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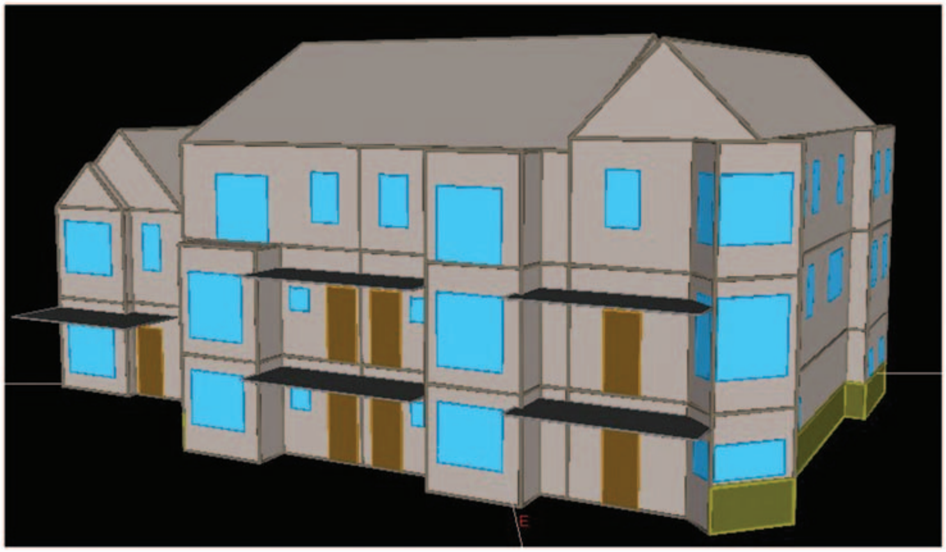
June 2004 • NREL/TP-550-35567

# Building America Performance Analysis Procedures

## *Revision 1*



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U.S. Department of Energy
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Building Technologies Program

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# List of Terms

| | |
|---|---|
| ACH | air changes per hour |
| A/C | air-conditioning |
| AFUE | annual fuel utilization efficiency |
| ASHRAE | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| B/C | benefit-to-cost ratio |
| BDL | Building Description Language |
| BESTEST | Building Energy Simulation Test |
| BSP | Builder Standard Practice |
| cfm | cubic feet per minute |
| DHW | domestic hot water |
| DOE | U.S. Department of Energy |
| EEM | energy efficiency measure |
| EF | energy factor |
| EIR | energy input ratio |
| HERS | Home Energy Rating System |
| HSPF | heating seasonal performance factor |
| HVAC | heating, ventilating, and air-conditioning |
| IECC | International Energy Conservation Code |
| MBtu | million Btu or $10^6$ Btu |
| MEC | Model Energy Code |
| NAECA | National Appliance Energy Conservation Act of 1987 |
| NFRC | National Fenestration Rating Council |
| NREL | National Renewable Energy Laboratory |
| PRC | Partnership for Resource Conservation |
| RSP | Regional Standard Practice |
| R-value | measure of resistance to the flow of heat through a given thickness of insulation; higher numbers indicate better insulating properties |
| SEER | seasonal energy efficiency ratio |
| S-G | Sherman-Grimsrud method |
| TMY | typical meteorological year |
| UA | measure of the building load coefficient |
| U-value | measure of the heat transmission through a building part (e.g., a wall or window) or a given thickness of insulation given in units of $Btu/hr \cdot ft^2 \cdot °F$; lower numbers indicate better insulating properties |

# Acknowledgments

The authors would like to thank Sara Farrar-Nagy, Paul Torcellini, Jay Burch, Blaise Stoltenberg, and Michael Smith of the National Renewable Energy Laboratory's Center for Buildings and Thermal Systems for their valuable technical contributions. In addition, the five Building America teams provided important new perspectives and critical assistance with the field tests and analytical studies cited in this report. We would also like to gratefully acknowledge the contributions of the rating community, including those of Steve Baden of Residential Energy Services Network (RESNET) and Philip Fairey of the Florida Solar Energy Center (FSEC). Finally, we would like to express our gratitude to Ed Pollock and George James of the U.S. Department of Energy for the leadership and resources needed to complete this work.

# Introduction

## Background

Building America 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 and existing residential buildings. This program supports seven 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; the overall goal is to reduce energy use significantly with little or no increase in initial construction costs. The energy efficiency concepts incorporated in these houses are evaluated by conducting successive design, test, redesign, and retest iterations, including cost and performance trade-offs; the result will be innovations that can be used cost-effectively in production-scale housing.

The multiyear goals of the Building America program are as follows:

- Reduce whole-house energy use by 40%-70% and cut both waste and construction time
- Improve indoor air quality and comfort
- Integrate clean, on-site power systems
- Encourage a systems engineering approach in the design and construction of new homes
- Accelerate the development and adoption of high-performance residential energy systems.

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 report summarizes the guidelines for reporting these analytical results using the Building America Research Benchmark (Version 3.1) in studies that also include consideration of current Regional and Builder Standard Practice models. Version 3.1 of the Building America Research Benchmark (in brief, the Benchmark) is generally consistent with the 1999 Home Energy Rating System (HERS) Reference Home, as defined by the the National Association of State Energy Officials/Residential Energy Services Network (NASEO/RESNET), with additions that allow the evaluation of all home energy uses.[1] Additional documentation to support the use of the Benchmark, including spreadsheets with detailed hourly energy usage and load profiles, can be found on the Building America Web site.[2] As Building America teams develop innovative new technologies and systems approaches that move the program toward its research goals, this report will be evaluated and updated periodically to ensure that energy savings from these features are accurately credited.

The Benchmark was developed to track and manage progress toward multi-year, average whole-building energy reduction research goals for new construction, using a fixed reference point. These research targets are summarized in Table 1. To provide a context for the potential impacts of research projects on local and regional markets at a given point in time, energy usage is also compared with current Regional Standard Practice and Builder Standard Practice. The use of the fixed Benchmark, combined with points of reference for the current Regional and Builder Standard Practice, provides a mechanism for tracking progress toward long-term research goals and ensuring that individual research projects are relevant to current builder needs.

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[1] The current HERS rating process is based on only hot water and space conditioning loads. RESNET has been considering amendments that will include additional end uses such as lighting and appliances.
[2] See www.eere.energy.gov/buildings/building_america/benchmark_def.html.

Standard user profiles for use in conjunction with these reference houses have been developed based on review of the available literature; the intent is to represent average occupant behavior. Additional analysis and end use monitoring are required to evaluate energy savings for specific occupants whose individual behavior could vary from the average profiles defined in the Benchmark (Norton 2003). In general, relative savings for an individual user are expected to be approximately the same as those for an average user.

**Table 1. Building America Energy Performance Goals for New Construction**
(% whole-house energy savings relative to the Benchmark)

| | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| Efficiency | 30 | 40-50 | 50-60 | 60-70 |
| On-Site Generation | 0-5 | 5-10 | 10-20 | 20-30 |
| Total (average) | 30 | 50 | 70 | 90 |

## Purpose of the Report

As Building America has grown to include a large and diverse cross-section of the home building industry, it has become more important to develop accurate, consistent analysis techniques. These are designed to help program partners as they 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 Building America teams and partners for calculating energy savings. This document illustrates some analysis concepts that are proven to be effective and reliable in analyzing the transient energy usage of advanced energy systems as well as of entire houses.

The analysis procedure described in this document provides a starting point for—

1. Calculating the whole-house energy savings of a Prototype house relative to three important base cases: the Building America Research Benchmark, Builder Standard Practice, and Regional Standard Practice.

2. Using building simulation analysis to calculate annual energy savings based on side-by-side short-term field testing of a Prototype house and base-case house(s).

3. Comparing analyses to field-test results.

This document is divided into two sections. Section I provides general recommendations for Prototype and base-case design assumptions, operating conditions, and analysis methods used to evaluate the performance of Building America houses. Many other valid techniques and definitions have been developed by other organizations, and they can be very useful to builders for specialized applications. For example, the HERS rating procedure (RESNET 2002) must be followed to obtain an ENERGY STAR® rating for building energy efficiency. Also, it might be necessary to determine whether or not a Prototype meets the International Energy Conservation Code (IECC) or Model Energy Code (MEC), which could apply if adopted by the state or local government.[3]

[3] Summaries of the IECC, MEC, and the HERS reference houses are included in Appendix B. Additional information about these reference cases can be found at the U.S. Department of Energy Codes and Standards Web

Section II presents guidelines for effective hourly analysis of residential buildings using the DOE-2.2 building simulation tool. 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. The simulation concepts are very robust and can be beneficial to both novice and experienced DOE-2 modelers.

For consistency, DOE-2 (with or without a graphical user interface, such as EnergyGauge) is recommended as the simulation program for Building America analysis. However, in cases where a house contains important features that cannot be modeled accurately with DOE-2, any simulation program with hourly or shorter time steps may be used as long as it has passed the Building Energy Simulation Test (BESTEST) software testing procedure. Additional information about BESTEST can be found at www.eren.doe.gov/buildings/tools_directory/software/bestest.htm.

Two example reports in Appendix C at the end of this document provide analytical results for a Building America project using DOE-2.2 simulations and the analysis and reporting guidelines in this report. Application notes are included in Appendix D to help users of EnergyGauge simulate a Building America Prototype or Benchmark in a consistent manner.

## What's New in Revision 1?

Revision 1 includes several important changes and updates to the original *Building America House Performance Analysis Procedures* (NREL Report No. TP-550-27754, September 2001):

- The Building America Research Benchmark has been added as an important base case alongside the Builder Standard Practice and Regional Standard Practice, for reporting analytical results.
- Specifications for all energy end uses have been added to the Builder Standard Practice and Regional Standard Practice base cases. The original version of this report included specific characteristics only for space conditioning and hot water.
- More comprehensive guidelines for modeling the Prototype are included, such as compliance with ASHRAE Standard 62.2 and calculation of duct losses using ASHRAE 152.
- New reporting requirements have been developed to allow users to quickly identify key analytical results and compare multiple Prototypes on a consistent basis.
- New examples have been created using all three base cases, all energy end uses, and the new reporting requirements.

We anticipate that further versions of this document will be required as the Building America teams gain experience in using this approach and as they identify any improvements that should be made to the evaluation procedures.

# Section I. General Performance Analysis Guidelines

## Analysis Tools

A key issue in any building energy analysis is which tool or program to choose 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 be accurately modeled only by using a model that calculates heat transfer and temperature in short time intervals. In addition, an hourly simulation program is also 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 DOE Building America program.

EnergyGauge[5] is a frequently used interface for DOE-2; it has been tailored specifically to residential buildings. EnergyGauge can also automatically calculate HERS scores and evaluate compliance with the IECC performance path. Teams are also encouraged to use other simulation tools when appropriate for specialized building simulation analysis, provided the tool has met the requirements of BESTEST in accordance with the software certification sections of the RESNET/HERS Guidelines (RESNET 2002). Regardless of the tool selected, teams should present complete analysis results, in accordance with the reporting guidelines described later in this section.

