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# Calculating Energy Savings in High Performance Residential Buildings Programs

## Preprint

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# CALCULATING ENERGY SAVINGS IN HIGH PERFORMANCE RESIDENTIAL BUILDINGS PROGRAMS

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## Abstract

Accurate and meaningful energy savings calculations are essential for the evaluation of residential energy efficiency programs sponsored by the U.S. Department of Energy (DOE), such as the Building America Program (a public-private partnership designed to achieve significant energy savings in the residential building sector). The authors investigated the feasibility of applying existing performance analysis methodologies such as the Home Energy Rating System (HERS) and the International Energy Conservation Code (IECC) to the high performance houses constructed under Building America, which sometimes achieve whole-house energy savings in the 50-70% range. However, because Building America addresses all major end-use loads and because the technologies applied to Building America houses often exceed what is envisioned by energy codes and home-rating programs, the methodologies used in HERS and IECC have limited suitability, and a different approach was needed. The authors have researched these issues extensively over the past several years and developed a set of guidelines that draws upon work done by DOE's Energy Information Administration, the California Energy Commission, the International Code Council, the Residential Energy Services Network (RESNET), and other organizations that have developed similar methodologies to meet their needs. However, the final guidelines are tailored to provide accurate techniques for quantifying energy savings achieved by Building America to help policymakers assess the effectiveness of the program.

## Introduction and Background

The Building America program is an industry-driven research program sponsored by the U.S. Department of Energy (DOE) that applies systems engineering approaches to accelerate the development and adoption of advanced building energy technologies in new residential buildings. This program supports five building industry teams in the production of advanced residential buildings on a community scale. These teams use a systems engineering process to perform cost and performance assessments relative to each builder's standard practice, with the overall goal of reducing energy use without increasing the construction cost. The energy efficiency concepts incorporated in these houses are evaluated by conducting successive design, test, redesign, and retest iterations until cost and performance trade-offs yield innovations that can be cost-effectively used in production-scale housing.

The goals of the Building America program are as follows: (1) accelerate the use of advanced building energy systems in new residential construction through development and application of systems engineering approaches among cross-cutting industry teams; (2) develop innovative technologies and strategies that allow the U.S. housing industry to deliver environmentally sensitive, quality housing on a community scale while maintaining profitability and competitiveness of homebuilders and product suppliers; and (3) reduce energy consumption by 40-60% for all end-uses in new houses built under the program, reduce construction site waste, increase the use of recycled materials, increase labor productivity, and reduce construction-cycle time.

To measure progress toward these goals, cost and performance trade-offs are evaluated through a series of controlled field and laboratory experiments supported by energy analysis techniques that use test data to "calibrate" energy simulation models. This paper summarizes these energy analysis procedures, which the authors feel have substantial relevance for the evaluation of homes in programs similar to Building America.

## Purpose

As Building America has grown to include a large and diverse cross-section of the home building industry, accurate and consistent analysis techniques have become more important to help program partners perform design trade-offs and calculate energy savings for prototype houses built as part of the program. Many useful approaches and tools are available to calculate energy savings, and this document illustrates some of the analysis concepts proven effective and reliable for analyzing the transient energy usage of advanced energy systems as well as entire houses.

The analysis procedure described in this document provides a starting point for (1) a standard approach for calculating the energy savings of a prototype house relative to two important base cases (Builder Standard Practice and Regional Standard Practice) and (2) using building simulation to calculate annual energy savings based on side-by-side short-term field testing of a prototype house and base-case house(s). By establishing a standard analysis approach with well-defined set of reference houses and operating conditions, energy savings can be calculated in a consistent and meaningful way. Builders are thereby able to make informed judgments about optimal energy efficiency packages, and program managers can confidently track progress toward the achievement of important performance goals.

The first section of this paper provides general recommendations for prototype and base-case design assumptions, operating conditions, and analysis tools. Many other valid techniques and definitions have been developed by other organizations and may be very useful to builders for specialized applications. For example, the Home Energy Rating System (HERS) rating procedure must be followed to obtain an ENERGY STAR™ certification.[1] Also, it may be necessary to determine whether or not a prototype meets the International Energy Conservation Code (IECC) or Model Energy Code (MEC), which may apply if adopted by the state or local government. Both HERS and IECC have developed their own base case definitions and standard operating conditions suited for the particular needs of their program constituents, but unfortunately these base cases were deemed inadequate for the performance levels targeted by Building America.[1]

The second section presents guidelines for the effective hourly analysis and reporting of energy savings in residential buildings. Although many of the suggestions were developed with Building America in mind, these guidelines are general enough to provide very useful techniques for comparing the energy performance of two similar houses in many other situations.

