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

BUILDING TECHNOLOGIES PROGRAM

Commercially Viable Energy Efficiency Solution Package

Mixed Humid Climate, Current Best Practice

M. DelBianco, D. Mallay, J. Wiehagen, A. Wood

December 2010

Building America® U.S. Department of Energy

Prepared by the NAHB Research Center
For the U.S. Department of Energy Building Technologies Program

Task Order Agreement KNDJ-0-40335-01 / Deliverable Task 11.2

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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

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
online ordering: http://www.ntis.gov/ordering.htm

♻ Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Commercially Viable Energy Efficiency Solution Package
Mixed-Humid Climate, Current Best Practice

Prepared for:

Building America
Building Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by:

NAHB Research Center
400 Prince George's Blvd
Upper Marlboro, MD 20774

December 2010

Principal Investigator:

Thomas Kenney
Phone: 301-430-6246
Fax: 301-430-3180
Email: tkenney@nahbrc.com

Project Manager:

Amber Wood
Phone: 301-430-6309
Fax: 301-430-3180
Email: awood@nahbrc.com

Energy Analyst (modeler):

Joseph Wiehagen & Marie DelBianco

[This page left blank]

Contents

Figures

Tables

Introduction

Under the Building America Program, production builder Winchester Homes Inc. (WHI)'s Camberley Homes subsidiary teamed with the NAHB Research Center through the NAHB Research Center Industry Partnership to design a new construction test home that uses 30% less energy than a comparable house that meets the 2009 International Energy Conservation Code. With technical guidance from the NAHB Research Center, the builder selected technologies, design elements, and construction methods that minimize cost while achieving 30% energy savings. Ultimately this design is a commercially viable energy efficiency solution package for the mixed-humid climate addressing both energy efficiency and costs.

House Description

The three-story, Victorian-style single family detached home (depicted in Appendix A) is under construction in WHI's Poplar Run community in the mixed-humid climate of Montgomery County in suburban Washington, DC. This first house constructed to meet the energy savings goals will serve as the neighborhood's model home. As a model, numerous options were selected that will affect overall energy usage including a finished basement with wet bar, full bath, and media room, an expanded morning room, and a finished attic suite. Overall, the home has 3,336 s.f. of above-grade living area and 1,386 s.f. of conditioned space below grade (the base model, without the optional additional square footage, contains 2724 s.f. of finished living area). Once the model home is complete and verified, another 100 homes using the same cost-effective energy efficiency solution package are planned.

Tables 1 and 2 summarize typical regional construction and the principal energy efficiency solutions for the new construction test house (NCTH) that were selected to most cost effectively meet the energy savings goal while, at the same time, meeting builder and other project constraints.

Table 1. Commercially Viable Energy Efficiency Envelope Solution Package

Builder	Foundation	Walls		Windows	Roof		Airtightness
		Frame	*Insulation*	*U/SHGC*	*Heel Hgt.*	*Insulation*	
Typical Regional	8" Concrete, Inground	2x4	R-13	0.34/0.30	4 - 3/4"	R-38	7ACH$_{50}$*
NCTH		2x6	R-23	0.31/0.28	14"	R-49	1.3ACH$_{50}$

** per 2009 IECC*

Table 2. Commercially Viable Energy Efficiency Equipment Solution Package

Builder	Heat/Cool				Ducts		Water Heater		Lighting
	# Systems	*# Zones*	*AFUE/SEER*	*Location*	*Location*	*Leakage*	*EF*	*Size*	
Typical Regional	2	2	80% / 13	Bsmt., Attic	Attic, Int.	8-10%	0.61	60 gal.	50% HE*
NCTH	1	2	92.5% / 15	Basement	Interior	<6%	>0.80	Tankless	80% HE

** per 2009 IECC*

Typical Regional Practice

Many of the nation's leading production builders are actively building new home communities in the Washington, DC, area. The typical production home is two stories over a basement foundation and built to meet the prescriptive requirements of Chapter 11 of the 2006/2009 International Residential Code (IRC). Typical standard practice, as outlined in Table 1 and Table 2, includes 2x4" construction with R-13 fiberglass batt insulation, standard-heel roof trusses spaced 24" o.c., R-38 blown ceiling insulation, and standard efficiency HVAC and water heating equipment. Larger houses in the area often employ two space conditioning zones, with each zone served by its own set of equipment and second floor ducts and equipment located in the attic.