Section II presents guidelines and examples based on DOE-2.2, but the analysis process is relevant regardless of the simulation tool being used. Example DOE-2 input files that define materials, systems, and boundary conditions consistent with the Benchmark and other base-case houses were developed to speed analysis and reduce the potential for input errors; these are included on the Building America Web site at www.eere.energy.gov/buildings/building_america/benchmark_def.html. Similarly, two EnergyGauge input files representing the Benchmark were developed in accordance with the guidelines in this report, and are also posted on the Web site. A full summary of building energy simulation tools can be found at www.eren.doe.gov/buildings/energy_tools/. This Web site also includes information about the new EnergyPlus tool sponsored by DOE.

## Standard Assumptions Used in the Base-Case Designs

Throughout the rest of this document, the term "base case" refers to one of the following:

- **Building America Research Benchmark**. This base case represents typical standard practice in the mid-1990s, when DOE initiated the Building America program. The Benchmark is used as the point of reference for tracking progress toward multiyear energy savings goals established by Building America. The Benchmark is generally consistent with the HERS Technical Guidelines established by NASEO/RESNET in 1999 with additional specifications for end uses not addressed by HERS.
- **Regional Standard Practice**. This base case represents a house design that is most commonly built in the same geographic region as the Prototype house. Energy savings relative to Regional

[4] Summaries of the IECC, MEC, and the HERS reference houses are included in Appendix B. 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/).

[5] This is available for purchase from the Florida Solar Energy Center (http://energygauge.com/).

Standard Practice is an important measure of how a Building America Prototype compares with similar houses currently being built in a particular market.

- **Builder Standard Practice**. This base case describes a house design that would be constructed by a builder who is not participating 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 a 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 is often not practical. Energy savings relative to the Builder Standard Practice provides a measure of the direct influence of Building America for a particular house.

The term "Prototype" refers to a research house with advanced systems and design features built for the first time as part of the Building America program.

## *1. Building America Research Benchmark*

### *General*

Any element of the Benchmark definition that is not specifically addressed in the following sections is assumed to be the same as the Prototype. Because the definition is intended to be tool-neutral, certain elements of the Benchmark cannot be modeled directly in DOE-2, EnergyGauge, or other simulation tools. To assist in the consistent application of these guidelines, Section II of this report discusses some of the practical issues associated with simulating the Benchmark using DOE-2.2; Appendix D includes similar application notes for EnergyGauge users.

### *Building Envelope*

All building envelope components (including walls, windows, foundation, roof, and floors) for the Benchmark shall be consistent with the HERS Reference Home as defined by NASEO/RESNET in the "National Home Energy Rating Technical Guidelines," dated September 19, 1999 (NASEO 1999). These requirements are summarized below, along with a few minor clarifications and additional requirements. References to U-values in the 1993 MEC have been updated to 2003 IECC, because the corresponding U-values are identical and the IECC is more readily available (ICC 2003).
The requirements are as follows:

- The same shape and size as the Prototype
- The same area of surfaces bounding conditioned space as the Prototype, with the exception of the attic (this shall be insulated at the attic floor and have a ventilation area of 1 $ft^2$ per 300 $ft^2$ ceiling area, regardless of the Prototype attic design)
- The same foundation type (slab, crawl space, or basement) as the Prototype
- The same basement wall construction type as the Prototype (e.g., masonry, wood frame, other)
- No sunrooms
- No horizontal fenestration, defined as skylights, or light pipes oriented less than 45 degrees from a horizontal plane
- Window area ($A_F$) determined by Equation 1 for detached homes and by Equation 2 for attached homes

**Equation 1:** $A_F = 0.18 \times A_{FL} \times F_A$ ,
**Equation 2:** $A_F = 0.18 \times A_{FL} \times F_A \times F$ ,

where

$A_F$ = total window area
$A_{FL}$ = total floor area, including basement
$F_A$ = (exposed thermal boundary wall area)/(total thermal boundary wall area).
F = (total thermal boundary wall area)/(total thermal boundary wall area + common wall area), or 0.56, whichever is greater,

and where

*total thermal boundary wall* is any wall that separates directly or indirectly conditioned space from unconditioned space or ambient conditions, including all insulated basement walls but not including unvented crawl space walls;

*exposed thermal boundary wall* is any thermal boundary wall not in contact with soil; and

*common wall* area is the total area of walls adjacent to another conditioned living unit, including basement and directly or indirectly conditioned crawl space walls.

- Window area assigned according to the following requirements:
  - Distributed equally in each of the four cardinal directions (north, south, east and west); for orientation neutrality in attached homes, this may require windows located in common walls.
  - Vertical distribution on each façade shall be in proportion to the fraction of thermal boundary wall area on the façade associated with each floor, including the basement. This may require window wells for below-grade basement walls if the Prototype includes a walk-out basement. If the modeling tool does not allow windows in basement walls, then the entire window area shall be distributed in proportion to the external wall area of the façade for above-grade floors.
- Thermal conductance of all thermal boundary elements equal to the requirements, expressed as U and $U_o$ values, of Paragraph 502.2 of the 2003 IECC (ICC 2003), as summarized below. Unless otherwise specified, these U-values are for entire assemblies, including sheathing, framing, finishes, and so on.
  - Total wall assembly $U_o$ from Figure 1 (excerpted from ICC 2003).
  - U-value ($U_w$) for the opaque fraction of exterior walls from Table 2 or 3, as appropriate.

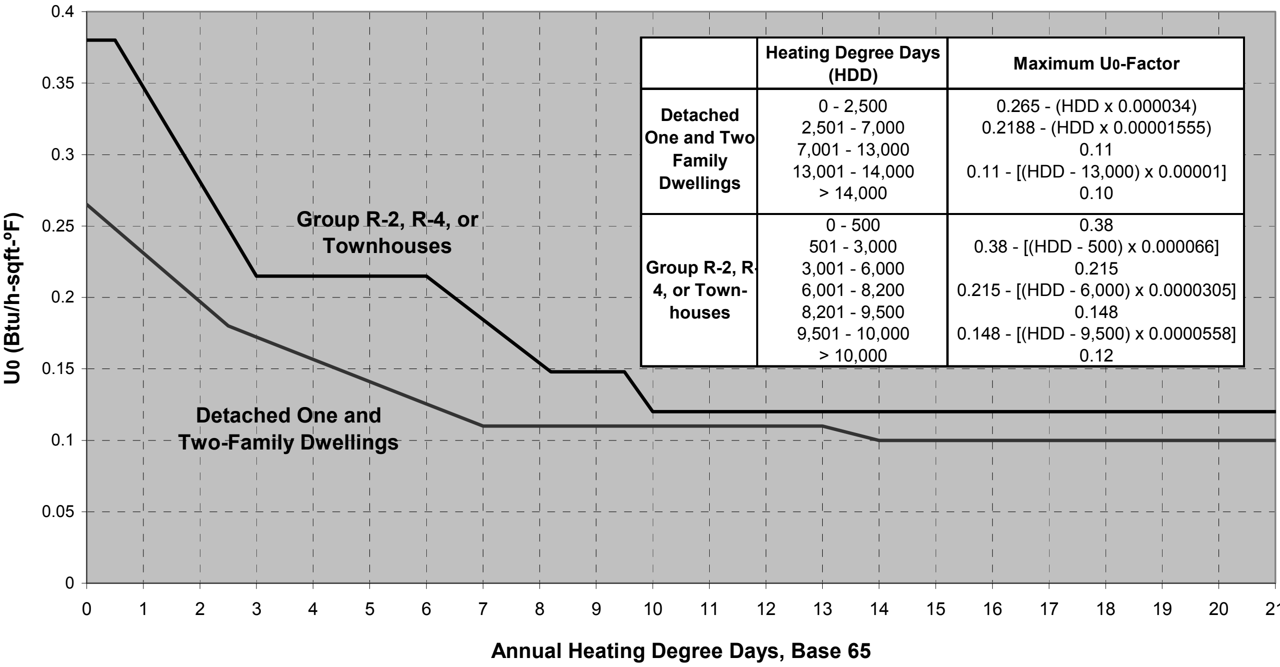



**Figure 1. Wall assembly U-value ($U_0$)** (Excerpted from ICC 2003)

**Table 2. Opaque Wall U-Values ($U_w$) for Detached Homes**

| Annual Heating Degree Days Base 65 (HDD65) from Nearest Location Listed in Chapter 9 of ASHRAE Standard 90.2 or NREL's *Solar Radiation Data Manual*[7] | $U_w$ Air to Air, Includes Framing |
|---|---|
| > 13000 | 0.038 |
| 9000-12999 | 0.046 |
| 6500-8999 | 0.052 |
| 4500-6499 | 0.058 |
| 3500-4499 | 0.064 |
| 2600-3499 | 0.076 |
| <2600 | 0.085 |

[7] See *Solar Radiation Data Manual for Buildings* (or the "Blue Book") published by the National Renewable Energy Laboratory (NREL 1995) (http://rredc.nrel.gov/solar/old_data/nsrdb/bluebook/).

**Table 3. Opaque Wall U-values ($U_w$) for Attached Homes**

| Heating Degree Days Base 65 (HDD65) from Nearest Location Listed in Chapter 9 of ASHRAE Standard 90.2, or NREL's *Solar Radiation Data Manual* | $U_w$ Air to Air, Includes Framing |
|---|---|
| >9000 | 0.064 |
| 7100-8999 | 0.076 |
| 3000-7099 | 0.085 |
| 2800-2999 | 0.100 |
| 2600-2799 | 0.120 |
| <2600 | 0.140 |

- The U-value for windows is calculated using Equation 3 or is equal to 1.3, whichever is less.