[1] Additional information about these reference cases can be found at the U.S. Department of Energy Codes and Standards Web site (http://www.eren.doe.gov/buildings/codes_standards/buildings/) or the National Association of State Energy Officials Web site (http://www.natresnet.org/techguide/).

## Performance Analysis Guidelines

### *Analysis Tools*

A key issue in any building energy analysis is the choice of the tool or program used to estimate energy consumption. An hourly simulation is often necessary to fully evaluate the time-dependent energy impacts of advanced systems used in Building America houses. Thermal mass, solar heat gain, and wind-induced air infiltration are examples of time-dependent effects that can only be accurately analyzed using a model that calculates heat transfer and temperature in short time intervals. In addition, an hourly simulation program is necessary to accurately estimate peak energy loads. Because of the large number of users, public availability, and level of technical support, DOE-2 is the hourly simulation tool recommended for systems analysis studies performed under the Building America program. Teams are also encouraged to use other simulation tools when appropriate for specialized building simulation analysis, provided the tool has met the requirements of HERS BESTEST (Judkoff and Neymark, 1995) in accordance with the software certification sections of the RESNET/HERS Guidelines (NASEO, 1999). Regardless of the tool selected, analysts should report a comprehensive set of results, including annual heating and cooling energy (both source and site), peak hourly energy consumption, and cost-benefit calculations if available. A full summary of building energy simulation tools can be found at the DOE building energy tools web site (www.eren.doe.gov/buildings/energy_tools/).

### *Prototype and Base-Case Definitions*

Throughout the remainder of this document, the term "prototype" refers to a reengineered house with advanced systems and design features built for the first time as part of the Building America program. In the model, all parameters for the prototype house are based on measured data or final design specifications, with a few exceptions as defined in Hendron et al (2001). The term "base case" refers to one of the following two designs (See also Figure 1):

- ***Regional standard practice***. This base case represents the house design that is most commonly built in the same geographic region as the prototype house. Energy savings relative to regional standard practice is an important measure of how a Building America prototype compares to similar houses currently being built in a particular market. The key elements of the regional standard practice are summarized in Figure 2.
- ***Builder standard practice***. This base case describes the house design that would have been built without the participation of the builder in the Building America program. It may be either an existing model in the builder's inventory, or a house similar to the prototype, but with design features and construction techniques consistent with the builder's current inventory. A side-by-side test combined with a calibrated hourly simulation provides the best comparison of a prototype with builder standard practice, but this situation is often not practical. Energy savings relative to builder standard practice provides a measure of the direct influence of Building America for a particular house. The specifications for the builder standard practice design are fairly straightforward to determine, but detailed guidelines are provided in Hendron et al (2001).