Energy Efficiency Solution Package

Overview

A set of high performance construction features was developed for a WHI new home design that is under construction in the mixed-humid climate (climate zone 4). The package of energy efficiency solutions results in predicted energy savings of 30% over a theoretical 2010 Building America Benchmark home (B10 Benchmark) that meets the minimum requirements of the 2009 International Energy Conservation Code.

The final energy efficiency solution package represents months of development by key stakeholders including NAHB Research Center and builder staff, trade contractor professionals, manufacturers, and product suppliers. This process, performed in cooperation with and with support from the Building America program, involved technical input, energy modeling, and optimization by NAHB Research Center staff and input on economic and other practical factors by team members. A detailed summary of the energy efficiency solution package, outlined in Table 1 and Table 2 above, follows.

Thermal Envelope. The thermal envelope was completely redesigned from standard specifications and upgraded to include:

- Poured concrete foundation with interior framed walls insulated to R-13 or R-19, depending on location
- 2x6" framing at 24" o.c. with double top plates to accommodate complex loads
- Wall panels optimized to eliminate unnecessary blocking, jack studs, and cripples
- First floor headers relocated to the band joist; 1st floor headers and jack studs eliminated
- R-23 dense-pack fiberglass insulation
- Raised-heel attic trusses to accommodate R-49 attic insulation extending over wall top plates

Windows. The builder's standard window specifications were upgraded to a slightly better rating (low-e, vinyl double hung windows, U-0.31, SHGC 0.29) but no changes were made to the fenestration area. (Factoring conditioned space below grade, fenestration is 12% of conditioned floor area; however, glass area is nearly 18% of above grade exterior wall surface area.)

Very Low Infiltration. To achieve very low infiltration rates (1.3 ACH50) given the building's complex thermal boundaries (see Appendix B for details), it was essential to carefully identify critical areas for air sealing and incorporate those details into the plans. Considerable time was spent identifying potential leakage areas and determining the methods and materials for sealing.

Many options were considered; the team ultimately opted for a new product that combines a water soluble elastomeric spray sealant at framing junctions and blown fiberglass with a bio-based binder in the wall cavities in tandem with other best practices as described below. Other details were included as well such as electrical trade contractors installing gasketed receptacle boxes at all exterior wall penetrations to reduce air infiltration at outlets.

To reduce framing air losses to the ceiling and attic, interior-exterior wall junctures were reduced or eliminated by offsetting the interior perpendicular walls from the exterior walls by a 1" space to accommodate the uncut wallboard finish. Metal plates secure the interior wall to the exterior wall. For the finished attic space, separate walls, delineated by the attic truss webs, were specified. An air barrier of taped rigid sheathing will be applied on the attic side of the walls and adhesive will be applied where top and bottom plates abut the attic ceiling and floor. To prevent unintentional airflow, continuous, full-depth blocking will be installed perpendicular to the attic truss bottom chords. Similar blocking and air sealing details are specified for the stairwell, the fireplace cantilever, and the HVAC chase. To minimize framing lumber and air sealing complexity, attic room dormers were excluded from the design for gable end windows.

HVAC & Duct Efficiency. The HVAC system was significantly redesigned from builder standard practice to bring ductwork into conditioned space, reduce investment in space conditioning equipment, add ventilation, and reduce energy loss in distribution. Instead of using a complete set of space conditioning equipment to serve each of two zones, the redesigned system will use a single set of variable capacity high efficiency furnace and air conditioning equipment to serve both zones in the house. Similar to standard practice, each zone will have electronic dampers and a zone controller.

