Best Practice Upgrades for Energy Efficient New Homes

David Meisegeier, ICF Consulting
Glenn Chinery, EPA Climate Protection Division

ABSTRACT

The EPA's ENERGY STAR® Homes program is a national voluntary program promoting the construction of new homes that are 30% more efficient than the Model Energy Code (for the HVAC and DHW end-uses only) (CABO 1995). Accordingly, with the Home Energy Rating System (HERS) scoring system, ENERGY STAR Homes must achieve at least a HERS score of 86 (HERS Council 1996). This performance-based compliance requirement enables builders to be creative in the specific energy efficiency features that they design and build in their new homes. However, builders often want to know what the minimum energy efficiency features of an ENERGY STAR Home would likely be - before they join the program. To solve this problem, EPA developed the Builder Option Packages (BOPs). BOPs are currently used as marketing tools to communicate the typical energy efficiency features of ENERGY STAR Homes in each of five climate regions of the U.S. This paper explains the technical methodology used to develop the BOPs and the HERS scores obtained for the various configurations analyzed. Each climate specific BOP is based on analyses of multiple house designs, sizes, foundation types, amount of glazing and its distribution at different orientations, and local climatic variations. Through these analyses, "worst case" and "best practice" case BOPs were identified for each region. The worst case BOPs ensure at least a score of HERS 86 anywhere in the climate region. The best case BOPS show how good design (i.e., optimized foundation type, window area, and window distribution) can improve the energy efficiency of a home.

Introduction

Energy efficiency is a term that is frequently used in the new housing industry. However, there is little understanding by both builders and consumers about what energy efficiency really means. For example, a feature being touted as energy efficient could in fact only meet the minimum efficiency level required by code. It could also be a feature that itself is very efficient but its impact on the home's energy use is nominal. In addition, the energy performance level of products and features is often greatly affected by their installation. Poor installation can result in poor energy performance.

There have been many efforts to clear up this confusion. For example, numerous best practice guides have been developed by building scientists and energy efficiency organizations. The Home Energy Rating System (HERS) was established to provide a consistent method that could be used nationally for evaluating the energy efficiency of a home. The key features of an energy efficient home should be low utility bills, improved comfort, and adequate indoor air quality.

Despite the efforts to promote energy efficient construction, the majority of builders in this country have not embraced the many tried and true technologies or construction practices that are known. EPA is trying to change this with its marketing based ENERGY

STAR Homes program. This national voluntary program is trying to make intelligent, cost effective, energy efficient designs easier for builders to adopt by promoting the benefits of energy efficiency to both builders and consumers. By setting minimum energy *performance* criteria, the program offers builders flexibility in design. At the same time, consumers are offered the assurance of truly buying an energy efficient home, because the energy performance of the house is verified by an independent third party. In addition, the ENERGY STAR Homes program makes it easier for home buyers to make a smart purchasing decision by awarding certificates to qualified homes and promoting the ENERGY STAR brand.

One component of the ENERGY STAR Homes program is Builder Option Packages (BOPs). BOPs are prescriptive packages that offer builders one solution for building an ENERGY STAR home. ICF Consulting developed the BOPs using the DOE-2.1E computer-modeling program and the anticipated energy performance level of the BOPs was verified by Lawrence Berkeley National Laboratory using both the DOE-2 and RemRate modeling tools. Each climate specific BOP is based on analyses of multiple house designs (single or double story), sizes (1000 to 2000 square feet of conditioned floor space per story), foundation types (basement, crawlspace, slab), glazing area (as a percentage of conditioned floor area), glazing distribution and orientation, and local climatic variations. Through these analyses, worst case and best practice case BOPs were identified for each region. The worst case BOPs ensure at least a score of HERS 86 anywhere in the climate region. The best case BOPS show how good design (i.e., optimized foundation type, window area, and window distribution) can be used to develop improved design solutions for a given location.

This paper will explain the technical methodology used by ICF in creating the BOPs. Example packages will be presented to illustrate the key concepts of this methodology. While the development of the BOPs focuses on the worst case scenario, the majority of houses incorporating the BOP features will likely be better. Therefore, this paper also examines the potential range of energy savings associated with a BOP by modeling a best case scenario. Much has been learned from the BOP development process but there is more to understand and several next steps are identified.