**Figure 1. The prototype is evaluated relative to two base cases**

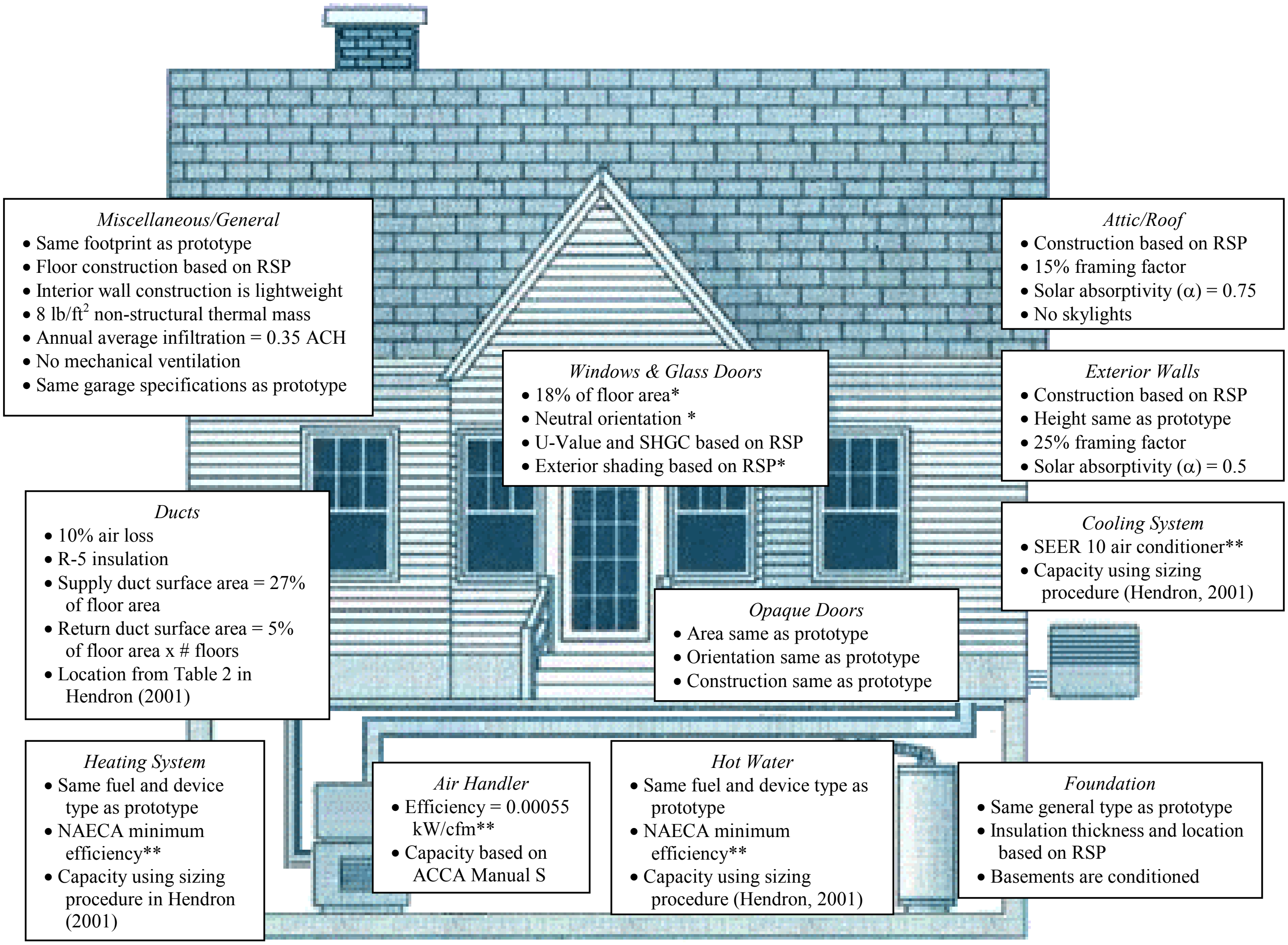


**Figure 2. Regional standard practice (RSP) specifications**

* Applies if the prototype house uses specific window or shading modifications to reduce heating or cooling loads as part of a broader bioclimatic strategy. Otherwise the same window area (up to 18%), orientation, and shading as the prototype are used. Neutral orientation means that energy use is calculated as the average of each house orientation using the same proportion of glazing in each orientation as the prototype.
** Part-load performance of space conditioning systems (air conditioners, heat pumps, furnaces, and air distribution) calculated using the methodologies described in the California Energy Commission Nonresidential ACM Approval Manual (CEC, 2001).

### *Operating Conditions*

The following operating conditions and other assumptions shall apply to both the prototype house and the two base cases defined in this document. These operating conditions are based on the cumulative experience of the authors through their work on Building America and other residential energy efficiency programs. Note that these operating conditions assume that the analyst is evaluating a new house or an existing house where the actual occupant behavior is unknown. In the case of an occupied house where the homeowner is considering energy improvements or a new house where the homebuyer has known behavior, it is more appropriate to use the expected operating conditions for the actual occupants.