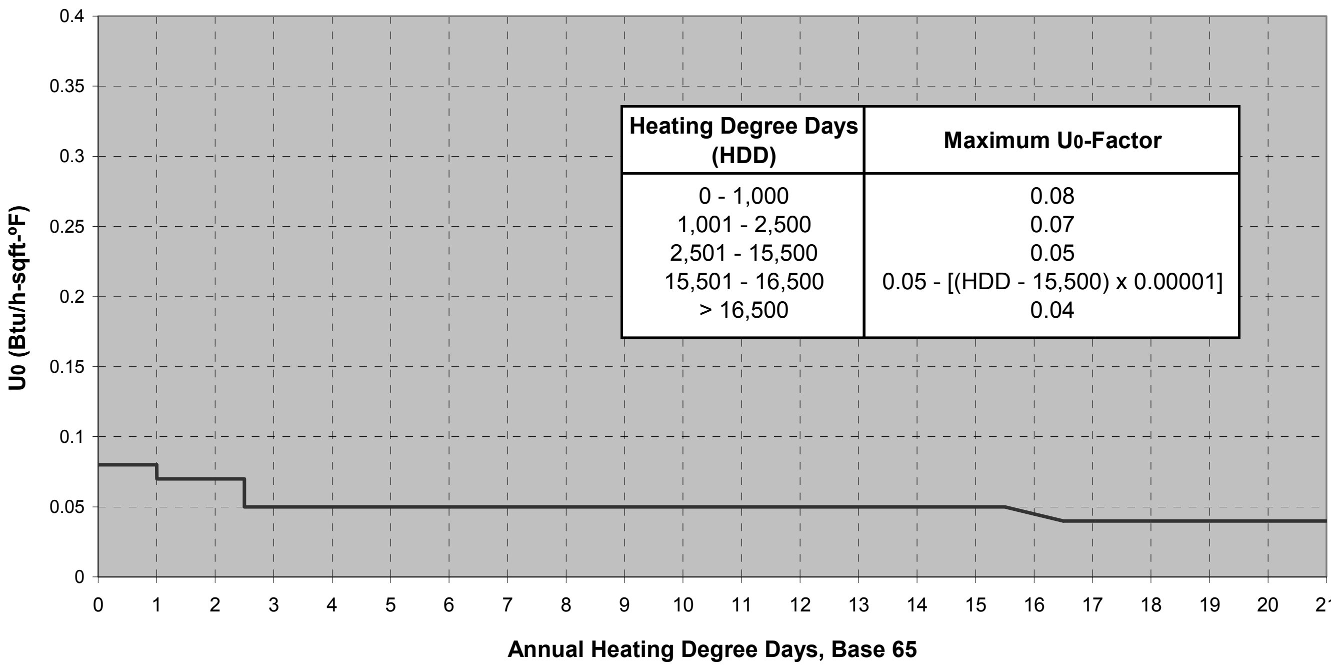
**Equation 3:** $U_F = [(U_o \times A_o)-(U_w \times A_w)-8]/A_F$ ,

where

$U_F$ = required average U-value of the windows, including framing and sash
$U_o$ = average U-value requirement for walls from Figure 1
$A_o$ = gross exposed wall area, not including basement or crawl space walls, of the Prototype
$U_w$ = U-value from Table 2 or 3
$A_w$ = net opaque wall area, calculated as: $A_o$ - $A_F$ - 40
$A_F$ = area of windows.

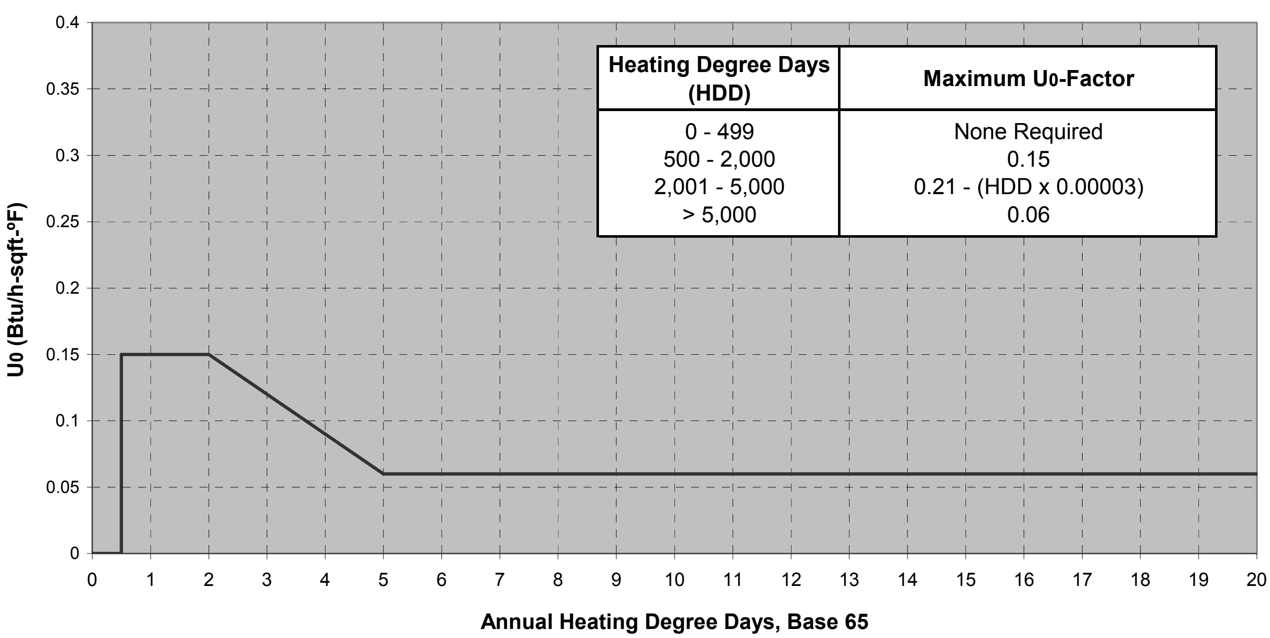
Note: For walls of attached homes, the U-value in Equation 3 is calculated by using the total window area calculated as $A_F$ and the actual area of walls that experience heat loss or gain. Areas of common walls that separate homes are not included in $A_o$.

- U-value of an insulated floor above a vented crawl space or other unconditioned space shall be as specified in Figure 2 (excerpted from ICC 2003).
- U-value of insulated walls in an unvented crawl space shall be as specified in Figure 3 (excerpted from ICC 2003). This U-value represents the combined effect of wall components and the surface air film, but it does not include adjacent soil.
- U-value of insulated basement walls shall be as specified in Figure 4 (excerpted from ICC 2003), and the insulation shall be located on the interior surface of the walls. This U-value represents the basement wall assembly, including the surface air film, but it does not include ground effects.
- R-value and depth of slab edge insulation for slab-on-grade construction shall be as specified in Figure 5 (excerpted from ICC 2003). This R-value is for rigid foam insulation and does not include ground effects.
- U-value of insulated roof/ceiling shall be as specified in Figure 6 (excerpted from ICC 2003). If the Prototype includes an attic, the Benchmark shall have an unconditioned attic with insulation at the attic floor.



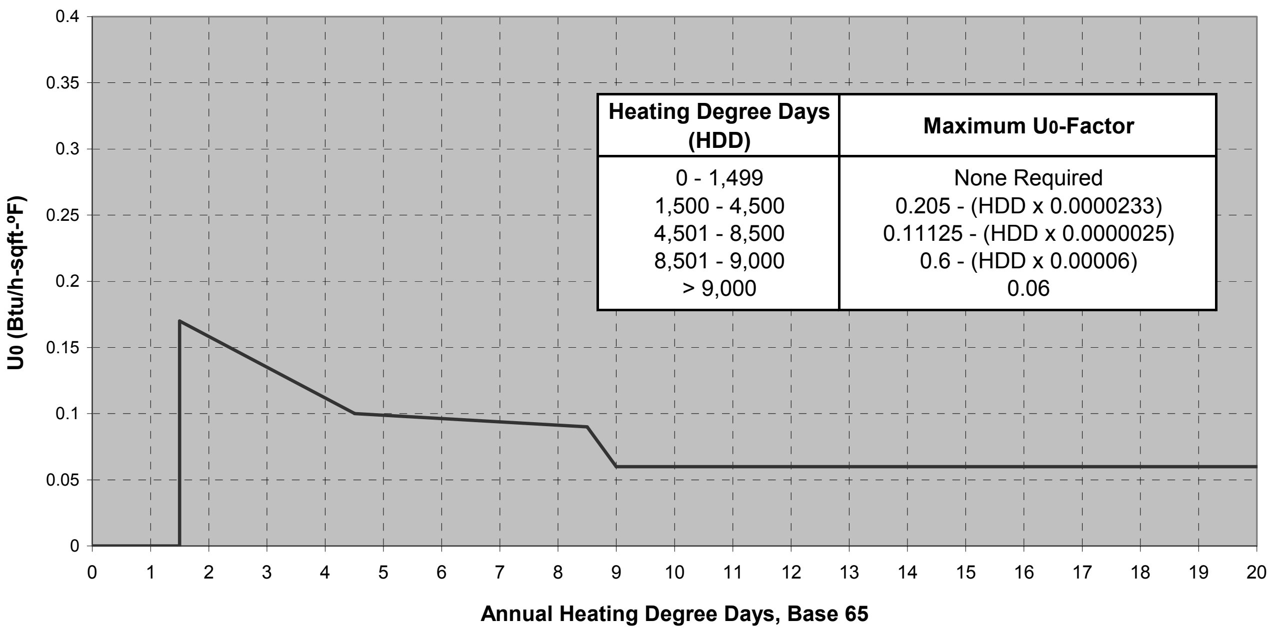

| Heating Degree Days (HDD) | Maximum U0-Factor |
|---|---|
| 0 - 1,000 | 0.08 |
| 1,001 - 2,500 | 0.07 |
| 2,501 - 15,500 | 0.05 |
| 15,501 - 16,500 | 0.05 - [(HDD - 15,500) x 0.00001] |
| > 16,500 | 0.04 |

**Figure 2. U-value of floor over unconditioned space** (Excerpted from ICC 2003)



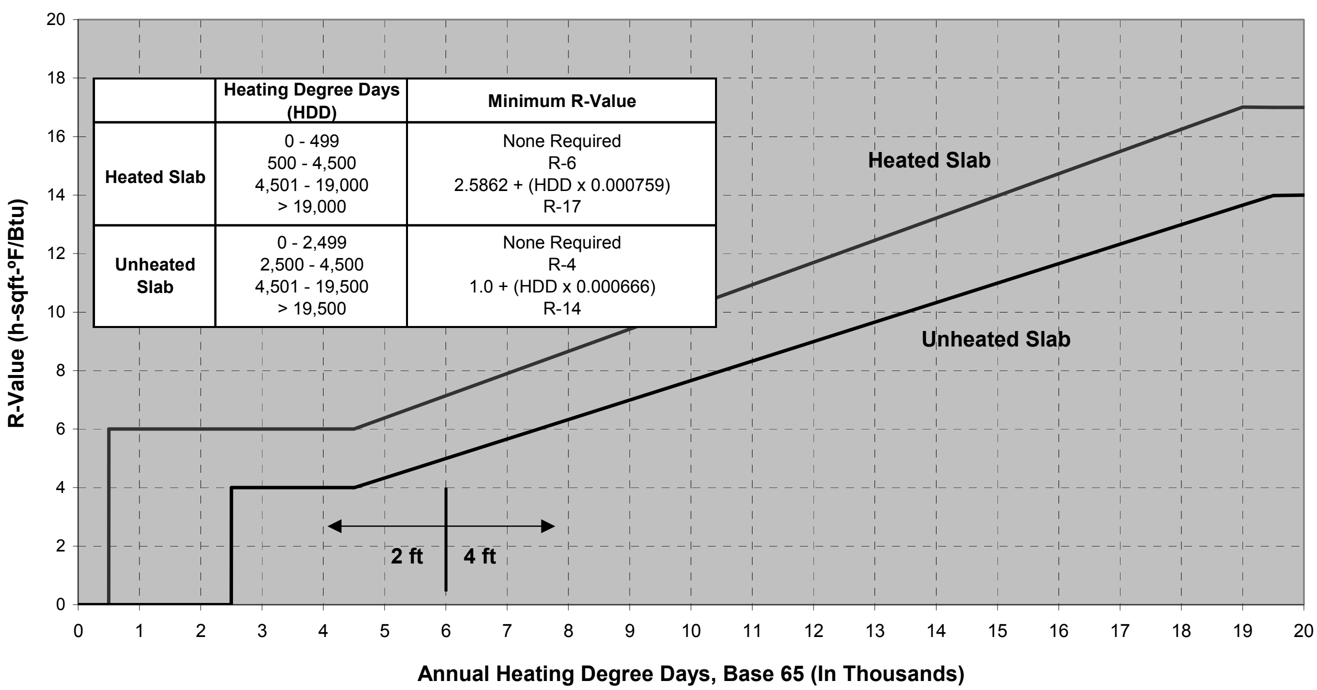

| Heating Degree Days (HDD) | Maximum U0-Factor |
|---|---|
| 0 - 499 | None Required |
| 500 - 2,000 | 0.15 |
| 2,001 - 5,000 | 0.21 - (HDD x 0.00003) |
| > 5,000 | 0.06 |