The I-joist floor system was redesigned to accommodate a centrally-located, 2x4' duct chase adjacent to the interior bearing wall that will serve as the primary conduit for ducts. Considerable planning and three-dimensional modeling of the system went into this change. Along with integrating the HVAC system into conditioned space to minimize energy losses from the duct system and improve flow dynamics, ducts were sized with Manual D and will be carefully sealed during installation to reduce leakage. A multifaceted approach to duct sizing was taken to address the demands of pressure loss, noise, installation simplicity, and effectiveness.

Lighting. High efficiency lighting was increased to 80% of total lighting by specifying dimmable fluorescents in recessed fixtures and fluorescent lamps in other standard fixtures. Recessed lighting was upgraded to sealed units to reduce air leakage (however, the incremental cost was attributed to the lighting budget).

Ventilation. Controlled mechanical ventilation is required in this tight house for moisture control and to ensure good indoor air quality. For fresh air distribution and filtration, a supply-only, central-fan-integrated design in which outdoor air is ducted to the return side of the central HVAC system was chosen for its performance and cost characteristics. This system, which is capable of meeting ASRAE 62.2 ventilation levels and which conditions the fresh air supply when the HVAC system is operational, includes a motorized damper and electronic control to optimize ventilation levels.

Locating the fresh air inlet was an important design consideration. Code dictates distance from the outlet of any appliance, plumbing, or exhaust vent, and avoidance of driveways, sidewalks, roofs, and any area where flammable vapors may be present. Further, equipment manufacturers specify minimum distance between the fresh air supply vent and the air handler in order to ensure adequate mixing—in this project, the manufacturer required at least 6 ft. Lastly, during installation, the inlet duct will be properly sized, sealed, and insulated to prevent condensation.

Water Heating. An 82% efficient, gas-fired demand water heater with a PEX, trunk-and-branch piping system was specified. Due to the thorough attention to air sealing in the design and construction of this house, a direct vent model was selected to prevent the use of indoor air for combustion and the potential for backdrafting byproducts of combustion into the house.

Estimated Cost of Energy Efficiency Solutions

Table 3 summarizes the options selected and the cost of each. Comparing the third and last columns underscores the discrepancy between BEopt's (version 1.0.1) cost library and realistic, regional costs that were discovered by the NAHB Research Center (see Supporting Research section for a discussion). Therefore, the builder's estimated incremental costs (above the standard practice) were input into the BEopt software to provide results with which the researchers had a high level of confidence. For the package of energy efficiency solutions, the estimated incremental cost to the builder is $9,763. Because accurate costs are essential to providing meaningful BEopt results, costs will continue to be refined throughout the project.

Measure Interactions

Components of a house work together as a system; therefore, when changing the design or specification of one aspect of a new home, there are resultant changes in other aspects. For example, improving the thermal envelope lowers heating and cooling loads and, hence, smaller capacity mechanical equipment is needed. Several notable interactions between systems of the home are summarized below.

Switching to 2x6 wall construction to improve thermal performance required a significant structural redesign. Yet, this structural redesign was more involved than would be typical of merely switching from 2x4 to 2x6 framing, because cutting-edge, advanced framing details (based on past NAHB Research Center Building America research)—such as headers integrated into the band joist—were incorporated. Further, the redesign created opportunities for improving air sealing and insulation in areas that would have previously been left uninsulated (e.g., at off-angle intersections of wall panels). Lastly, the advanced framing details facilitated moving ducts into conditioned space, but required extra work from the fabricator to customize the design.

Redesigning the ducts to minimize return air losses and bring supply ducts into conditioned space resulted in a framing system design that accommodates piping, wiring, and ducts in a centrally-located chase. While frequently at odds over space to run their respective conduits, the mechanical trades can now share space in a framing system that was designed to integrate the systems. Future reports will highlight this issue.