1. Thermostat set point for cooling: 78°F
   Thermostat set point for heating: 68°F
2. Schedules for opening and closing windows and shades vary greatly with climate, house orientation, and occupant behavior. For the purpose of modeling the prototype and base-case houses, draperies are assumed to be drawn over half of the windows all of the time. The drawn curtains are assumed to decrease the solar gain by 40% and add approximately an R -0.5 to the fenestration. Screens are assumed to be present on half of the windows as well, and the combined dirt and screen is assumed to decrease solar gains by 10%. The natural ventilation temperature schedule is set to a constant 68°F, forcing the windows closed if the indoor temperature falls below this value. In situations where there is a cooling load, the outdoor temperature is below the indoor temperature, and the window is not already open, the probability of the window being opened is set at a constant 50%.
3. Total internal sensible heat gain from lights, people, and equipment varies with the size of the prototype house. Typical equipment intensity is calculated using Equation 1:

   ***Equation 1:*** **Equipment load (Btu/day/ft$^2$) = [House area (ft$^2$) x 12.5 (Btu/day/ft$^2$) + 15,000 (Btu/day)] / House area (ft$^2$)**

   Smaller loads may be used for lighting in the prototype house if the light fixtures contain ballasts that only function with energy efficient bulbs, or for home appliances (e.g., dishwashers and refrigerators) if the appliances are included as standard equipment by the builder. Because the equipment heat gains may vary by space (i.e., bedrooms and nonbedrooms) and time of day, separate schedules should be created that reflect realistic occupancy patterns. However, the total daily heat gain due to this component should still equal the calculated equipment load. Sensible heat gain from each person is 210 Btu/hr and latent heat gain is 140 Btu/hr. The total number of people living in a typical house is assumed to be equal to the number of bedrooms plus one. An appropriate occupancy schedule should be developed to calculate total heat gains from people on an hourly basis.

4. Estimated hot-water usage based on Equation 2.

   ***Equation 2:*** **Gallons/day = 30 gallons + (10 gallons x number of bedrooms)**
5. Weather data is based on typical meteorological year (TMY2) data from 1961 to 1990[1] or equivalent data for the location most similar in climate.

***Comparing a Prototype House to a Base Case***

The process of evaluating Building America house performance involves the comparison of energy use between a base case and a Building America design. Energy savings are typically calculated by comparing the total annual heating and cooling energy for each house, but the procedures described in this paper can easily be extended to all end-uses. Only energy derived from fossil fuel, nuclear, or hydropower sources is considered; contributions from site-generated renewable energy are excluded from the calculation of total energy consumption.

To calculate energy usage for a prototype house and either the regional standard practice or builder standard practice base case, the following equation is used. Energy usage for the prototype

[1] Downloadable from the NREL web site (http://rredc.nrel.gov/solar/old_data/ nsrdb/tmy2/)

should always be calculated in each of the four cardinal orientations, plus any other orientations that may be expected as part of the community layout. Energy units shall be in Btu and source energy is the basis for comparison. For propane and fuel oil, it is assumed that the source energy multipliers are equal to unity (CEC, 1999).

**Equations 3 & 4:**

Total annual heating/cooling energy usage (Btu) = Annual electric heating and cooling energy (kWh) • 3412 • $M_e$
+ Annual gas heating and cooling energy (therms) • 100,000 • $M_g$
+ Annual propane heating and cooling energy (gallons) • 91,080
+ Annual fuel oil heating and cooling energy (gallons) • 138,400

Total annual home energy usage (Btu) = Annual electric energy for all applications (kWh) • 3412 • $M_e$
+ Annual gas energy for all applications (therms) • 100,000 • $M_g$
+ Annual propane energy for all applications (gallons) • 91,080
+ Annual fuel oil energy for all applications (gallons) • 138,400

Where: $M_e = 3.57$ = Site to source multiplier for electricity (EIA, 1995).
$M_g = 1.02$ = Site to source multiplier for natural gas (EIA, 1995).

To calculate percent energy savings for a prototype house compared to either the regional standard practice or builder standard practice base case, Equation 5 is used. In the case of a prototype that uses a bioclimatic design strategy, the energy usage of the base case will be the average of the energy usage in each of the four cardinal orientations.