**Figure 3. Unvented crawl space wall U-value** (Excerpted from ICC 2003)




| Heating Degree Days (HDD) | Maximum $U_0$-Factor |
|---|---|
| 0 - 1,499 | None Required |
| 1,500 - 4,500 | 0.205 - (HDD x 0.0000233) |
| 4,501 - 8,500 | 0.11125 - (HDD x 0.0000025) |
| 8,501 - 9,000 | 0.6 - (HDD x 0.00006) |
| > 9,000 | 0.06 |

**Figure 4. Basement wall U-value** (Excerpted from ICC 2003)




| | Heating Degree Days (HDD) | Minimum R-Value |
|---|---|---|
| Heated Slab | 0 - 499<br>500 - 4,500<br>4,501 - 19,000<br>> 19,000 | None Required<br>R-6<br>2.5862 + (HDD x 0.000759)<br>R-17 |
| Unheated Slab | 0 - 2,499<br>2,500 - 4,500<br>4,501 - 19,500<br>> 19,500 | None Required<br>R-4<br>1.0 + (HDD x 0.000666)<br>R-14 |

**Figure 5. Slab insulation R-value and depth** (Excerpted from ICC 2003)

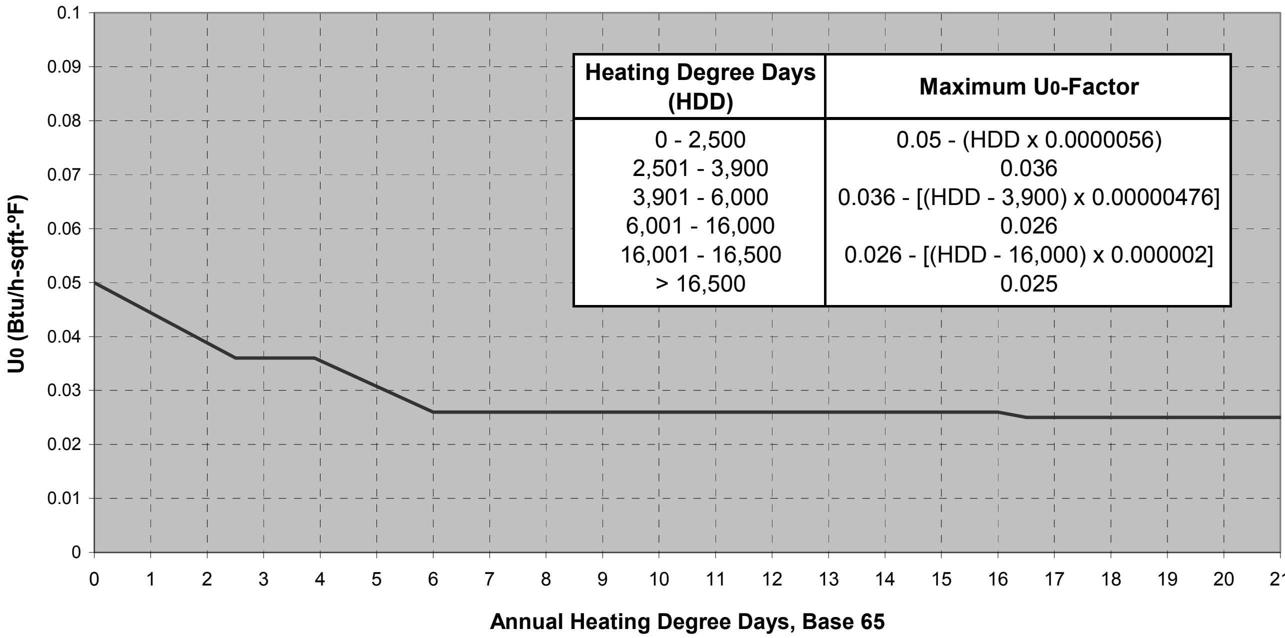



**Figure 6. Roof/ceiling assembly U-value** (Excerpted from ICC 2003)

- Solar heat gain coefficient (SHGC) equal to 0.581 for window assemblies, including the effects of framing and sash. [8]
- No external shading at any time from roof projections, awnings, adjacent buildings, trees, etc.; basic architectural features such as attached garages and enclosed porches shall be included in the Benchmark model, but it shall not include window shading effects from these features.
- No self-shading shall be modeled for the Benchmark.
- Total area of opaque exterior doors is equal to 40 $ft^2$, facing north, with door U-value equal to 0.20 (air to air).
- Solar absorptivity is equal to 0.50 for opaque areas of exterior walls, and 0.75 for opaque areas of roofs.
- Total emittance of exterior walls and roofs is equal to 0.90.
- The above-grade exterior walls shall be light-frame 2x4 or 2x6 wood construction with sufficient insulation to achieve the correct overall U-value. The framing factors in Table 4 are representative of typical construction practices, and shall be used as inputs for the Benchmark model.

[8] When using EnergyGauge in the Rating Entry Mode for simulation of the Benchmark, the window assembly SHGC should be entered as 0.65. This value of SHGC yields summer and winter SHGC values consistent with the autogenerated HERS Reference Home after interior shading coefficients are applied by EnergyGauge. In the Detailed Entry Mode, when the HERS score is not an issue, the "internal shading" option should be selected in conjunction with the Benchmark SHGC of 0.581. The EnergyGauge internal shading coefficients of 0.9 and 0.7 are acceptably close to the Benchmark coefficients of 0.85 and 0.7.

**Table 4. Benchmark Framing Factors**

| Enclosure Element | Frame Spacing (inches o.c.) | Framing Fraction (% area) |
|---|---|---|
| Walls | 16 | 23% |
| Floors | 16 | 13% |
| Ceilings | 24 | 11% |

- Interior partition walls shall be light-frame (2x4) wood construction.
- Masonry floor slabs shall have 80% of floor area covered by R-2 carpet and pad and 20% of floor area directly exposed to room air.

*Space Conditioning/Air Distribution Equipment*

Space conditioning equipment type and efficiency for the BA Benchmark shall meet the following requirements:

- The minimum National Appliance Energy Conservation Act (NAECA) efficiency in effect on January 1, 1992, for the same type of heating, ventilating, and air-conditioning (HVAC) equipment found in the Rated Home, except that the efficiencies given in Table 5 are assumed when
    (a) A type of device not covered by NAECA is used in the Prototype.
    (b) The Prototype is heated by electricity using a device other than an air source heat pump.
    (c) The Prototype does not have a heating system, and there is at least one month in which heating is required (see the section on Operating Conditions).
    (d) The Prototype does not have a cooling system.
- Heating and cooling equipment (including the air handler) shall be sized using the procedures published by the Air Conditioning Contractors of America (ACCA). (See www.accaconference.com/Merchant2/merchant.mv?Screen=CTGY&Store_Code=ACCOA&Category_Code=M)
- The Benchmark shall not have a whole-house fan.
- The Benchmark shall have no supplemental dehumidification beyond that provided by a standard air conditioner.
- The Benchmark air handler shall have power consumption equal to 0.00055 kW/cfm.

The air distribution system in the Benchmark shall have the properties listed in Table 6; the location of the ductwork is based on the air handler's location in the Prototype. If the simulation tool does not permit the input of duct specifications to this level of detail, then two values (one for heating, one for cooling) of seasonal distribution system efficiency (DSE) shall be estimated and applied to the heating and cooling system efficiencies to represent typical losses from ducts. The DSE values shall be determined using Table 6 and the procedures in the Draft ASHRAE Standard 152P (ASHRAE 2001). A spreadsheet developed by Lawrence Berkeley National Laboratory (LBNL) and modified by the National Renewable Energy Laboratory (NREL) is posted on the Building America Web site to assist with this calculation.

### Table 5. Benchmark Space Conditioning Equipment Efficiencies

| Prototype Equipment | Function | Benchmark Space Conditioning Device |
|---|---|---|
| Electric or No System | Heating | 6.8 HSPF Air Source Heat Pump |
| Non-Electric Boiler | Heating | 80% AFUE Gas Boiler |
| Non-Electric Warm Air Furnace or Other Non-Electric Heating | Heating | 78% AFUE Gas Furnace |
| Any Type or No System | Cooling | 10 SEER Electric Air Conditioner |

### Table 6. Duct Locations and Specifications for the Benchmark

| | Prototype Air Handler Location[a] | Benchmark Duct Specification | |
|---|---|---|---|
| | | ***One-Story*** | ***Two-Story or Higher*** |
| Supply Duct Surface Area ($ft^2$) | All | 0.27 x FFA[b] | 0.20 x FFA |
| Return Duct Surface Area ($ft^2$) | All | 0.05 x $N_{returns}$ x FFA (Maximum of 0.25 x FFA) | 0.04 x $N_{returns}$ x FFA (Maximum of 0.19 x FFA) |
| Supply Duct Insulation (Conditioned Space) | All | R-3.3 | |
| Return Duct Insulation (Conditioned Space) | All | None | |
| Supply/Return Duct Insulation (Unconditioned Space) | All | R-5.0 | |
| Duct Material | All | Sheet Metal | |
| Duct Leakage (Inside + Outside) | All | 10% of Air Handler Flow (6.5% Supply, 3.5% Return) (Percentage lost to each space equal to percentage of duct area in that space, as specified below) | |
| Supply Duct Location | Attic | 100% Attic | 65% Attic, 35% Conditioned Space |
| | Crawl space | 95% Crawl space, 5% Exterior Walls | 60% Crawl space, 35% Conditioned Space, 5% Exterior Walls |
| | Basement | 95% Basement, 5% Exterior Walls | 60% Basement, 35% Conditioned Space, 5% Exterior Walls |
| | Other Location or Ductless System (≥ 5000 HDD) | 95% Basement (Or attic if Prototype has no basement), 5% Exterior Walls | 60% Basement (Or attic if Prototype has no basement), 35% Conditioned Space, 5% Exterior Walls |
| | Other Location or Ductless System (< 5000 HDD) | 100% Attic | 65% Attic, 35% Conditioned Space |
| Return Duct and Air Handler Location | Attic | 100% Attic | 100% Attic |
| | Crawl space | 95% Crawl space, 5% Exterior Walls | 95% Crawl space, 5% Exterior Walls |
| | Basement | 95% Basement, 5% Exterior Walls | 95% Basement, 5% Exterior Walls |
| | Other Location or Ductless System (≥ 5000 HDD) | 95% Basement (Or attic if Prototype has no basement), 5% Exterior Walls | 95% Basement (Or attic if Prototype has no basement), 5% Exterior Walls |
| | Other Location or Ductless System (< 5000 HDD) | 100% Attic | 100% Attic |

[a] If the Prototype has more than one air handler, the properties of the Benchmark air distribution system shall be apportioned based on the capacity of each air handler.
[b] Finished floor area.