Table 3. Estimated Costs of Energy Efficiency Options

Group Name	Category Name	BEopt's Incremental Capital Cost	Current Option Name	Ref Option Name	Builder's Incremental Capital Cost
Building	Orientation	$0	Southwest	Same as Prototype	
	Neighbors	$0	at 20ft	None	
Operation	Heating Set Point	$0	71 F		
	Cooling Set Point	$0	76 F		
	Misc Electric Loads	$0	1	4599 kWh	
	Misc Gas Loads	$0	1	11 therms	
	Misc Hot Water Load	$0	Benchmark	70.0 gal/day	
	Natural Ventilation	$0	Benchmark		
Walls	Wood Stud[F]	$2,047	R23 blown 2x6 24"	R13 batts 2x4 16"o.c.	$3,088
	Exterior Finish	$0	Gray Vinyl Siding	Abs=0.60 Emiss=0.90	
	Interzonal Walls	$322	R-23 blown 2x6 24"	R13 batts 2x4 16"o.c.	
Ceilings/Roofs	Unfinished Attic	$97	Ceiling R49 FG Blown	R38 Ceiling SLA=0.00333	$100
	Roofing Material	$0	Asphalt Shgls. Med.	Abs=0.75 Emiss=0.90	
	Radiant Barrier	$0	None		
Foundation/Fl	Finished Basement[C]	$0	R-13 2x4 at 24"	8-ft R10 Rigid	
	Exposed Floor	$0	20% Exposed	None	
Thermal Mass	Floor Mass	$0	Wood Surface		
	Ext Wall Mass	$0	1/2" Drywall		
	Partition Wall Mass	$0	1/2" Drywall		
	Ceiling Mass	$0	1/2" Ceiling Drywall		
Windows & Sh	Window Areas	$0	Camberley A; 554 sf	416 sf; 25%/side	
	Window Type	$0	U-.31 SHGC-.28	U-0.35 SHGC 0.35	
	Interior Shading	$0	Benchmark	Benchmark (0.70)	
	Eaves	$0	1 ft	2 ft	
Airflow	Infiltration	$1,918	NGBS 1.3ACH50; elastomeric seal[A]	SLA=0.00036	$1,910
	Mechanical Vent.[B]	$0	Supply 100%: A-62.2	Exhaust 100% 84 WH cfm	$600
Major Applianc	Refrigerator	$200	EnergyStar S-by-S	Standard (669 kWh)	$200
	Cooking Range	$0	Gas Conventional	Gas (33 therms)	
	Dishwasher	$0	EnergyStar	Standard (204 kWh)	
	Clothes Washer	$270	EnergyStar	Standard (90 kWh)	$270
	Clothes Dryer	$0	Gas	Gas (46 therms 100 kWh)	
Lighting	Lighting	($35)	100% Fluorescent/CFL	Liv 2893 Grg 0 Ext 685 kWh	$126
Space Conditio	Air Conditioner	($261)	SEER 15	SEER 13 (11.09 EER)	$1,014
	Furnace[E]	$604	Gas AFUE 92.5%	Gas AFUE 78%	($859)
	Ducts[D]	$0	In Finished Space	Uninsulated ducts	$2,414
	Ceiling Fans	$0	Benchmark		
Water Heating	Water Heater	$900	Gas Tankless Cond.	Gas 50 gal 0.57 EF	$900
	Distribution	$0	Trunk&Branch PEX	R-0 TrunkBranch Copper	
	Solar DHW	$0	None		
	SDHW Azimuth	$0	Back Roof	None	
	SDHW Tilt	$0	Roof Pitch	None	
Power Generat	PV System	$0	0 kW		
	PV Azimuth	$0	Back Roof	None	
	PV Tilt	$0	Roof Pitch	None	
HVAC Sizing	Cooling Capacity	$0	3.5 tons	3.0 tons	
	Heating Capacity	$0	60kBtu/hr	70 kBtu/hr	
Total Incremental Capital Cost		$6,062			$9,763

The streamlined duct system that reduces distribution energy losses and air leakage and allows air to be distributed freely around the home eliminated the need for separate HVAC systems to serve each heating and cooling zone. By delivering the air more efficiently, and specifying variable capacity heating and cooling equipment, the entire house can efficiently be served by a single furnace and a single air conditioning unit.

