leakage." Washington, DC.: International Code Council. www.iccsafe.org/Store/Pages.

IECC (2012). 2012 International Energy Conservation Code, Section 402.4 "Air Leakage," International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages.

Lstiburek, J. (2005). "Multifamily Buildings: Controlling Stack-Driven Airflows." *ASHRAE Journal* 47, 30–38, December 2005. Accessed July 30, 2014: http://bookstore.ashrae.biz/journal/download.php?file=28274lstiburek.pdf.

Metzger, C.E.; Wilson, E.; Horowitz, S. (2012). *Addendum to the Building America House Simulation Protocols*. Golden, CO: National Renewable Energy Laboratory. DOE/GO-102012-3855. Accessed December 26, 2013: http://www.nrel.gov/docs/fy13osti/57450.pdf.

Otis, C.; Maxwell, S. (2012). *Measure Guideline: Air Sealing Attics in Multifamily Buildings*. Consortium for Advanced Residential Buildings. DOE/GO-102012-3573. Accessed April 22, 2014: http://www.carb-swa.com/Collateral/Documents/CARB-SWA/Guides/Air Sealing_Attics_Multifamily.pdf.

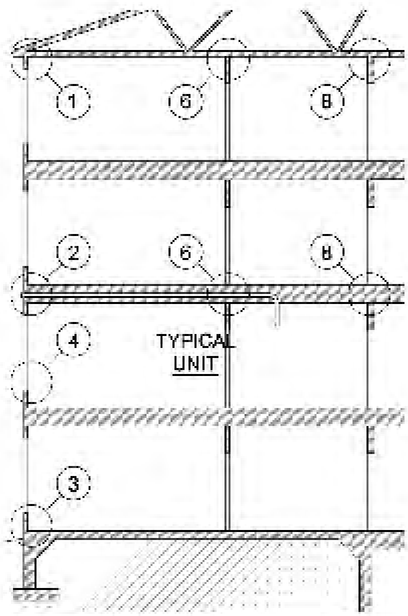
Appendix: 2012 IECC Multifamily Air Sealing Guide

2012 IECC MULTIFAMILY AIR SEALING GUIDE

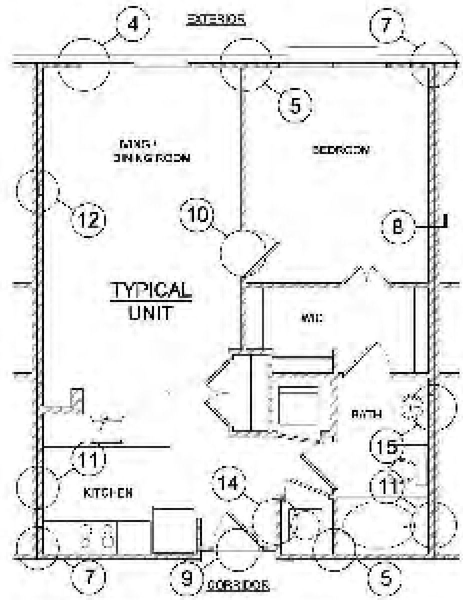
WOOD CONSTRUCTION

Steven Winter Associates, Inc. www.swinter.com

61 Washington Street, Norwalk, Connecticut 06854 — tel 203-857-0200 — fax 203-852-0741
307 7th Avenue, Suite 1701, New York, NY 10001 — tel 212-564-5800 — fax 212-741-8673
1112 16th Street NW, Suite 240, Washington, D.C. 20036 — tel 202-628-6100 — fax 202-393-5043