### *Domestic Hot Water*

The assumptions in Table 7 shall be made for the domestic hot water system in the Benchmark. Both storage and burner capacity are determined using the guidelines recommended by ASHRAE in the *HVAC Applications Handbook* (ASHRAE 1999); these are based on the minimum capacity permitted by the Department of Housing and Urban Development (HUD) and the Federal Housing Administrations (FHA) (HUD 1982). Energy factor is the NAECA minimum for the corresponding fuel type and storage capacity (DOE 2002a). An example set of DHW specifications for a typical three-bedroom, two-bathroom Prototype is shown in Table 8. The "Appliance and DHW" spreadsheet developed by NREL automates many of the equations discussed in the following paragraphs and can be downloaded from the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html).

**Table 7. Characteristics of Benchmark Domestic Hot Water System**

| | Water Heater Fuel Type in Prototype | |
|---|---|---|
| | ***Electric*** | ***Gas*** |
| Storage Capacity (V) (Gallons) | See *ASHRAE HVAC Applications 1999* | See *ASHRAE HVAC Applications 1999* |
| Energy Factor (EF) | 0.93 – (0.00132 x V) | 0.62 – (0.0019 x V) |
| Recovery Efficiency (RE) | 0.98 | 0.76 |
| Burner Capacity | See *ASHRAE HVAC Applications 1999* | See *ASHRAE HVAC Applications 1999* |
| Hot Water Set-Point | 120°F | |
| Fuel Type | Same as Prototype[a] | |
| Tank Location | Same as Prototype | |

[a] *If the Prototype does not have a DHW system, or the hot water system uses solar energy or a fuel other than gas or electricity, the Benchmark shall use the same fuel for water heating as that used for space heating.*

**Table 8. Example Characteristics of Benchmark Domestic Hot Water System for a Prototype with Three Bedrooms and Two Bathrooms**

| | Water Heater Fuel Type in Prototype | |
|---|---|---|
| | ***Electric*** | ***Gas*** |
| Storage Capacity (V) (Gallons) | 50 | 40 |
| Energy Factor (EF) | 0.86 | 0.54 |
| Recovery Efficiency (RE) | 0.98 | 0.76 |
| Burner Capacity | 5.5 kW | 36,000 Btu/hr |
| Supply Temperature | 120°F | |
| Fuel Type | Same as Prototype | |
| Tank Location | Same as Prototype | |

NREL has also developed a spreadsheet that calculates the correct DHW inputs for the TRANSYS computer program, including standby heat loss coefficient (UA). The spreadsheet also has a comprehensive set of inputs and outputs that can be used to help calculate DHW properties for the Prototype house (Burch 2004). It can be found on the Building America Web site in the section for building scientists (www.eere.energy.gov/buildings/building_america/benchmark_def.html).

Four major end uses are identified for domestic hot water: showers, sinks, dishwasher, and clothes washer. The average daily water consumption by end use is shown in Table 9. The specified volume is the combined hot and cold water for showers and sinks, which allows hot water use to fluctuate, depending on the cold water (mains) temperature.[10] Hot water usage for the clothes washer and dishwasher is derived from the EnergyGuide labels for the least efficient of several common models sampled by NREL. For showers and sinks, the water usage is based on the average of four domestic hot water studies (Christensen 2000, Burch 2002, ASHRAE 1999, and CEC 2002). The relationship between the number of bedrooms and hot water usage was derived from the 1997 Residential Energy Consumption Study (RECS) (DOE 1999). This relationship also applies to machine energy for certain appliances.

**Table 9. Domestic Hot Water Consumption by End Use**

| End Use | End-Use Water Temperature | Water Usage |
|---|---|---|
| Clothes Washer | N/A | 7.5 + 2.5 x $N_{br}$ gal/day (Hot Only) |
| Dishwasher | N/A | 2.5 + 0.833 x $N_{br}$ gal/day (Hot Only) |
| Shower and Bath | 105°F | 14 + 4.67 x $N_{br}$ gal/day (Hot + Cold) |
| Sinks | 105°F | 10 + 3.33 x $N_{br}$ gal/day (Hot + Cold) |

The typical ASHRAE hot water use profile (see Figure 7) is adequate for analyzing most applications (ASHRAE 1999). NREL is currently investigating profiles for individual hot water end uses. In the meantime, the ASHRAE profile shall be used for each hot-water-consuming appliance, as well as sinks and showers.

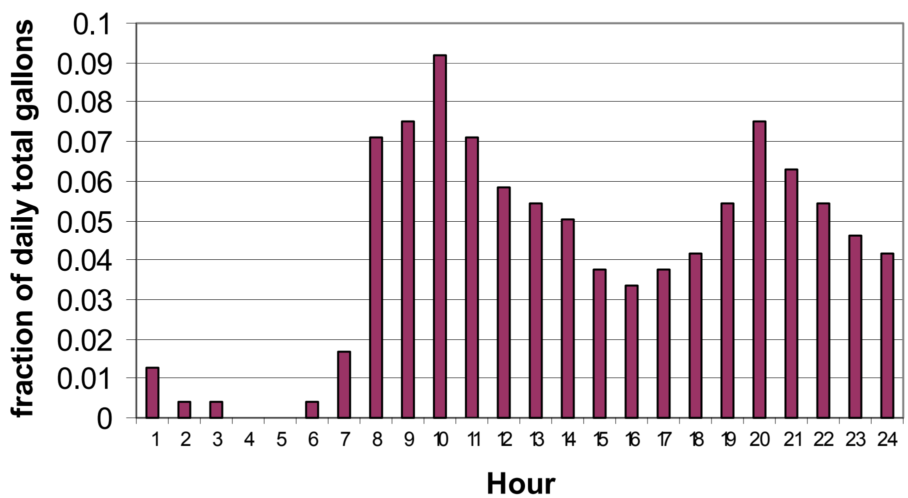



**Figure 7. ASHRAE hot water use profile** (Source: ASHRAE 1999)

The mains water temperature for a typical house varies significantly depending on the location and time of year. The following equation, based on TMY2 data for the location of the Prototype, shall be used to determine the daily mains water temperature for both the Benchmark and the Prototype:

**Equation 5:** $T_{mains} = (T_{amb,avg} + \mathit{offset}) + \mathit{ratio} * (\Delta T_{amb,max} / 2) * \sin(0.986 * (\mathrm{day\#} - 15 - \mathit{lag}) - 90)$ ,

[10] The clothes washer in the Prototype may also consume a variable amount of hot water depending on mains temperature if it uses a thermostatic control valve to adjust the proportion of hot and cold water necessary to maintain a certain wash temperature. However, the Benchmark clothes washer does not have this feature.

where

| | |
|---|---|
| $T_{mains}$ | = mains (supply) temperature to domestic hot water tank |
| $T_{amb,avg}$ | = annual average ambient air temperature |
| $\Delta T_{amb,max}$ | = maximum difference between monthly average ambient temperatures (e.g., $T_{amb,avg,july} - T_{amb,avg,january}$) |
| 0.986 | = degrees/day (360/365) |
| day# | = Julian day of the year (1-365) |
| *offset* | = 6°F |
| *ratio* | = $0.4 + 0.01\ (T_{amb,avg} - 44)$ |
| *lag* | = $35 - 1.0\ (T_{amb,avg} - 44)$. |

This equation is based on analysis by Christensen and Burch of NREL using data for multiple locations, as compiled by Abrams and Shedd (Abrams 1996), Florida Solar Energy Center (Parker 2002), and Sandia National Laboratories (Kolb 2003). The *offset, ratio,* and *lag* factors were determined by fitting the available data. The climate-specific *ratio* and *lag* factors are consistent with water pipes being buried deeper in colder climates.

In order for the constant terms in the *ratio* and *lag* factors to be representative of an average climate, the data fitting was done relative to a nominal $T_{amb,avg}$ = 44ºF. The *lag* is relative to ambient air temperature, and $T_{amb,minimum}$ is assumed to occur in mid-January (day# = 15). The choices for these nominal values are not critical, because although different assumptions would change the constant terms in the *ratio* and *lag* factors, the coefficients would also change, so the prediction of $T_{mains}$ values would be unchanged. For models that use average monthly mains temperature, day# in Equation 5 shall be calculated using Equation 6.

**Equation 6: day# = 30 * month# - 15 ,**
where month# = month of the year (1–12).

An example of using Equations 5 and 6 to determine the monthly mains temperature profile for Chicago, Illinois, is shown in Figure 8.

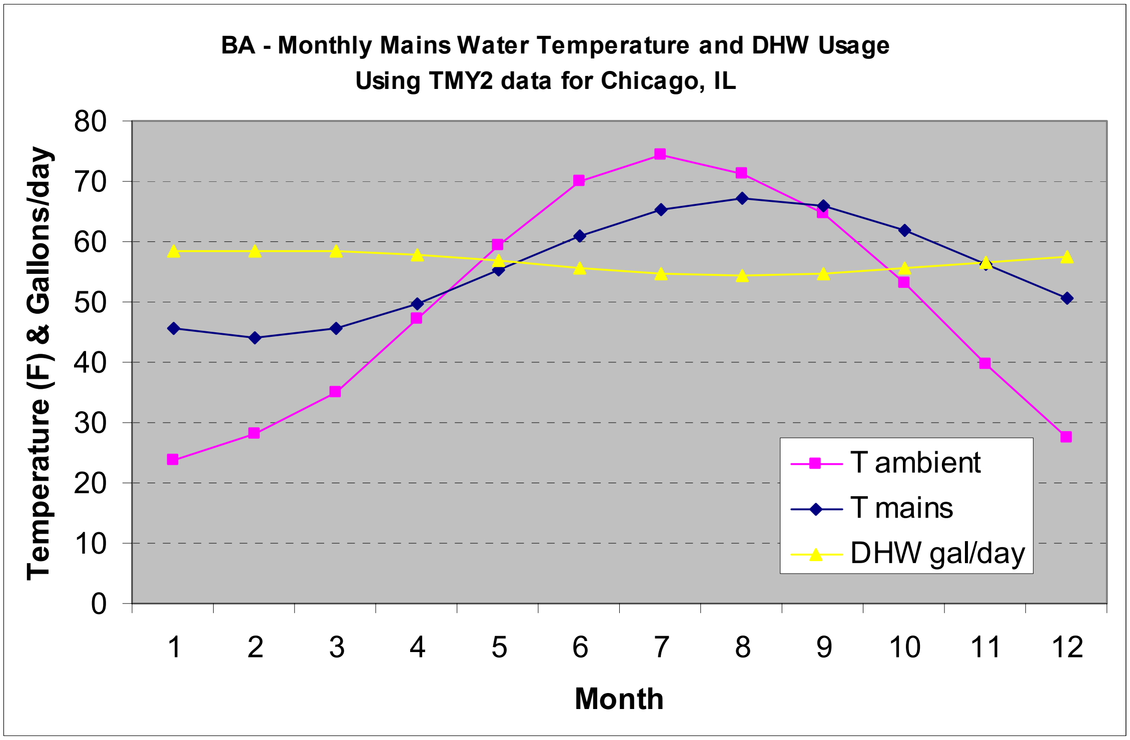



**Figure 8. Mains temperature profile for Chicago**

*Air Infiltration and Ventilation*

The natural air change rate for the Benchmark shall be based on the annual average ACH determined using Equation 7:

**Equation 7:** $\mathbf{ACH = L_n \times W \times F_B}$ **,**

where ACH = (volumetric rate at which outside air enters the home) / (building volume including all directly or indirectly conditioned basements and crawl spaces)

$L_n$ = normalized leakage = 0.75 [11]

W = Weather factor from W tables in ASHRAE Standard 136-1993 for the site most representative of the climate at the Prototype's location

$F_B$ = (exposed thermal boundary surface area)/(total thermal boundary surface area),

and where

*total thermal boundary surface area* is the area of all surfaces that separate directly or indirectly conditioned space from unconditioned space or ambient conditions, including the walls and floors of unvented crawl spaces and directly or indirectly conditioned basements.