EPA's ENERGY STAR Homes Program

EPA's ENERGY STAR Homes program is a national voluntary program that promotes the construction of new homes that are at least 30% more energy efficient than a comparable home built to the Model Energy Code (for the HVAC and DHW end-uses only). It promotes healthy homes by recommending the homes maintain ASHRAE's minimum recommended ventilation rate of 0.35 ac/h by building the house tight and using an active ventilation system (ASHRAE 1997). Homes certified as ENERGY STAR are also third party verified to ensure the builder is properly installing the energy efficiency features. Home buyers do not need to be energy efficiency experts to feel confident about purchasing decisions; they only need to look for the ENERGY STAR logo and house certificate.

The ENERGY STAR Homes program uses the Home Energy Rating System (HERS) (or equivalent) methodology for determining an energy score for the home. A home built to the Model Energy Code receives a score of 80. Each 5% of energy savings is equal to 1 HERS point. Hence, an ENERGY STAR home has a HERS score of 86 or higher. Currently, there are two methods used for determining the HERS score: the modified loads method, and the normalized modified loads method. The HERS scores reported in this paper are based on the modified loads method. More information on these methodologies can be found at www.fsec.ucf.edu/temp/methods.htm.

By using a performance-based compliance requirement, builders are able to be creative in the specific energy efficiency features that they design and build in their new homes. However, builders often want to know what the minimum energy efficiency features of an ENERGY STAR home would likely be - *before* they join the program. To solve this problem, EPA developed Builder Option Packages (BOPs). BOPs are a set of prescriptive measures and limitations that are designed to meet or exceed a HERS score of 86. The BOPs are designed to be applicable to a wide range of homes within a given climate region. BOPs can be used as marketing tools to communicate the typical energy efficiency features of ENERGY STAR Homes built in each of five climate regions of the U.S. As an implementation tool, BOPs require the same field diagnostics as a HERS rating (i.e., a blower door and duct leakage test.)

Technical Methodology for Developing BOPs

The goal of a BOP is to establish a set of energy upgrades that will result in a minimum HERS score of 86 for a wide range of homes in a broad climate region. These upgrades are determined using the DOE-2.1E computer modeling software in a three step process. The first step is to establish a likely worst case scenario. The second step is to determine the energy upgrades required to reach a HERS 86 for that worst case scenario. The third step is to model the resulting package in other scenarios to ensure a minimum HERS 86 is consistently achieved. The modified loads methodology was used in determining the HERS scores for this paper. These three steps are described in detail below.

The first step is to establish a likely worst case scenario. This scenario is comprised of both climate and house parameters. Because the BOPs are applicable to one of five broad climate regions, as defined by EIA (see Figure 1), the range of climate experienced in a region must be analyzed in the development of the BOPs (EIA 1992). This will ensure that the BOP will achieve a minimum HERS 86 throughout the climate region. To capture this climatic variation, the hottest, coldest, driest and most humid cities for each climate region were selected for modeling. Generally the most humid city corresponded to the hottest city, therefore three cities were selected per climate zone. The selection of cities has changed slightly over time, reflecting ICF's growing knowledge of their climatic impacts on HERS scores. By modeling a constant home in the three cities, the worst city for the climate zone is identified by the lowest HERS score. The worst case cities used for BOP development are presented in Table1.