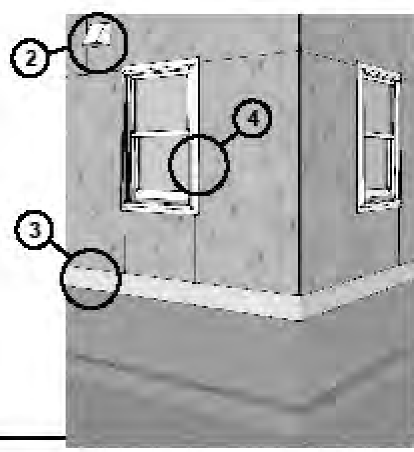


SECTION KEY
TYPICAL MULTIFAMILY BUILDING



PLAN KEY
TYPICAL UNIT PLAN

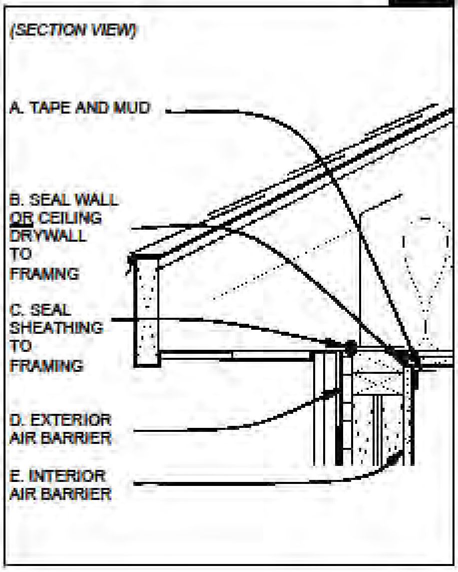
ELEVATION KEY
TYPICAL WOOD-FRAMED BUILDING



RULES OF THUMB

1. Design simple layouts (minimal corners, etc.)
2. Install wood framing with tight connections and minimize extra material
3. Do not use resilient channels on exterior walls or apartment-side of interior walls
4. Use temperature-appropriate sealant (i.e. high -temp caulk at flues, heating pipes, etc.)
5. Clean out cracks before applying sealant (i.e. compressed air, vacuum, damp cloth, etc.)
6. Assign responsibility to one trade/person for confirming completion of air sealing tasks (this guide includes suggestions for which trades should be initially responsible for each task)

1 EXTERIOR WALL - TOP



Notes:

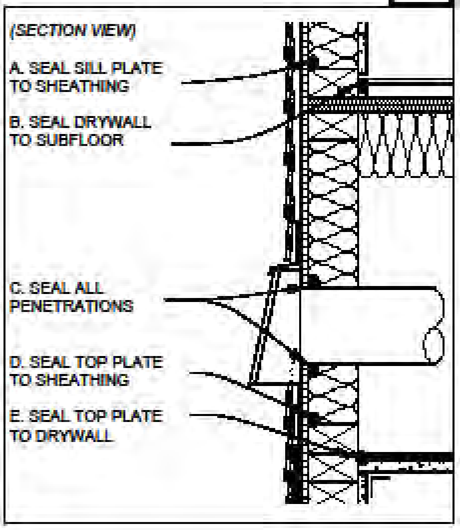
A. Typical

B, C. Elastomeric sealant

D. Options:
- Sheathing with seams sealed (i.e. ply wood or rigid foam board)
- Fluid-applied/adhesive membrane on sheathing (i.e. Grace / Henry products)

E. Drywall: typical

2 EXTERIOR WALL - MIDDLE



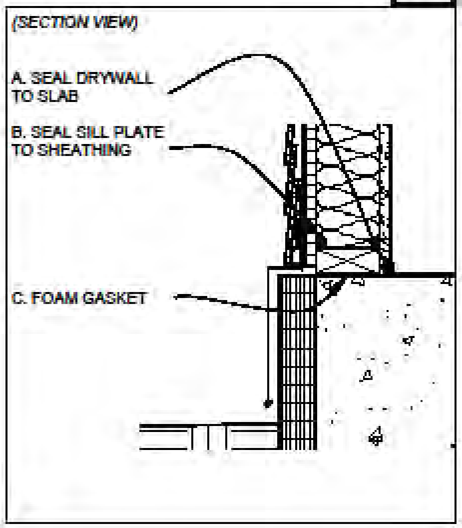
Notes:

A, C, D, E. Elastomeric sealant

B. Self-leveling subfloor (i.e. gypcrete)

C. Includes ducts, pipes, wires, etc. (high priority)

3 EXTERIOR WALL - BOTTOM (INTERIOR WALL SIMILAR)

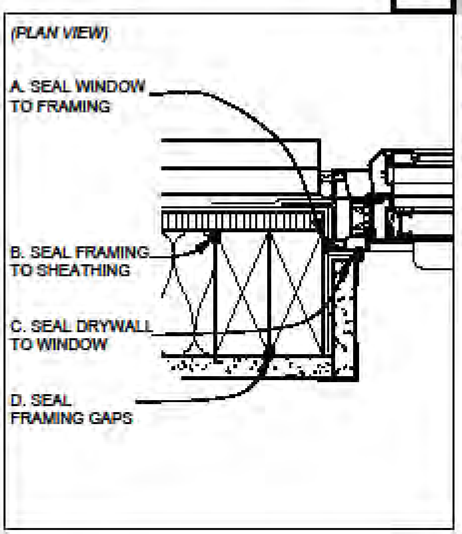


Notes:

A, B. Elastomeric sealant

C. To be installed in addition to sealant between the plate and slab

4 WINDOW JAMB (HEAD AND SILL SIMILAR)



Notes:

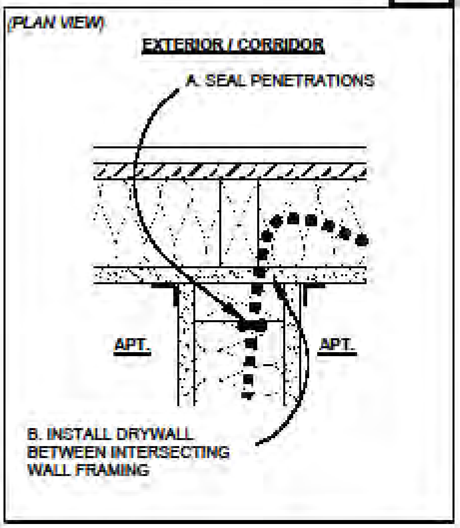
A. Low-expanding foam

B, D. Elastomeric sealant

C. Caulk

H108 (HELD) - Carl Seville

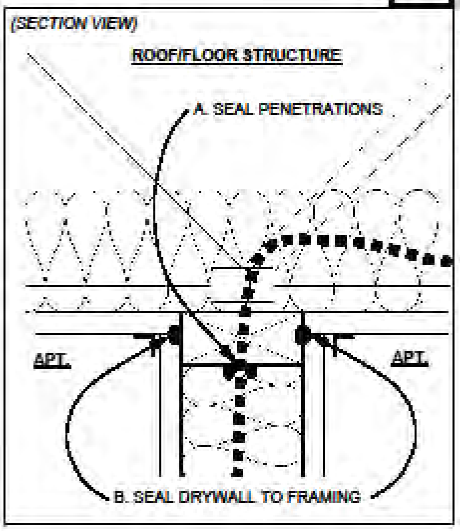
5 INTERIOR PARTITION AT EXTERIOR/ CORRIDOR WALL



Notes:

A. Fire caulk (penetrations include ducts, pipes, wires, etc.).

6 INTERIOR PARTITION - TOP

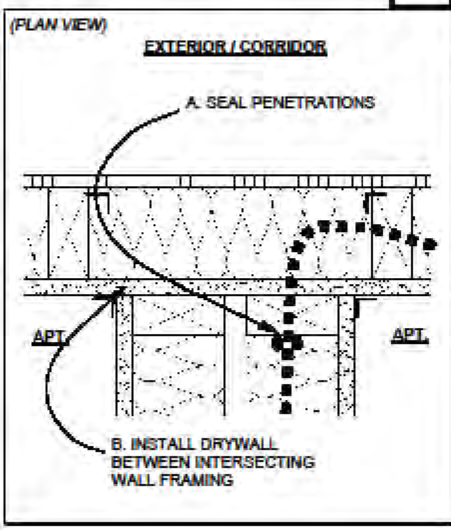


Notes:

A. Fire caulk (penetrations include ducts, pipes, wires, etc.).

B. Elastomeric sealant (before interior partition dry-wall is installed)

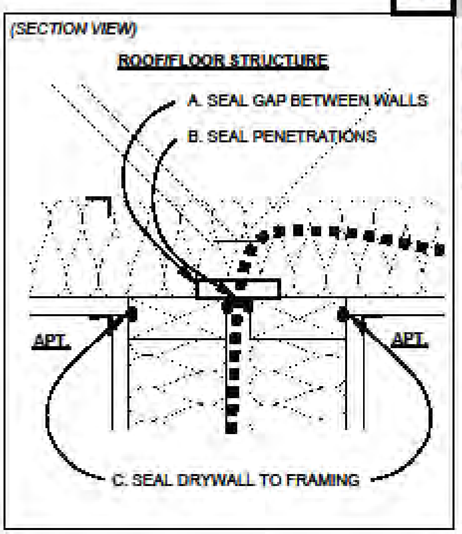
7 DOUBLE-FRAMED DEMISING WALL AT EXTERIOR/CORRIDOR WALL



Notes:

A. Fire caulk (penetrations include ducts, pipes, wires, etc.).

8 DOUBLE-FRAMED DEMISING WALL - TOP (SHAFTS SIMILAR)



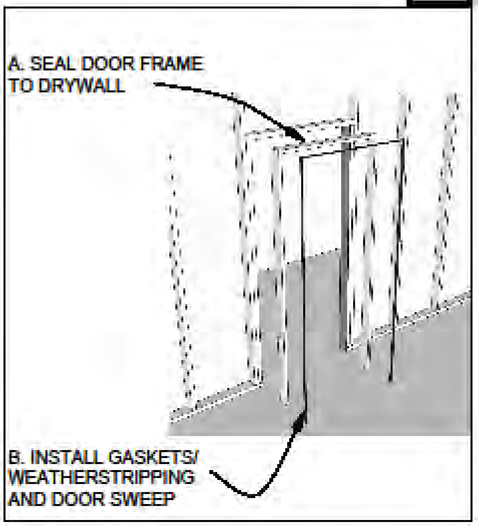
Notes:

A. Solid blocking and elastomeric sealant

B. Fire caulk (penetrations include ducts, pipes, wires, etc.)

C. Elastomeric sealant (before demising wall drywall is installed)

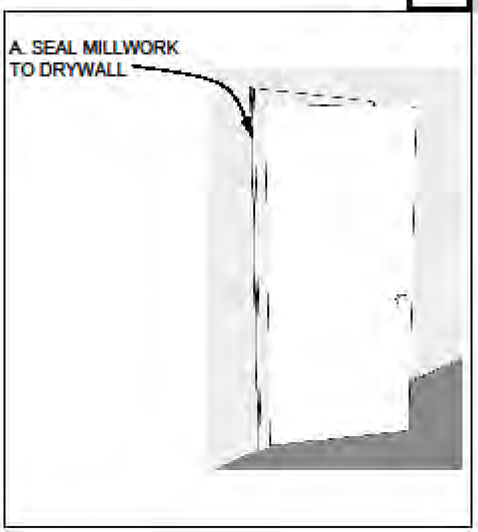
9 CORRIDOR/EXTERIOR DOOR



Notes:

A. Elastomeric sealant (before trim is installed)

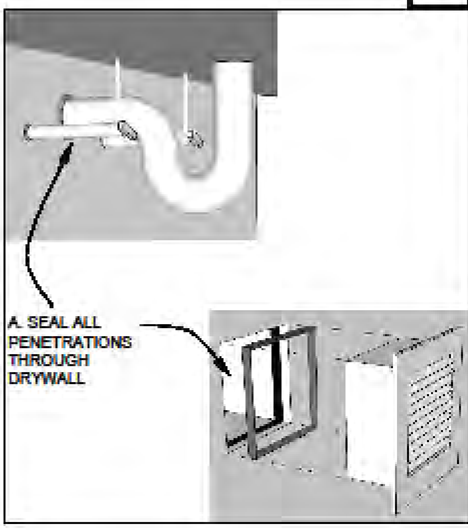
10 MILLWORK (TRIM)



Notes:

A. Includes all windows, doors, etc.

11 PLUMBING PENETRATIONS



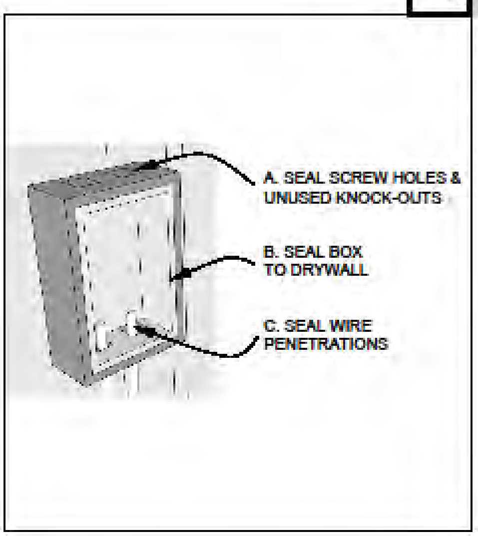
Notes:

A. Seal all penetrations BEFORE installing cabinetry and/or escutcheons

A. Typical plumbing penetrations include:
- Sink faucet supplies & drain
- Toilet supply
- Showerhead stub-out
- Heating supply/return
- Gas supply
- Sprinklers