[11] The normalized leakage for the Benchmark has been increased from 0.57 (specified in the HERS 1999 guidelines) to 0.75 to compensate for the use of the term $F_B$, which ranges from 0-1 and adjusts ACH based on the fraction of thermal envelope area that is exposed to the outside (therefore contributing to the effective leakage area). The increased normalized leakage results in a typical slab-on-grade Prototype having the same annual average ACH as the Reference Home in HERS 99. Vented crawl spaces would result in higher ACH, while conditioned basements would have a lower ACH.

*exposed thermal boundary surface area* is the area of all thermal boundary surfaces not in contact with soil. An exception is the area of floors over unconditioned basements, which shall not be considered exposed in calculating $F_B$.

If the simulation tool is capable of calculating hourly air infiltration, an Effective Leakage Area or other input may be specified, as long as the annual average ACH is approximately equal to the value calculated above. No additional air exchange due to mechanical ventilation shall be assumed for the Benchmark.

An alternative approach for specifying natural infiltration for a Benchmark with a directly or indirectly conditioned basement is to adjust the Specific Leakage Area (SLA) to account for the in-ground portions of the walls of the conditioned basement. Equation 8 can be used to do this.

**Equation 8:** $$SLA_{overall} = [(CFA_{bsmt} * SLA_{bsmt}) + (CFA_{a\text{-}g} * SLA_{a\text{-}g})] / [CFA_{total}] ,$$

where

| | |
|---|---|
| SLA | = effective leakage area ($ft^2$) / CFA ($ft^2$) |
| $SLA_{a\text{-}g}$ | = $SLA_{std}$ (where subscript 'a-g' indicates above-grade or exposed) |
| $SLA_{bsmt}$ | = $SLA_{std}$*(above-grade basement wall area)/(total basement wall area) |
| $SLA_{std}$ | = 0.00057 |
| CFA | = conditioned floor area. |

This can be calculated by zone, applying $SLA_{bsmt}$ to the basement zone and $SLA_{std}$ to the above-grade zone of the Benchmark and treating the energy balances separately for each zone. It could also be done by applying $SLA_{overall}$ to the combined space in the Benchmark as a single zone.

Fan energy use for the Benchmark shall be calculated using Equation 9.

**Equation 9:** $$\text{Ventilation fan energy (kWh/yr)} = 0.03942 \times FFA + 29.565 \times (N_{br} + 1) ,$$

where FFA = finished floor area ($ft^2$)
$N_{br}$ = number of bedrooms.

Note that finished floor area is used in this equation instead of conditioned floor area. We believe that finished floor area more accurately represents the area that occupants use in their daily activities (see also the treatment of lighting and plug loads).

Cross-ventilation is available to provide natural ventilation in the Benchmark under favorable weather conditions.

### *Lighting Equipment and Usage*

The total annual lighting use for the Benchmark is determined using Equations 10-12. These equations are derived from data for both single-family and multi-family housing documented in a lighting study conducted by Navigant for DOE (Navigant 2002).

**Equation 10: Interior lighting = (FFA * 0.8 + 455) kWh/yr .**
**Equation 11: Garage lighting = 100 kWh/yr .**
**Equation 12: Exterior lighting = 250 kWh/yr .**

Annual indoor lighting, in kilowatt-hours, is expressed as a linear function of finished house area relative to a constant base value, while garage and exterior lighting are constants. This equation is in the middle range of residential lighting energy use found in other lighting references, as shown in Figure 9, including Huang and Gu (2002), the 1993 Residential Energy Consumption Survey (RECS) (DOE 1996), a Florida Solar Energy Center study (Parker 1992), default lighting for Visual DOE software (Eley 2002), a lighting study conducted by Navigant for DOE (Navigant 2002), and two other studies in Grays Harbor, Washington (Manclark and Nelson 1992), and Southern California (SCE 1993).

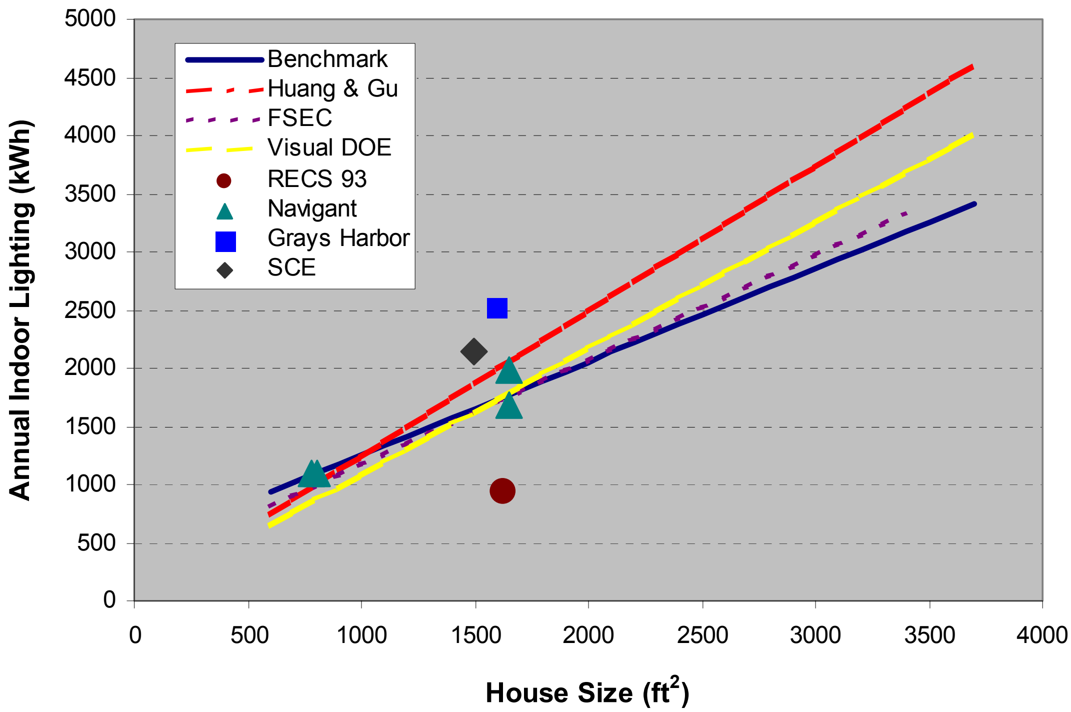



**Figure 9. Comparison of Benchmark lighting equation to other references**

The Benchmark lighting budget is based on an assumption that 90% of the interior lighting comes from fixtures that contain incandescent lamps, and the remaining 10% is assumed to come from fixtures containing fluorescent lamps. This is consistent with the source data set from 161 homes monitored by Tacoma Public Utilities (TPU) for the Bonneville Power Administration, which was the basis for the Navigant study. Although the core data set used in this study is the most complete and comprehensive residential lighting data set that we have identified, it is nevertheless limited in terms of geographic location, number of homes, length of study, percent of fixtures monitored, and type of homes studied. The Navigant report includes an appendix providing information about the characteristics of the homes monitored in the TPU study.

The annual average normalized daily load shape for interior lighting use is shown in Figure 10, and it is based on a draft LBNL report by Huang and Gu (2002). This load shape is also used for exterior and garage lighting. Monthly variations in load shape and lighting energy use due to changes in the length of days can be accounted for, as long as the variation is applied to all the simulation models and total annual energy use remains the same.

Energy savings may be calculated on the basis of a number of usage variations, depending on the capability of the modeling tool. Variations include day types (weekday vs. weekend), occupancy types (day-use vs. non-day-use or “nuclear” vs. “yuppie”), season (summer vs. winter), and room types (living area vs. bedroom area).

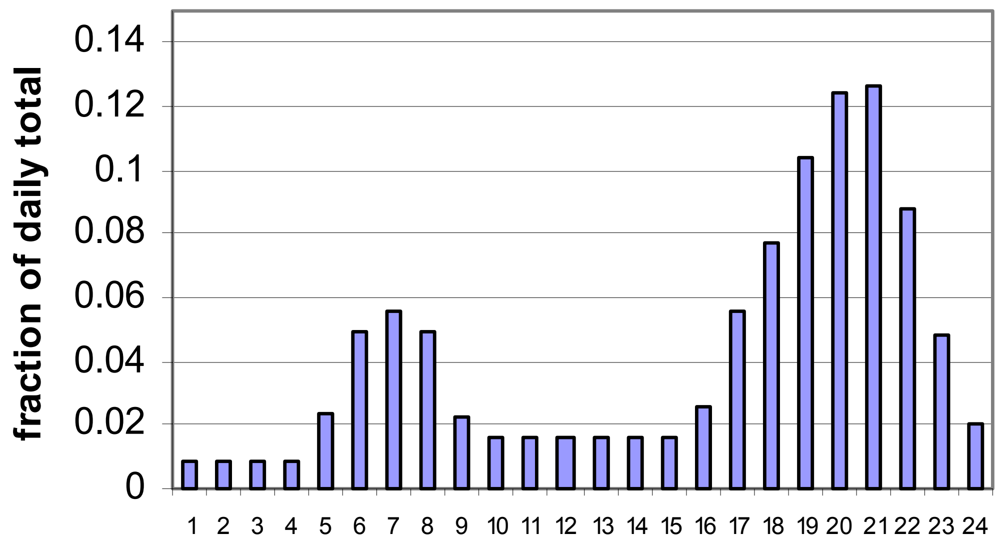



**Figure 10. Interior lighting profile** (Built up from detailed profiles)

Individual normalized profiles can be “rolled up” to various levels of detail appropriate to the simulation model. An example of one detailed set of profiles developed by NREL is shown in Figure 11. Other profiles are included in spreadsheets available on the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html).