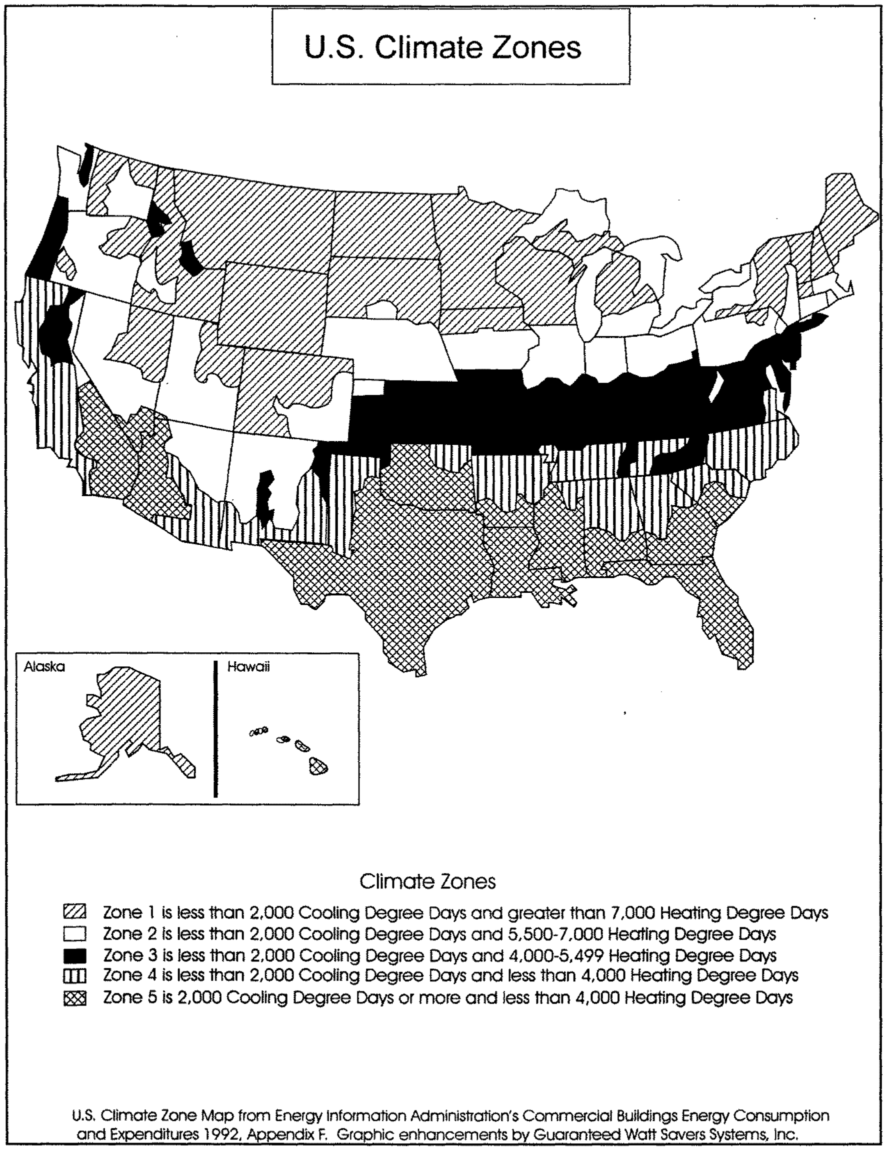

Figure 1. EIA Climate Zone Map

Table 1. Worst Case Cities Used for BOP Development

Climate Zone 1	Madison, WI
Climate Zone 2	Grand Junction, CO
Climate Zone 3	Albuquerque, NM
Climate Zone 4	Greensboro, NC
Climate Zone 5	Miami, FL

In addition to climate, the parameters of a house have varying effects on its energy use. Through literally thousands of DOE-2 runs, ICF has identified several key features that have a significant impact on a home's energy use. These features are:

- the size of the home;

- the number of floors;
- the foundation type;
- the aspect (length to width) ratio;
- the percent glazing; and,
- the distribution of that glazing.

By varying the combinations of these key features, a worst case house configuration (i.e., one with the lowest HERS score) could be established for a given climate region. A true worst case configuration would probably never be built in reality. Thus, a "likely" worst case configuration needed to be established to provide reasonable limitations for the packages. These limitations were identified through the review of hundreds of plans and through conversations with many builders and building industry professionals. The features of a likely worst case home configuration are:

- Aspect ratio of 2:1;
- House sizes up to 2000 square feet for single story and 4000 square feet for two stories;
- 20% window to floor area (WFA); and,
- Window distribution of 50% on the front, 25% on the back and 12.5% on the left and right.