Redesigning the structural framing system and adding air sealing protocols will tighten the building shell by a factor of five. Hence, for moisture control and indoor air quality, mechanical ventilation was added to the house. Supply-only ventilation without heat recovery was selected, with the result of increasing HVAC loads slightly.

Technical Pathway

Technical pathways to achieve energy savings levels of 30% compared to the B10 Benchmark design were evaluated for the house and for the builder's standard practice in general. To determine possible technologies and techniques to employ in the final design, the team considered numerous interacting objectives, including:

- Minimize increased construction costs
- Minimize change from builder standard practice
- Select materials that are readily available
- Minimize change from standard trade contractor practice
- Choose construction methods that are familiar to designers, engineers, and the builder
- Manage risk
- Maximize energy performance
- Provide reasonable value to the consumer

Identifying and balancing interconnected objectives is paramount to Building America research. In addition, understanding those relationships is essential for making tradeoffs and selecting solution packages that can be successfully implemented in practice.

Inputs to Building Energy Optimization (BEopt) Software

Energy Features. Based on the combined objectives of the team, a limited number of energy features which were most likely to be implemented were selected for analysis. Beyond that, several features (such as solar water heating) were added to demonstrate the impact of further steps. Several energy features were purposefully excluded from the analysis due to builder concerns with constructability, warranty, or long term performance issues, including:

- Passive solar design: Development constraints limit orientation flexibility, therefore worst-case cardinal orientation (front of the house facing southwest) was assumed.
- Wall systems other than light-frame (i.e., SIPs and ICFs)
- Ground source heat pumps
- Solar photovoltaic systems

Other features were eliminated by Research Center staff based on experience. For example, a maximum air conditioner efficiency of 16 SEER was specified because of the lack of field performance data for higher SEER air-source units and high builder costs for units above 16 SEER.

<u>Costs</u>. Cost inputs to the BEopt software, for the features selected in the final energy solution package, are summarized in the last column of Table 3. Costs for other measures, that were not ultimately selected, were also input into the software. Costs represent the builder's estimated incremental expense above standard practice and the price to the homeowner (including builder overhead and profit). This cost structure was chosen, in part, due to the influence that consumer cost has on builders' decisions. In addition, it is consistent with BEopt software results, which report energy savings to the homeowner. Cost inputs were substantially modified from the BEopt cost library, as a result of careful research regarding regional and builder-specific cost. A more in-depth discussion of the research that went into developing the cost library for this project can be found in the Supporting Research section.

Simulation Output

Through optimization, BEopt produces a set of options that provide the highest energy savings for the lowest investment costs, within the limits of the software and cost data. Figure 1 graphically depicts the simulation results.