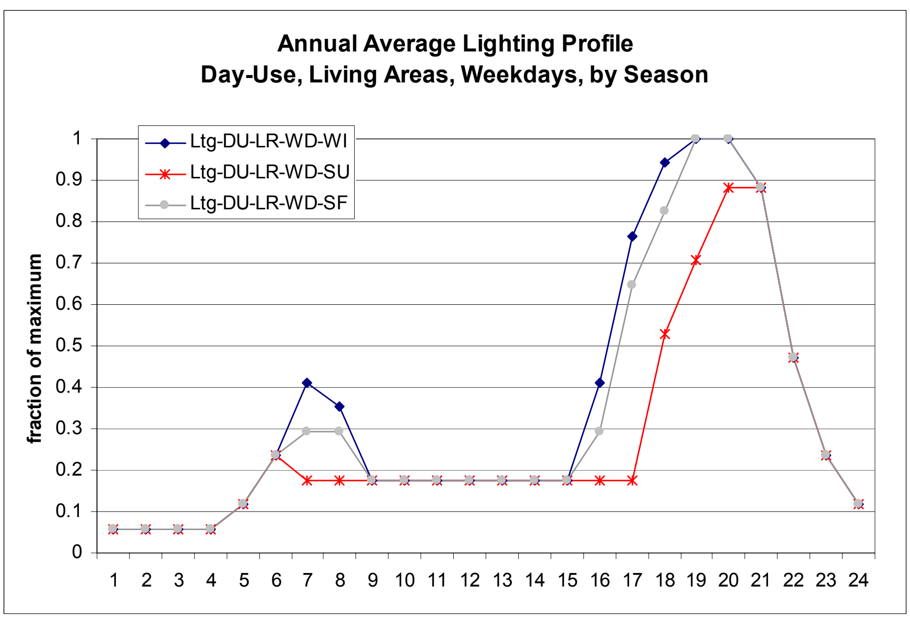



**Figure 11. Example of a detailed lighting profile** (Expressed as fraction of peak daily lighting energy)

The lighting plans for the Prototype and Benchmark should be based on the same hours of operation unless the Prototype includes specific design measures that alter the operating time of the lighting system, such as occupancy sensors, dimming switches, or a building automation system. Average operating hours estimated in the Navigant study are generally a good starting point (Table 10), but there may be substantial differences between typical lighting designs found in the TPU sample and the lighting design developed in conjunction with the architecture of the Prototype. The analyst must ultimately apply good engineering judgment when specifying operating hours for the lighting system.

**Table 10. Average Lighting Operating Hours for Common Room Types in a Sample of 161 Homes in the Pacific Northwest** (Source: Navigant 2002)

| Room Type | Operation (Hours/day/room) | Room Type | Operation (Hours/day/room) |
|---|---|---|---|
| Bathroom | 1.8 | Kitchen | 3.0 |
| Bedroom | 1.1 | Living Room | 2.5 |
| Closet | 1.1 | Office | 1.7 |
| Dining Room | 2.5 | Outdoor | 2.1 |
| Family Room | 1.8 | Utility Room | 2.0 |
| Garage | 1.5 | Other | 0.8 |
| Hall | 1.5 | | |

### *Appliances and Other Plug Loads*

As with lighting, several characteristics must be defined for appliances and other plug loads: the amount of the load, the schedule of the load, the location of the load, the fraction of the load that becomes a sensible load, and the fraction of the load that becomes a latent load. Though the internal load may be treated as an aggregate, the energy consumption for each end use must be considered separately. A breakdown of annual energy consumption and associated internal loads for major appliances and other equipment is shown in Table 11. Not all of the energy consumed by appliances is converted into internal load; much of the waste heat is exhausted to the outside or released down the drain in the form of hot water. The appliance loads were derived by NREL from EnergyGuide labels and from a Navigant analysis of typical models available on the market that meet current NAECA appliance standards. The daily loads rolled up at the whole-house level for a typical 1800 $ft^2$, three-bedroom house are shown in Table 12.

For a house of typical size (1000-3000 $ft^2$), the loads from the occupants and most appliances are assumed to be a function of the number of bedrooms. The exceptions are the refrigerator and cooking loads, which are assumed to be constant regardless of the number of bedrooms. The "Other Appliance & Plug Loads" end use is assumed to be a function of finished floor area. This function brings the total internal sensible load (including heat gain from occupants) approximately in line with the equation used to calculate internal loads in the IECC (ICC 2003). Note, however, that the internal load from appliances and lighting in the IECC equation is not a function of the number of bedrooms. Therefore, it is impossible to fully reconcile the Benchmark internal heat gain with that of the IECC for all combinations of floor area and number of bedrooms. However, the internal loads for the Benchmark and IECC are consistent for a typical 1800 $ft^2$, three-bedroom house.

The constant internal sensible load value of 72,000 Btu/day specified in the HERS guidelines (RESNET 1999) is even less flexible than the equation in the IECC. Still, it is approximately the same as the sensible load for the Benchmark (73,052 Btu/day) for a typical 1800 $ft^2$, three-bedroom house. Table 9 also reconciles latent load for a house of typical size with 20% of the sensible load, as specified in the HERS Guidelines. The IECC does not address latent load.

**Table 11. Annual Appliance and Equipment Loads for the Benchmark**[13]

| Appliance | Electricity (kWh/yr) | Natural Gas (therms/yr) | Sensible Load Fraction | Latent Load Fraction |
|---|---|---|---|---|
| Refrigerator | 669 | | 1.00 | 0.00 |
| Clothes Washer (3 $ft^3$ drum) | $52.5 + 17.5 \times N_{br}$ | | 0.80 | 0.00 |
| Clothes Dryer (Electric) | $418 + 139 \times N_{br}$ | | 0.15 | 0.05 |
| Clothes Dryer (Gas) | $38 + 12.7 \times N_{br}$ | $36 + 12.0 \times N_{br}$ | 1.00 (Electric)<br>0.10 (Gas) | 0.00 (Electic)<br>0.05 (Gas) |
| Dishwasher (8 place settings) | $103 + 34.3 \times N_{br}$ | | 0.60 | 0.15 |
| Range (Electric) | 604 | | 0.40 | 0.30 |
| Range (Gas) | | 78 | 0.30 | 0.20 |
| Other Appliance & Plug Loads | 1.67 x FFA | | 0.90 | 0.10 |

**Table 12. Total Rolled-Up Appliance and Equipment Loads for the Benchmark** (1800 $ft^2$, three-bedroom prototype)

| House Type | Electricity (kWh/yr) | Sensible Fraction | Latent Fraction | Nat. Gas (therms/yr) | Sensible Fraction | Latent Fraction |
|---|---|---|---|---|---|---|
| All Electric | 5425 | 0.75 | 0.10 | | | |
| Elec w/gas dryer | 4666 | 0.85 | 0.11 | 72 | 0.10 | 0.05 |
| Elec w/gas cooking | 4821 | 0.79 | 0.08 | 78 | 0.30 | 0.20 |
| Gas dryer/cooking | 4062 | 0.92 | 0.08 | 150 | 0.20 | 0.13 |

The hourly normalized load shape for interior residential equipment use is shown in Figure 12 (Huang and Gu 2002). The equipment profile is the sum of individual profiles of each piece of equipment; some individual profiles are nearly constant (such as refrigerator and transformer loads) and some are highly dependent on time of day (such as the range and dishwasher). NREL is developing hourly profiles for individual appliances. In the meantime, the equipment profile in Figure 10 can be used for either individual appliances or equipment in the aggregate. Internal sensible and latent loads from equipment should also be modeled using this profile. Appliance loads may be modeled in either the living spaces or bedroom spaces, depending on their location in the Prototype.

Large end uses in the Prototype that are not part of typical houses (such as swimming pools, Jacuzzis, and workshops) are not included in the models for either the Prototype or the Benchmark. The efficiency of these end uses should be addressed in a separate analysis.

[13] End-use loads in this table include only energy used within the machine. Associated domestic hot water use is treated separately (see "Domestic Hot Water"). The Appliance spreadsheet on the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html) can assist with the calculation of this split for an energy-efficient clothes washer or dishwasher based on the EnergyGuide label.

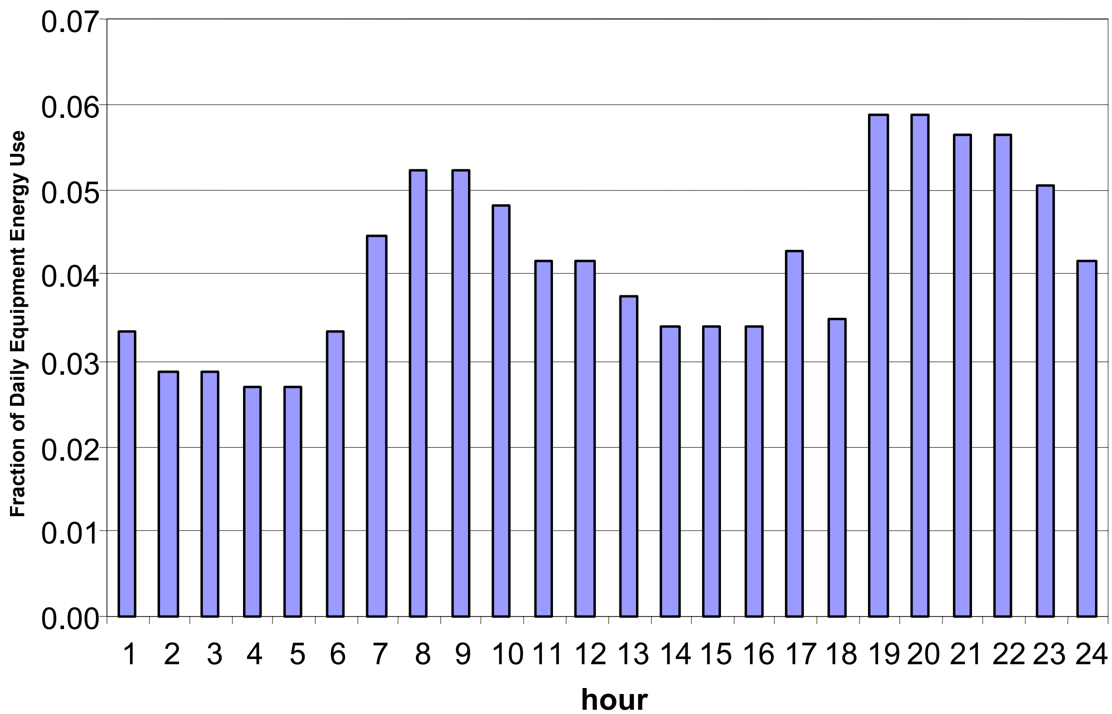



**Figure 12. Interior residential equipment profile**

*Site Generation*

A review of data from the Energy Information Administration (DOE 2001a) shows that there is rarely any site electricity generation in a 1990s vintage house. This is a reflection of the low market penetration of site electricity systems. Therefore, all electricity is purchased from the local utility in the Benchmark. As costs for photovoltaic systems and other site electricity systems continue to decline, they are expected to begin to make a significant contribution toward meeting residential energy needs by the year 2020. Therefore, it is important that site electricity generation be included in the analysis of whole-house energy performance.

### *2. Regional Standard Practice*

Regional Standard Practice consists of design specifications and construction techniques that are currently most common for new construction in a particular region of the country. This is very difficult to define with a high degree of confidence. Often, typical construction practices are similar to those required by applicable state or local energy codes. Some builders exceed these minimum requirements on a regular basis. Other builders consistently meet the minimum code requirements. As a result, an objective rule base that defines "true" Regional Standard Practice is usually not realistic for evaluating Building America Prototype houses. Therefore, teams are strongly encouraged to perform a field survey to identify patterns in regional construction practices.