The front of the house is modeled facing the worst orientation for each climate zone. For example, homes in Climate Zone 1 (coldest) face the north. This minimizes the solar gain benefits.

Using these limitations as a starting point, combinations of the home's size, number of floors, and foundation type are modeled to identify the likely worst case scenario (i.e., the house configuration with the lowest HERS score.) The combinations of house size and floors analyzed are a single story home with 1000 and 2000 square feet, and a two story home with 2000 square foot per floor. Each of these houses is modeled with a slab on grade, basement, and crawlspace. The HERS scores for Madison, WI, the worst city in Climate Zone 1, are summarized in Table 2. From this exhibit, the worst case house configuration in Climate Zone 1 is identified as the double story, 2000 square foot per floor house with a crawlspace.

Table 2. Summary of HERS Scores for Various House Configurations in Madison, WI

	Slab on Grade	Basement	Crawlspace
Single Story, 1000 Sq.Ft.	78.7	79.0	78.5
Single Story, 2000 Sq.Ft.	76.6	77.3	75.4
Double Story, 2000 Sq. Ft./Flr.	76.2	77.1	75.3

The second step is to determine a set of energy efficiency upgrades for the worst case scenario (e.g., a double story, 2000 sq.ft./flr. house with a crawlspace in Madison, WI) that results in a HERS score of 86. This is done for each climate zone. The selection of upgrades is based on four basic criteria: the relative energy use of the end use equipment; the components contributing to the peak loads; the cost effectiveness of the upgrades; and the willingness of builders to incorporate the upgrade. The resulting BOPs for the five climate zones are presented in Table 3.

Table 3. Builder Option Packages for Five Climate Zones

	Climate Zone 1 Madison, WI	Climate Zone 2 Grand Junction, CO	Climate Zone 3 Kansas City, MO	Climate Zone 4 Greensboro, NC	Climate Zone 5 Tulsa, OK
Building Geometry					
Single Story Floor Area (sqft)	</= 2000	</= 2000	</= 2000	</= 2000	</= 2000
Multi Story Floor Area (sqft)	</= 4000	</= 4000	</= 4000	</= 4000	</= 4000
Total Window Area (% WFA)	</= 20%	</= 20%	</= 20%	</= 20%	</= 20%
South and West (% WFA)	>/= 7.5%	>/= 7.5%	</= 12.5%	</= 12.5%	</= 12.5%
Thermal Envelope					
Exterior Wall Insulation	>/= R-19	>/= R-15	>/= R-15	>/= R-13	>/= R-13
Attic Insulation	>/= R-38	>/= R-38	>/= R-38	>/= R-30	>/= R-30
Basement Wall Insulation	>/= R-13	>/= R-13	>/= R-13	>/= R-11	>/= R-11
Slab Insulation	>/= R-8	>/= R-6	>/= R-6	>/= R-4	n/a
Crawlspace Floor Insulation	>/= R-19	>/= R-19	>/= R-19	>/= R-11	>/= R-11
infiltration	0.35	0.35	0.35	0.35	0.35
Window Performance					
U-Value	0.33	0.33	0.33	0.33	0.40
SHGC	0.52	0.52	0.42	0.42	0.42
Door	>/= R-5	>/= R-5	>/= R-5	>/= R-5	>/= R-5
Mechanical Equipment					
Thermostat	Programmable	Programmable	Programmable	Programmable	Manual
Gas Water Heater EF	>/= 0.56	>/= 0.56	>/= 0.56	>/= 0.56	>/= 0.56
Wrap Insulation	>/= R-5	>/= R-5	>/= R-5	>/= R-5	None
Heating Equipment	>/= 90 AFUE	>/= 90 AFUE	>/= 80 AFUE	>/= 80 AFUE	>/= 80 AFUE
Cooling Equipment	>/= 10 SEER	>/= 10 SEER	>/= 12 SEER	>/= 12 SEER	>/= 12 SEER
Ventilation	Recommended	Recommended	Recommended	Recommended	Recommended
Duct Distribution	</= 6%	</= 6%	</= 6%	</= 6%	</= 6%
Duct Insulation	>/= R-8	>/= R-6.5	>/= R-6.5	>/= R-6.5	>/= R-8
HERS Score	86.0	86.0	86.0	86.0	86.0

Once a HERS 86 has been achieved for the worst case scenario, the third step is to model the resulting package in the remaining cities to ensure that scores of 86 or higher are also reached. These results are summarized in Table 4, with the HERS score rounded to the nearest half point. This table verifies that the packages do meet or exceed a HERS 86 in the cities representing the climatic range for each climate zone. It also demonstrates that climate alone can affect a home's HERS score by as much as two HERS points.