**Equation 5:**

% Annual energy savings = (Annual source energy usage for base case - Annual source energy usage for prototype) / Annual source energy usage for base case

Peak hourly energy consumption is calculated in a similar manner and is based on the hour with the greatest gas or electric energy consumption during the course of one year as determined by the hourly simulation

### *Differences Among Base Case Definitions*

Because each of the base cases has a unique purpose in the analysis of Building America prototype houses, there are important differences in how elements of each base case are defined. Table 1 illustrates some of these differences between the two base-case definitions described in this paper, along with the HERS Reference Home and the IECC Standard Design. Note that several measures seen in high performance homes are not credited or only partially credited relative to the HERS or IECC base cases, but are credited using the approach described in this document. Examples include important energy saving measures such as duct performance improvements (adding duct insulation, reducing duct leakage, moving the ducts into conditioned space), sealing and insulating normally vented spaces such as crawl spaces and attics, bioclimatic design measures (enhanced shading, thermal mass, cool roofs), efficient lighting and appliances, advanced framing, site generated electricity, HVAC downsizing, and fuel switching (Builder Standard Practice only).

Conversely, certain measures credited by HERS or IECC were deemed inappropriate for Building America because of unproven effectiveness (air tightness below 0.35 ACH, programmable thermostats, exterior door improvements). For example, a house with air infiltration of 0.1 ACH (well below that recommended by ASHRAE) and no ventilation will likely result in occupants opening windows more often, negating any positive effects of the additional air tightness. In addition to the differences listed below, there are a number of specific differences in the values used for various design features of the base cases and the detail in which these features are defined (Hendron et al., 2001). These values were chosen because the authors felt they were more representative of actual current standard practice in the building industry.

It is very difficult to make definitive statements regarding which base case is the most energy efficient. However, we do know that the HERS Reference Home was based on the 1995 Model Energy Code, a somewhat less stringent predecessor to IECC, especially in southern climates where low solar heat gain windows were not required until IECC was adopted. Also, Regional Standard Practice will generally exceed the requirements of the IECC in those jurisdictions where the code has been adopted. Builder Standard Practice could be more or less efficient that Regional Standard Practice, but most Building America partners are lead builders in their market and typically build homes more energy efficient than their competitors. As an example, Builder Standard Practice for one Building America partner in Tucson was calculated to be approximately 24% more efficient than the HERS Reference Home and 14% more efficient than Regional Standard Practice.

**Table 1. Credit for Energy Savings from Various Design Measures Using Common Base Cases**

| *Design change* | *Regional Standard Practice* | *Builder Standard Practice* | *HERS Reference Home* | *IECC Standard Design* |
|---|---|---|---|---|
| Move ducts into conditioned space | Yes | Yes | Yes | No |
| Reduced energy loss of ducts | Yes | Yes | No[a] | No[a] |
| Reduce air infiltration below 0.35 ACH | No | No | Yes | Yes |
| Fuel switching | No | Yes | No | No |
| Combo water/space heater | No | Yes | Yes | Yes |
| No skylights | Yes | Yes | No | Yes |
| Unvented attic or crawl space | Yes | Yes | No | No |
| Exterior shading | Yes | Yes | Yes | No |
| Added thermal mass in walls | Yes | Yes | Yes | No |
| Reduced wall/attic framing factor | Yes | Yes | Yes | No |
| Cool roofs/walls | Yes | Yes | Yes | No |
| Door area and U-value | No | No | Yes | Yes |
| Site-generated electricity | Yes | Yes | No | No[b] |
| Programmable thermostat | No | No | Yes | Yes |
| Downsize HVAC capacity below Manual J | Yes | Yes | No | No |
| Energy efficient lights and appliances | Yes | Yes | No | No |

(a) Except when leakage is reduced below 5%.
(b) Except for photovoltaics with battery storage.

## Residential Energy Modeling Approach

This section offers a set of guidelines for creating the simulation models needed for the analysis of Building America prototype house designs, sets forth a clear methodology for conducting the analysis, and presents a format for reporting the results. These guidelines and the examples presented are based on the National Renewable Energy Laboratory's (NREL) analysis of past and current Building America projects. The modeling efforts associated with Building America are intended to quantify the energy savings of a wide variety of efficiency measures. For this reason, Building America energy simulations, as compared to many other residential energy simulations, require a relatively high level of detail in the building shell, building operation, and equipment performance. While the framework for the analysis is presented here, it is the responsibility of each analyst to use this framework in the most appropriate way for each project.

***Analysis Approach***

The analysis approach covered in this paper assumes the use of DOE-2. Other simulation tools may be used with minor modifications, depending on the specific inputs allowed by that tool. The typical heating and cooling annual energy use of a new building design is compared to a base-case building of the same basic description, only without the improved features. Energy for domestic hot water, lighting, and appliances may also be included if efficiency measures are applied for these end-uses. Site energy use, energy costs, and source energy use are all used to compare the buildings.