NOT REQUIRED AT INTERIOR PARTITIONS

12 ELECTRICAL BOXES



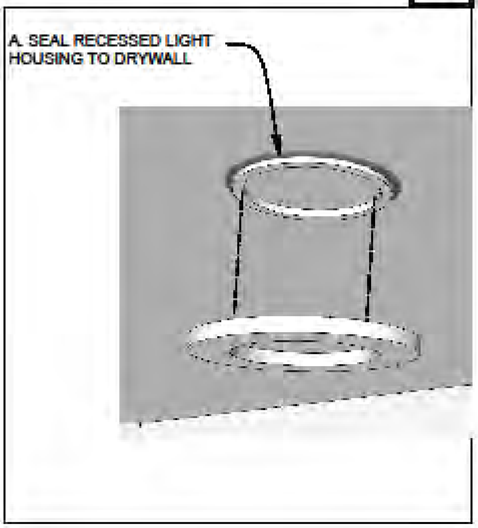
Notes:

A, B, C. Includes boxes in floors and ceilings

A, C. Mastic is preferable to caulk or foam

NOT REQUIRED AT INTERIOR PARTITIONS

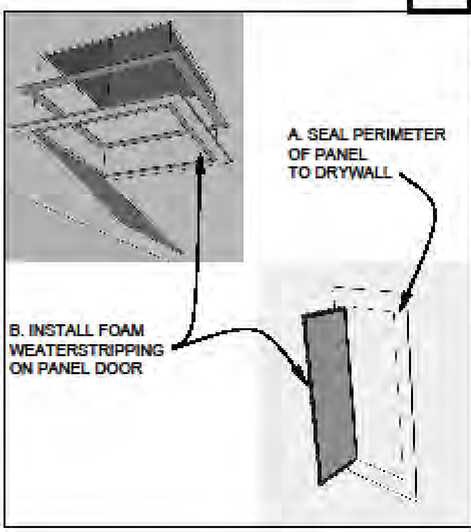
13 RECESSED LIGHTING



Notes:

A. Use insulation contact air-tight cans (ICAT)

14 UTILITY/ACCESS PANELS



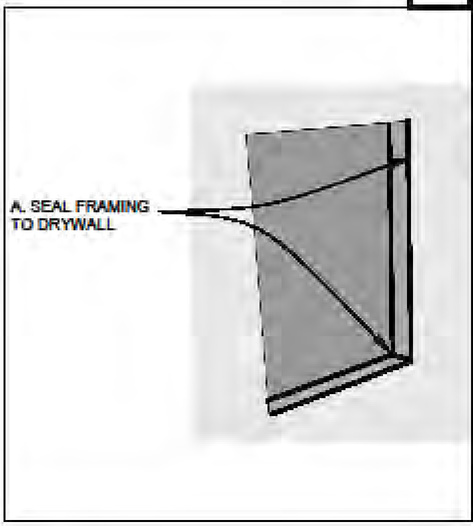
Notes:

A. Caulk

B. Inexpensive, adhesive-backed weatherstripping usually works best

"""INSTALL UTILITY/ACCESS PANELS IN INTERIOR PARTITIONS ONLY—DO NOT INSTALL IN WALL/CEILING ASSEMBLIES SHARED WITH ADJACENT APARTMENTS OR COMMON AREAS"""

15 RECESSED COMPONENTS



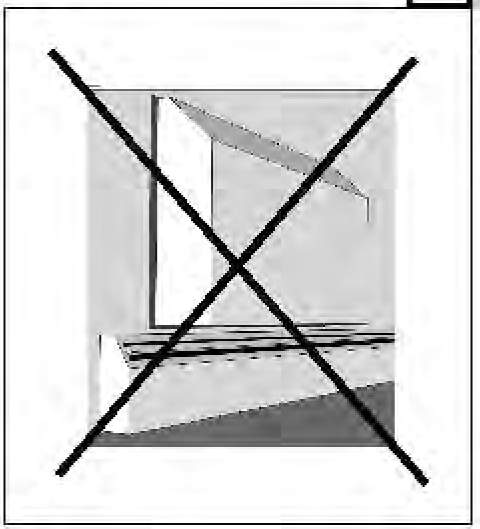
Notes:

A. Seal all cracks/seams BEFORE recessed component is installed

A. Typical recessed components include:
- Medicine cabinet

NOT REQUIRED AT INTERIOR PARTITIONS

16 PACKAGED HEATING/COOLING EQUIPMENT (PTACs)



Notes:

DO NOT USE PTACs!

H108 (HELD) - Carl Seville

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102014-4507 ▪ October 2014

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.