Table 4. Summary of HERS Scores for BOPs in the Cities Modeled

Climate Zone	City	HERS Score
1	Madison, WI	86.0
	Duluth, MN	86.5
	Norfolk, NE	87.0
2	Grand Junction, CO	86.0
	Sioux City, IA	86.0
	Springfield, IL	86.5
3	Kansas City, MO	86.0
	Wichita, KS	86.0
	Albuquerque, NM	86.0

4	Greensboro, NC Fresno, CA Wilmington, NC	86.0 87.0 88.0
5	Tulsa, OK Miami, FL Las Vegas, NV	86.0 86.5 87.0

Best Case Configurations

The analyses above focused on the worst case scenarios that might be encountered when implementing a BOP. This was necessary to ensure that a home following a BOP would result in a HERS 86 regardless of its configuration or location within a climate zone. However, most homes implementing a BOP will likely be better than the worst case scenario. A likely best case configuration was modeled to better understand the range of HERS scores that a home could achieve through implementing a BOP. This configuration consisted of a single story, 1000 square foot home with a basement. In addition, the glass area was reduced to 16% WFA and distributed to take advantage of the solar radiation. For example, the majority of glass was oriented facing South and West for the northern packages while the majority of glass faced North and East for the southern packages. Each of these changes was modeled so that their relative impacts on the HERS score could be seen. The results are presented in Table 5.

Table 5. Summary of HERS Scores for BOPs in a Best Case Configuration

Climate Zone	City	Configuration	HERS Score
1	Norfolk, NE	1000 sq.ft. Basement + 16% WFA + Oriented South	88.0 88.5 89.0
2	Springfield, IL	1000 sq.ft. Basement + 16% WFA + Oriented South	87.5 88.0 88.5
3	Wichita, KS	1000 sq.ft. Basement + 16% WFA + Oriented South	88.5 89.0 89.5
4	Wilmington, NC	1000 sq.ft. Basement + 16% WFA + Oriented South	88.5 89.0 89.5
5	Las Vegas, NV	1000 sq.ft. Basement + 16% WFA + Oriented South	87.5 88.5 89.5

This exhibit demonstrates how significant each of these parameters are on a home's energy use. Changing the foundation type to a basement can add as much as two and a half points to the HERS score. Reducing the window area from 20% WFA to 16% WFA can increase the HERS score by as much as one HERS point. Optimizing the window distribution can further increase a home's HERS score by another point. While the BOPs designed to the worst case scenarios achieved a HERS score of 86, the best case scenarios achieved HERS scores as high as 89.5. These best case homes add an additional 18% more energy efficiency to the minimum required by the ENERGY STAR Homes program.

This range in HERS score illustrates that while the BOPs represent energy efficient construction, they are not optimized for the majority of house designs included within the package limitations. While the BOPs offer builders a quick answer to what the features of an ENERGY STAR home can be, there is much room for customization and cost savings. These are just some of the additional benefits that builders can realize by working with a HERS rater.

Areas for Further Research

Much has been learned from the BOP development process but there is more to understand. Specific areas for further research include: the correlation between the HERS score and actual energy savings; the defining of a worst case scenario; and, the quantification of the downsizing potential in HVAC equipment due to reduced loads.

While the HERS score was developed to be a simple unbiased metric for quantifying the energy efficiency of a home, the score does not always correlate to the actual energy savings achieved. This is primarily due to two factors: the definition of a HERS reference home; and, the methodology used for determining the HERS score.