***Modeling Process***

The process of creating a series of energy simulation models using DOE-2 can take many paths. For some projects, detailed hourly data from short-term testing may be available; for other projects, little more than schematic design data will be available. The major steps in the modeling process are identified below and described in detail in Hendron et al., (2001).

1. **Thermal zoning.** Identify the separate thermal zones for the model based on the floor plan and HVAC design of the Building America prototype building.
2. **Floor plan take-off.** Use the prototype floor plans to create the basic layout of the building, using DOE-2.2's polygon features.
3. **Building shell take-off.** Use the prototype construction documents to quantify individual window areas, door areas, wall areas, roof areas, etc.
4. **Building constructions.** Use the prototype construction documents to create constructions for windows, doors, walls, roof, and underground surfaces.
5. **Shading surface take-off.** Use construction documents and site information to identify building and site shading.
6. **Energy efficiency measure design.** Create DOE-2 macros for each variable of each component that will change from the base case to the prototype case.
7. **Base-case definition.** Use this document, as well as knowledge of local building practice, to define the base-case characteristics.
8. **Base case to prototype.** Translate the design improvements to DOE-2 BDL code in the simulation model to incrementally change the base-case model to the prototype design.
9. **DOE-2 simulation and design verification.** Use the DOE-2 simulation results to verify both the simulation model and building design.
10. **Energy efficiency measure analysis and reporting results.** Use the results of all the DOE-2 simulations to analyze each of the building improvements.

***From Regional Standard Practice to Prototype***

Once the regional standard practice house is modeled, the prototype house is created by changing the characteristics of each component that differs between the base case and prototype. In the interest of quality control and of assessing each measure's value, the incremental changes are added progressively and one at a time. Each component improvement is analyzed by simulating the new combination of measures and comparing the energy performance to the previous combination of measures.

The order and grouping of the measures is left up to the analyst. However, proper consideration should be given to a measure's benefit-to-cost (B/C) ratio. Measures with the highest B/C ratio should be added to the base case first. Measures for which savings are highly sensitive to the order in which they are added to the base case should be identified and explored further.

As an example of measures that can be highly sensitive to the order in which they are added to the base building, consider an unvented attic measure and a duct improvement measure that were used for a Building America prototype in Tucson. The duct improvement measure lowers the air-loss rate to the attic from 15% to 3%, and the unvented attic strategy moves the insulation from the attic floor to the attic roof. If the unvented attic measure is added first, the results in Table 2 are obtained.

**Table 2. Scenario 1: Unvented Attic Analyzed First**

| Measure Description | Htg/Clg (kWh) | Heating (therms) | Htg/Clg Cost ($/yr) | Measure Value ($/yr) | Package Savings ($/yr) | Cost Savings | Source Energy | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | kBtu | Savings |
| Base case | 3000 | 600 | 600 | N/A | N/A | N/A | 9715 | N/A |
| Unvented attic | 2500 | 590 | 554 | 46.0 | 46 | 8% | 8202 | 16% |
| Duct improvement | 2438 | 575 | 540 | 13.7 | 60 | 10% | 7999 | 18% |

Under Scenario 1, the unvented attic measure has a savings of $46 per year, much higher than the duct improvement savings of less than $14 per year. The B/C ratio is higher for the unvented attic measure and should come first, according to this analysis. But when the measure order is reversed, the results in Table 3 are obtained.

**Table 3. Scenario 2: Duct Improvement Analyzed First**

| Measure Description | Htg/Clg (kWh) | Heating (therms) | Htg/Clg Cost ($/yr) | Measure Value ($/yr) | Package Savings ($/yr) | Cost Savings | Source Energy | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | kBtu | Savings |
| Base case | 3000 | 600 | 600 | N/A | N/A | N/A | 9715 | N/A |
| Duct improvement | 2666 | 533 | 533 | 66.8 | 67 | 11% | 8633 | 11% |
| Unvented attic | 2438 | 575 | 540 | –7.1 | 60 | 10% | 7999 | 18% |

These results indicate that when measures are highly interactive, it is important to explore the sensitivity of the savings to the order of the measures. Results should be presented in multiple sequences to illustrate this sensitivity and clarify the B/C analysis.