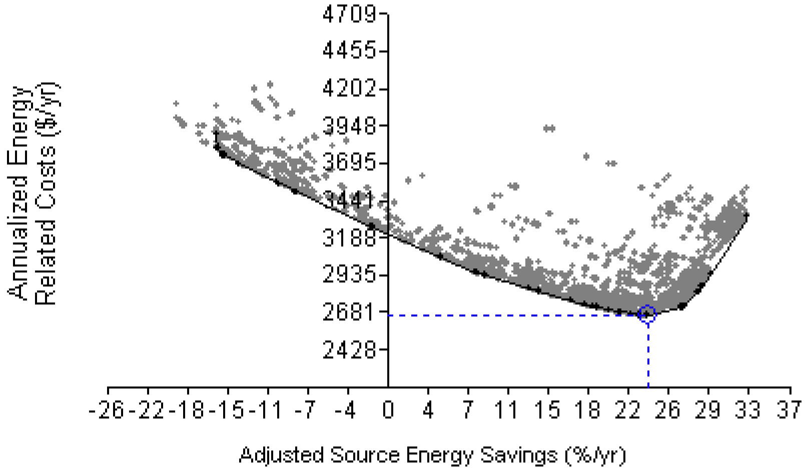


Figure 1. BEopt simulation results

The "swoosh" shape of the graph indicates that the minimum annualized energy cost occurs at source energy savings of approximately 24% (indicted by blue dotted lines). Before reaching the minimum cost point, investment in energy savings measures decreases annualized energy costs (mortgage plus utilities) at a roughly linear rate. Just beyond the minimum (after about 27% source energy savings), additional energy savings are attainable, but the investment needed to attain incremental efficiency gains rises sharply. For example, meeting the project goals of 30% energy savings requires an approximately 10% higher annualized energy cost than would reaching 27% savings. The results indicate that, for this home design in the Washington, DC, area, the maximum practical energy savings for production builders is near the 30% level. Attaining higher energy savings requires a better understanding and experience with new technologies, construction methods, and the benefits of efficiency investments.

Energy Simulation Results

Although the energy efficiency solution package is anticipated to reduce the home's energy consumption by nearly 30% over the B10 Benchmark, the as-built design (which will serve as a model home and, as such, includes nearly 2,000 s.f. of optional conditioned space) is subject to a size penalty that reduces overall projected savings. Because of the additional conditioned space, the Building America program administers a penalty (which is manifested in a source energy reduction for the B10 Benchmark design). Figure 2 shows source energy use for the B10 Benchmark and the final house design. The size penalty reduces theoretical source energy savings (SES) by about 7% (from 29% to 22% SES).

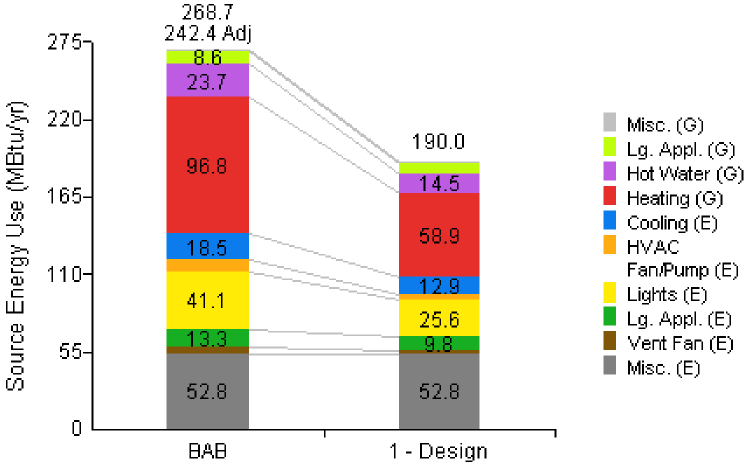


Figure 2. Source energy savings for energy efficient design compared to the B10 Benchmark
(Adjusted source energy use includes a penalty for the energy efficient design's additional square footage.)

Cost savings, which are not subject to a size penalty, are estimated to be about $1,100 per year. Components of the savings are depicted in Figure 3.

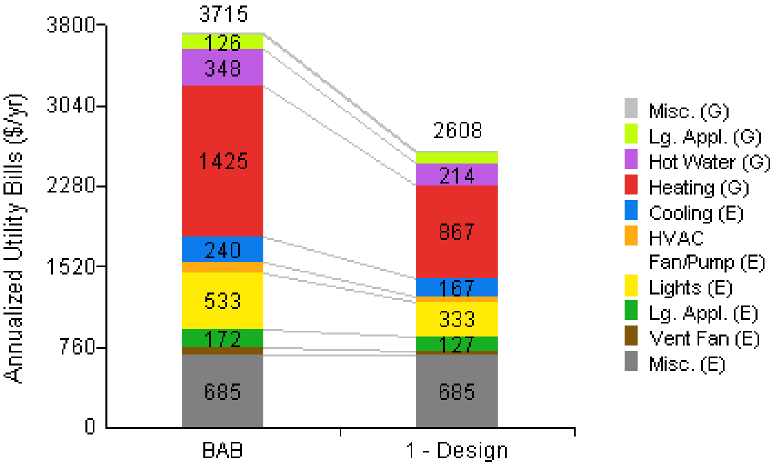


Figure 3. Annualized utility bill comparison for B10 Benchmark and energy efficient design

For a house having the same energy efficiency solution package but that does not include the 700 s.f. above-grade finished attic space nor the 1,300 s.f. finished basement, a 30% source energy savings (with a 1% size penalty) is predicted. Results are shown in Figure 4 and Figure 5.