The Guidelines for Uniformity were established by the HERS Council to provide a consistent definition of a reference home. Used as a benchmark for energy use, this reference home is the same shape and size as the home being rated. However, the window area and distribution for the reference home are fixed at 18% WFA, distributed equally on all four orientations. As noted in the analyses of the best case scenarios, these two parameters can have significant impact on a home's energy use. A home with reduced window area and inefficient windows might achieve a good HERS score, but it is not the best energy efficient design.

In addition, the methodology for determining the HERS score has evolved over time. The score originally was determining by dividing the rated home's energy use by the reference home's energy use. This straight forward calculation did accurately capture the energy savings achieved by the house. However, many saw a need to "better" capture the benefit from the individual gains in equipment efficiency. This led to the modified loads methodology. This method too was perceived as inadequate by many and a new methodology, the normalized modified loads methodology, was created. While the goal of these methods was to improve on the rating of a home's energy use, they each inaccurately boost the energy efficiency gains realized at the house. Hence, a home may achieve a HERS 86, but not actually realize 30% savings in the heating, cooling and hot water use. It may be in the HERS industry's best interest to revisit these two issues regarding the correlation between HERS score and actual energy savings.

A second area for further research is that of defining a worst case scenario. As one might expect, the worst case house configuration is dependent upon the initial assumptions of the house features. For example, a home with a very efficient shell but poor equipment efficiencies will behave differently than a home with very efficient equipment but a poor shell. ICF tried to account for this by performing the initial analyses with shell and equipment values equal to the HERS reference home. However, as the upgrades are made to create the energy efficient BOPs, the energy use characteristics of the home change. Therefore, the worst case house configuration of the completed BOP could be very different from that of the original analyses.

Additionally, the worst case cities selected for modeling were based on the heating and cooling degree days. Our experience has shown that these are not the only indicators of climates' effect on energy use. Variables such as solar radiation, wind speed, humidity, and design day temperatures may provide a more comprehensive analysis of the climate. This could result in the selection of different worst case cities. Additional research into these two areas could help in defining a more accurate worst case scenario.

The third area for further research is better quantifying the downsizing potential in HVAC equipment. With the heating and air-conditioning loads reduced through the implementation of energy efficiency measures, the HVAC equipment can often be downsized. These cost savings could help overcome builder's fear of the expense for energy efficiency upgrades. In addition, occupant comfort will be increased by ensuring the installation of properly sized equipment.

Conclusions

The BOPs are designed to meet or exceed a HERS 86 for given limitations within a broad climate zone. In fact, this paper demonstrates that the average house implementing a BOP will likely achieve a score above an 86 and could be as high as an 89.5. Key factors contributing to the energy use of a home are its configuration (i.e., foundation type and size), window area and window distribution. While the BOPs offer quick guidance on energy efficient construction, further customization of the packages, focusing on these key factors, could result in more cost-effective designs.

BOPs not only improve the energy efficiency of a home's design, but they are also likely to increase the adoption of energy efficient design by builders. Three reasons are as follows. Firstly, they offer builders a quick answer to what is meant by an energy efficient design, and provide a "minimum criteria checklist" route to an assured ENERGY STAR label. Secondly, BOPs make it easier for HERS raters to obtain the business of production builders, a market that has traditionally been difficult to enter but offers a large business and market transformation opportunity. This is because the more costly up-front energy analyses have already been done in creating the BOPs. Therefore, the BOPs allow the HERS rater to focus their efforts on assisting builders in proper construction and installation techniques as well as performing diagnostics. Lastly, BOPs offer HERS raters a starting point for offering more customized and cost effective packages to builders.

References

[ASHRAE] American Society of Heating, Refrigerating and Air Conditioning Engineers. 1997. *ASHRAE Handbook of Fundamentals.* Atlanta, Georgia.

[CABO] Council of American Building Officials. 1995. *Model Energy Code.*

[EIA] Energy Information Administration. 1992. *Commercial Buildings Energy Consumption and Expenditures 1992.* Washington, D.C.: U.S. Department of Energy.

[HERS] Home Energy Rating Systems Council. 1996. *Guidelines For Uniformity: Voluntary Procedures for Home Energy Ratings.* Washington, D.C.