Another important issue to consider when analyzing a high performance home is orientation. Annual heating and cooling loads, and even the relative benefits of energy efficiency measures, can vary significantly when different orientations are considered. An illustration of this effect is shown in Figure 3, based on an analysis of a Building America prototype in Pensacola, Florida. Most windows in the house are on the back wall, facing toward the east, and no passive solar design features are present in the prototype. Orientation is an important consideration when evaluating energy efficiency improvements, and is certainly essential if passive or active solar energy is used.

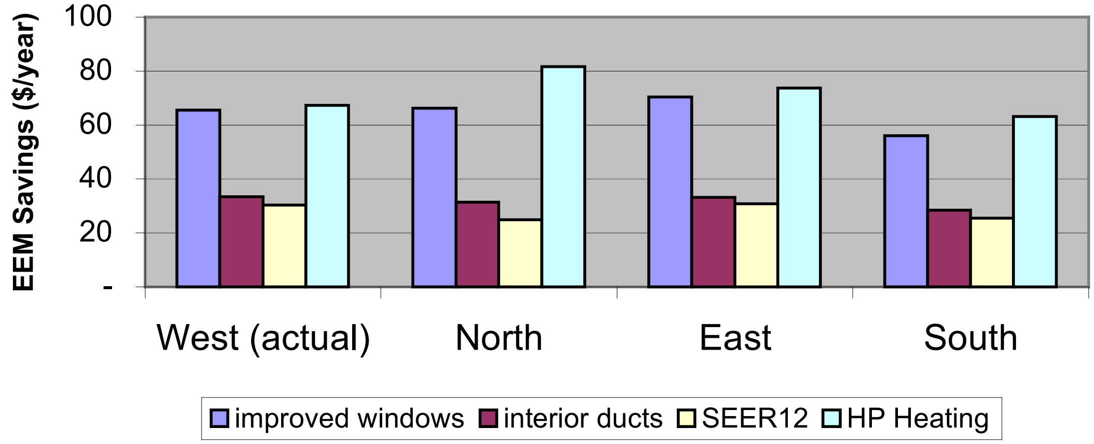


**Figure 3. Energy savings for energy efficiency measures (EEM) sorted by house orientation**

In addition to measure sequence and orientation, there are a number of other modeling issues to consider when evaluating a high performance house, such as zoning, buffer spaces, air infiltration, duct leakage, and air conditioner sizing. Many of these are addressed in a Technical Report developed by NREL (Hendron et al, 2001).

***Reporting of Results***

Consistent reporting of the analysis is important for proper and timely interpretation of the results. A description of the building and system characteristics for the starting point and for each increment in the analysis should accompany the table. Builder's standard practice (BSP) should be identified as a separate run if it differs from the regional standard practice (RSP) base case. Table 4 shows the minimum recommended data for a sample analysis that includes DHW improvements.

**Table 4. Sample Simulation Report**

| **Description** | **Space Conditioning and DHW** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Htg/Clg (kWh) | Heating (therms) | Htg/Clg Cost ($/yr) | Measure Value ($/yr) | Package Savings ($/yr) | Cost Savings | Source Energy kBtu | Savings |
| **RSP Base Case** | 5225 | 190 | $ 461 | | | | 75910 | |
| Base + SEER12 (**BSP Base Case**) | 4404 | 190 | $ 403 | 57.47 | $ 57 | 12% | 67,495 | 11% |
| Base + Imp. Ducts | 3526 | 182 | $ 338 | 65.48 | $ 123 | 27% | 57,552 | 24% |
| Base ++ Increased Infiltration | 3658 | 200 | $ 356 | -18.23 | $ 105 | 23% | 61,021 | 20% |
| Base ++ Improved Windows | 3055 | 179 | $ 303 | 34.49 | $ 157 | 34% | 52,369 | 31% |
| Base ++ Increased Ceiling Insulation | 2969 | 174 | $ 295 | 8.55 | $ 166 | 36% | 50,896 | 33% |
| Base ++ 2-ton Capacity | 2944 | 174 | $ 293 | 1.74 | $ 168 | 36% | 50,641 | 33% |
| Base ++ DHW EF | 2944 | 160 | $ 286 | 7.00 | $ 175 | 38% | 48,994 | 35% |
| Base ++ Ventilation (**BA Proto**) | 4113 | 178 | $ 377 | -90.82 | $ 84 | 18% | 63,092 | 17% |
| Proto + AFUE 94 | 4113 | 170 | $ 373 | 4.00 | $ 88 | 19% | 62,151 | 18% |