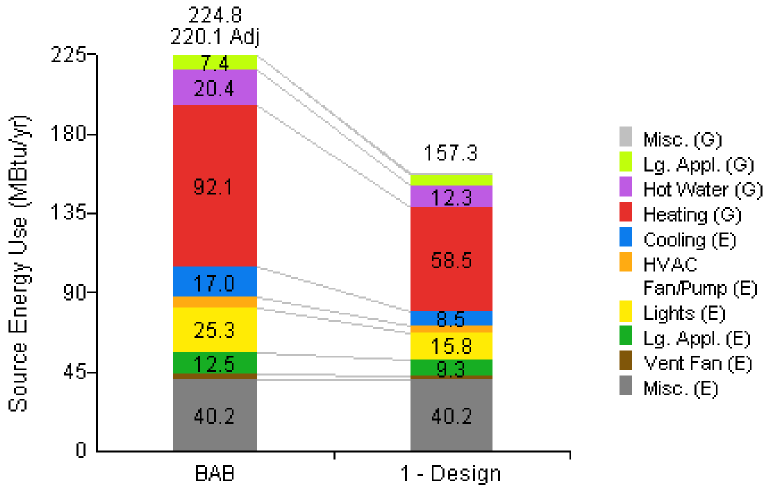


Figure 4. Source energy use for B10 Benchmark and Energy Efficient Design
(for house without 3rd floor bedroom and finished attic)

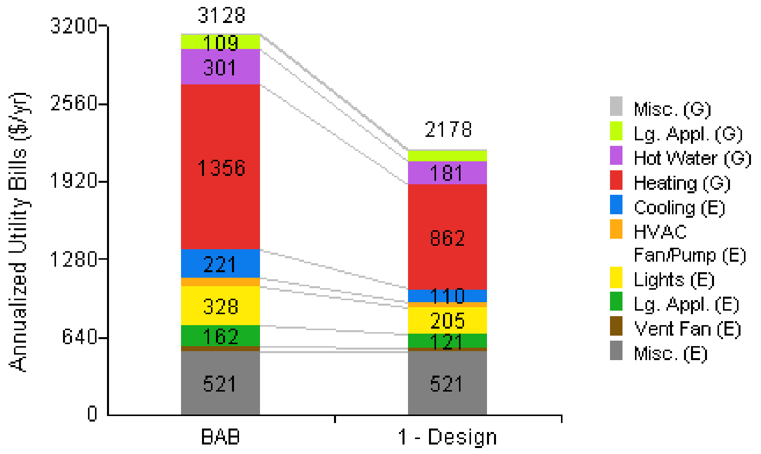


Figure 5. Annual utility bills
(for house without above-grade finished space)

Supporting Research

Summary of Modeling Issues

A number of issues affecting the modeling results were encountered during the project.

Costs

One major issue was obtaining accurate cost estimates for each of the individual energy features. After review of the BEopt library of material and system costs, life expectancy, and other performance factors, modifications were made as needed. Because the simulation program optimizes annualized costs, the analysis is extremely sensitive to costs and life expectancy.

Costs used in the analysis came from a combination of NREL's (or R.S. Means 2009) databases and costs compiled by the Research Center in 2008, some of which were recently verified with big box retailers and builders. Several cost sources were consulted to produce the most accurate and consistent cost library possible. Research Center staff added options to the library to better represent the current energy features available to the builder and substantially modified the cost library to accurately represent residential building costs based on experience, research, and direct inquiry with manufacturers, fabricators, and the builder.