## Conclusions

Although a standard set of guidelines for performance analysis of residential buildings is an appealing concept, there are fundamental difficulties. The end-use of the analysis can have an enormous impact on the requirements for accuracy, flexibility, and simplicity. Because the mission of Building America includes energy savings targets as high as 70%, it was necessary for researchers to develop a performance analysis procedure suitable for the needs of the program. The authors believe these procedures are valuable for other energy efficient homes programs that anticipate very high levels of energy savings. Of course, this level of accuracy and consistency is less essential for programs focused on minimum performance levels (such as code compliance) or moderate levels of energy savings (Energy Star).

A meaningful analysis approach for high performance homes must have four important features: (1) a clearly defined reference house that truly reflects standard practice; (2) a consistent set of operating conditions that represents realistic patterns of occupant behavior; (3) a modeling technique that accurately predicts energy savings; and (4) a reporting process that communicates essential information about the source and magnitude of energy savings.

Two important reference houses were identified for the evaluation of Building America houses. The first is *Builder Standard Practice*, which represents the house that would have been built without the influence of Building America and, therefore, provides an assessment of the direct impact of Building America on residential energy use. The second is *Regional Standard Practice*, which takes into account local construction practices and energy code requirements and is more representative of competitive houses in the marketplace. Both reference houses must include sufficient detail to allow credit for creative energy saving techniques and reductions in all major end-use loads.

In addition to a meaningful and robust reference house, it is very important to establish fair and consistent rules for defining the operating conditions of a high performance house, which can have substantial effect on energy savings calculations, especially in very energy efficient houses with passive solar design features. These operating conditions include thermostat set-points, operation of windows and draperies, magnitudes and hourly profiles of internal loads, and other influences that are under the control of the occupants. This added detail in the definition of operating conditions requires additional effort the first time a model is developed, but this detail can be embodied and saved in libraries and schedules within most modeling tools, thereby allowing much quicker analysis of future projects.

Thirdly, it is very strongly recommended that an hourly simulation program be used for calculating energy savings and peak demand, especially when bioclimatic design techniques are used, such as solar load avoidance, thermal mass, and passive ventilation. Simplified “bin” methods do not adequately capture these energy flows, which are heavily dependent on thermal behavior over time. Building America researchers commonly use a variety of whole-house hourly simulation tools, including DOE-2, EnergyPlus, and Energy 10. Most hourly simulation tools do not require excessive computational time, and they usually have very flexible and friendly user interfaces that minimize or eliminate the additional effort required to perform an accurate hourly analysis.

Finally, the reporting of the simulation results must be done in a way that communicates all of the essential information for decision-making. The report should include savings in terms of site energy, source energy, and energy cost. It should also clearly differentiate the effects of each major energy efficiency measure.

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13. ABSTRACT *(Maximum 200 words)* Accurate and meaningful energy savings calculations are essential for the evaluation of residential energy efficiency programs sponsored by the U.S. Department of Energy (DOE), such as the Building America Program (a public-private partnership designed to achieve significant energy savings in the residential building sector). The authors investigated the feasibility of applying existing performance analysis methodologies such as the Home Energy Rating System (HERS) and the International Energy Conservation Code (IECC) to the high performance houses constructed under Building America, which sometimes achieve whole-house energy savings in the 50-70% range. However, because Building America addresses all major end-use loads and because the technologies applied to Building America houses often exceed what is envisioned by energy codes and home-rating programs, the methodologies used in HERS and IECC have limited suitability, and a different approach was needed. The authors have researched these issues extensively over the past several years and developed a set of guidelines that draws upon work done by DOE's Energy Information Administration, the California Energy Commission, the International Code Council, RESNET, and other organizations that have developed similar methodologies to meet their needs. However, the final guidelines are tailored to provide accurate techniques for quantifying energy savings achieved by Building America to help policymakers assess the effectiveness of the program.

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Energy savings; high performance houses; residential houses; Building America; U.S. Department of Energy; performance analysis

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