Infiltration

Because the home was a new design that had not yet been constructed, determining a realistic building infiltration value for the modeling—and an incremental cost to assign to the air sealing measures—was challenging. The house will include an elastomeric air sealant sprayed at all framing member junctions that, based on experience and performance testing in other houses, is anticipated to cut air infiltration to 1.3 ACH50 from the builder standard of about 7 ACH50.

Economic Analysis

Because the home builder is making the capital investment, but the homeowner is reaping the rewards of that investment, a conventional net present value analysis is not always a worthwhile decision making tool for builders. Therefore, throughout the process of optimization, NAHB Research Center made numerous trial runs to identify how the BEopt software handled some calculations and, thus, how to effectively input cost and life span so that the results would be more meaningful to the builder. The introduction of BEopt versions 1.0.0 and 1.0.1, in which output is reported in incremental capital cost, simplified and significantly contributes to this analysis.

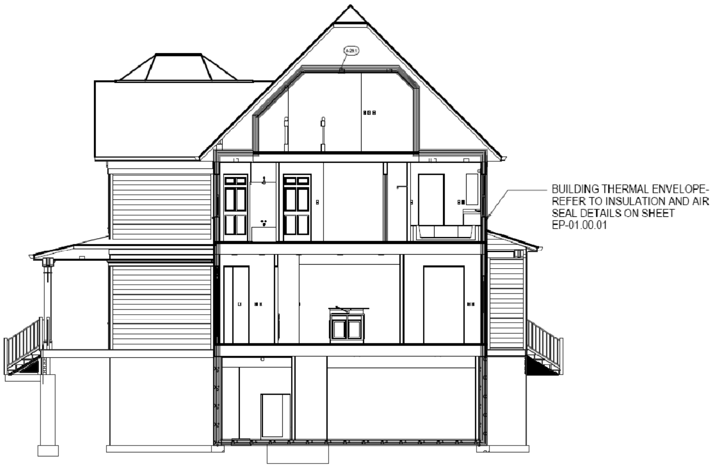
Appendix A: House Elevation

Winchester Homes Inc. (WHI)'s Camberley Homes
Poplar Run Community, Silver Spring, MD
Victorian Model

Appendix B: Complexity of the Home's Thermal Boundaries

Winchester Homes Inc. (WHI)'s Camberley Homes
Poplar Run Subdivision, Poplar Run Community, Silver Spring, MD
Victorian Model

Thermal Boundaries on house plans

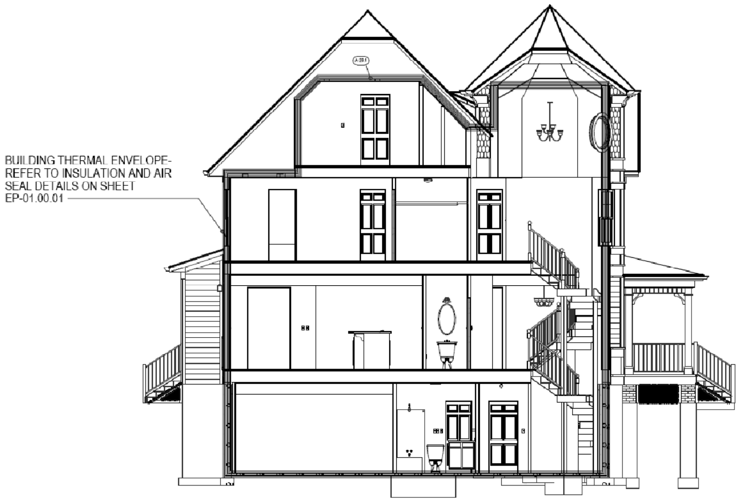


THERMAL ENVELOPE

BUILDING SECTION A-A SCALE: 1/8" = 1'-0"

THERMAL ENVELOPE

BUILDING SECTION B-B SCALE: 1/8" = 1'-0"



THERMAL ENVELOPE

BUILDING SECTION C-C SCALE: 1/8" = 1'-0"

EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov/informationcenter

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

NREL KNDJ-0-40335-01 ▪ December 2010

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