The following set of guidelines is based on the general approach taken by NREL engineers to quantify energy savings in comparison to Regional Standard Practice, and it is intended to serve as a practical starting point for analysis. If more accurate information is available from local surveys, this information should be used in place of the base-case definition provided below. Teams are strongly encouraged to provide documentation for alternate definitions.

Unless otherwise required by local codes, the Regional Standard Practice is a hypothetical reference house that has the following features.

### *General*

Any element of the Regional Standard Practice house that is not specifically addressed in the following sections is assumed to be the same as the Prototype.

### *Building Envelope*

- Basement either directly or indirectly conditioned. Basements are considered finished only if the basement in the Prototype is finished.
- A geographically appropriate foundation construction type, including the dimensions and location of insulation and other construction materials consistent with local practice. If insulated crawl spaces are standard practice for the region, the crawl space is modeled with wall insulation and no ceiling insulation; otherwise, floor insulation is modeled in the Regional Standard Practice base case.
- A geographically appropriate exterior wall construction type, including the materials used and the thickness of each layer, consistent with local practice. Wall R-values may be either higher or lower than those of the Benchmark.
- The same vertical fenestration area (including sliding glass doors) as the Prototype design for each story up to a maximum of 18% of floor area, distributed in the same orientation as the Prototype. Alternatively, if the Prototype house uses specific window area modifications to reduce heating and/or cooling loads as part of a broader bioclimatic strategy, then the Regional Standard Practice house may use a total window area of 18% of the conditioned floor area, with the same proportion in each orientation as the Prototype. The energy usage is calculated in each of the four cardinal orientations, and the average of these four cases is used to represent Regional Standard Practice.
- A geographically appropriate glazing type, U-value, and SHGC consistent with local practice.
- The same door construction, including U-value, as in the Prototype house.
- The same amount of opaque external door area as the Prototype design, distributed in the same orientation as the Prototype design.
- A geographically appropriate roof and attic construction type, including the materials used and thickness of each layer, consistent with local practice. Attic R-value may be either higher or lower than that of the Benchmark.
- A geographically appropriate floor construction type for floors over unconditioned space, consistent with local practice. Floor R-value may be either higher or lower than that of the Benchmark.

- A geographically appropriate interior floor/ceiling construction type, consistent with local practice.

- The same interior wall construction type as the Prototype house. In cases where massive interior walls are used as part of a bioclimatic design strategy, the base case will have interior walls of lightweight construction, using the local standard for gypsum board and framing.

- Internal and external thermal mass of walls, floors, and other structural elements consistent with the construction materials and dimensions used in the Regional Standard Practice model.

- The same garage configuration, dimensions, and insulation as those of the Prototype house.

- The same site shading conditions that exist for the Prototype. In cases where intentional site shading features are used as part of a bioclimatic design strategy, the base case is modeled using site shading that is representative of Regional Standard Practice.

- The same levels of exterior shading from awnings, soffits, and other overhangs as the Prototype. Fixed exterior shading consistent with local practice may be used for the base case if the Prototype includes shading features specifically intended to reduce energy consumption as part of a broader bioclimatic design strategy.

- All other building envelope features are the same as those of the Building America Research Benchmark.

### *Space Conditioning/Air Distribution Equipment*

- For hydronic systems, a heat loss rate calculated assuming R-5 pipe insulation and pipe surface area and location consistent with the Prototype house.

- No supplemental dehumidification beyond that provided by the cooling system.

- All other space conditioning specifications the same as those of the Building America Research Benchmark.

### *Domestic Hot Water*

- All domestic hot water specifications the same as those of the Building America Research Benchmark.

### *Air Infiltration and Ventilation*

- Annual average natural air-change rate equal to 0.35 ACH. Air-change calculations shall include the basement volume, which is assumed to be part of the conditioned space for the purpose of base-case comparisons. If the simulation tool is capable of calculating hourly air infiltration, an Effective Leakage Area or other input may be specified, as long as the annual average natural infiltration is approximately equal to 0.35 ACH.

- Mechanical ventilation in accordance with ASHRAE Standard 62.2, assuming a small continuous exhaust or supply ventilation fan, as appropriate for the climate. Fan energy is calculated using Equation 9, and the interactive effects of natural infiltration and mechanical ventilation are estimated using the guidelines in ASHRAE Standard 136.

### *Lighting Equipment and Usage*

- All lighting specifications are the same as those of the Building America Research Benchmark.

### *Appliances and Other Plug Loads*

- Specifications for all appliances and other plug loads are the same as those of the Building America Research Benchmark.

### *Site Generation and Solar Energy*

- No site generation, solar water heating, or solar space heating. All electricity is purchased from the local utility.

## 3. Builder Standard Practice

Builder Standard Practice is defined as the current house design used by the builder partner. Builder Standard Practice can either be an existing model in the builder's current inventory or a hypothetical model if the Prototype is a newly designed floor plan. If the Prototype is based on an existing model, particularly if the analysis is part of a side-by-side evaluation, then the base case will have the specifications of that model. If the Prototype is an original model, then the base case will have the specifications most commonly used by the builder in the same county or metropolitan area.

The Builder Standard Practice model shall have the following features.

### *General*

Any element of the Builder Standard Practice house that is not specifically addressed in the following sections is assumed to be the same as that of the Prototype.

### *Building Envelope*

- Basement either directly or indirectly conditioned. Basements are considered finished only if the basement in the Prototype is finished.

- The same basic foundation type (slab, crawl space, or basement) as the Prototype. Alternatively, a foundation consistent with the existing floor plan or builder's standard practice may be used if the Prototype includes a change to the basic foundation type that is specifically intended to reduce heating and cooling energy consumption

- Basement or crawl space wall construction type, including the materials used and the thickness of each layer, consistent with the existing floor plan or the builder's standard practice. Wall R-values may be either higher or lower than the Benchmark.

- An exterior wall construction type, including materials and thickness of each layer, consistent with the existing floor plan or the builder's standard practice. Wall R-values may be either higher or lower than those of the Benchmark.

- The same vertical fenestration area (including sliding glass doors) as the Prototype design for each story up to a maximum of 18% of floor area, distributed in the same orientation. The energy usage of the Prototype and the Builder Standard Practice house should be compared separately in each of the four cardinal orientations. Alternatively, if the Prototype house uses specific window area modifications to reduce heating and/or cooling loads as part of a broader bioclimatic design strategy, then the Builder Standard Practice house is modeled with a total window area of 18% of the conditioned floor area, distributed with the same proportion in each orientation as the Prototype. Also, in the case of a bioclimatic design strategy, the energy usage for the Builder Standard Practice house is calculated in each of the four cardinal orientations, and the average of these four cases is assumed to represent Builder Standard Practice. If the standard window area and distribution can be reasonably established for the local builder, they should be incorporated into the Builder Standard Practice model instead of the window areas and distributions referenced above.

- Glazing type, U-value, and SHGC consistent with the existing floor plan or the Builder Standard Practice.

- The same door construction, including U-value, as in the Prototype house.

- The same amount of opaque external door area as the Prototype design, distributed in the same orientation as that in the Prototype design.

- Roof and attic construction type, including materials used and the thickness of each layer, consistent with the existing floor plan or that of the Builder Standard Practice. Attic R-value may be either higher or lower than that of the Benchmark.

- Floor construction type for floors over unconditioned space consistent with the existing floor plan or the Builder Standard Practice. Floor R-value may be either higher or lower than that of the Benchmark.

- The same interior wall construction type as the Prototype. In cases where massive interior walls are used as part of a bioclimatic design strategy, the Builder Standard Practice model shall have a construction type consistent with the existing floor plan or the Builder Standard Practice.

- Interior floor/ceiling construction type consistent with the existing floor plan or that of the Builder Standard Practice.

- Internal and external thermal mass of walls, floors, and other structural elements consistent with the construction materials and dimensions used in the Builder Standard Practice model.

- The same garage configuration, dimensions, and insulation as in the Prototype.

- The same site shading conditions that exist for the Prototype. In cases where intentional site shading features are used as part of a bioclimatic design strategy, site shading that is representative of the builder or region may be used.

- The same levels of exterior shading from awnings, soffits, and other overhangs as those in the Prototype. Fixed exterior shading consistent with the existing model or the builder's standard practice may be used if the Prototype includes shading features specifically intended to reduce energy consumption as part of a broader bioclimatic design strategy.

- All other building envelope features are the same as those of the Building America Research Benchmark.

### *Space Conditioning/Air Distribution Equipment*

- Heating and cooling system type, fuel, capacity, location, and efficiency consistent with the existing floor plan or that of the Builder Standard Practice.

- Air handler size, location, and efficiency consistent with the existing floor plan or that of the Builder Standard Practice.

- Dehumidification strategy consistent with the existing floor plan or that of the Builder Standard Practice.

- Distribution system loss calculations:
  (a) For forced air systems, conductive losses from the ducts are calculated assuming duct insulation and a duct surface area consistent with the existing floor plan or that of the Builder Standard Practice.

  (b) For hydronic systems, a heat loss rate calculated assuming pipe insulation and pipe surface area and location consistent with the existing floor plan or that of the Builder Standard Practice.

- All other space conditioning and air distribution specifications are the same as those of the Building America Research Benchmark.

### *Domestic Hot Water*

- Domestic hot water system tank size, capacity, location, and efficiency consistent with the existing floor plan or the builder's standard practice.

- All other domestic hot water specifications, including hourly demand profiles, end use consumption, and mains temperature, are the same as the Building America Research Benchmark.

### *Air Infiltration and Ventilation*

- Annual average natural air-change rate equal to 0.35 ACH, unless test results for a statistically significant sample of the Builder Standard Practice houses clearly demonstrate that the average air exchange rate differs from 0.35 ACH. The ACH calculations include the basement volume, which is assumed to be part of the conditioned space in all situations. If the simulation tool is capable of calculating hourly air infiltration, an Effective Leakage Area or other input may be specified, as long as the annual average natural infiltration is approximately equal to 0.35 ACH or another value that is established as typical for the builder.

- If the builder typically installs mechanical ventilation in new houses, then the Builder Standard Practice model shall include the system most commonly used. Otherwise, mechanical ventilation shall be in accordance with ASHRAE Standard 62.2, assuming a small continuous exhaust or supply ventilation fan (whichever is appropriate for the climate). Fan energy is calculated by using Equation 9, and the interactive effects of natural infiltration and mechanical ventilation are estimated by using the guidelines in ASHRAE Standard 136.

### *Lighting Equipment and Usage*

- Pre-installed light fixtures and lamp designs consistent with the existing floor plan or those of the Builder Standard Practice.

- All other lighting specifications are the same as those of the Building America Research Benchmark, including total annual lighting energy use.

### *Appliances and Other Plug Loads*

- Pre-installed appliances consistent with the existing floor plan or Builder Standard Practice.

- Specifications for all other appliances and other plug loads are the same as the Building America Research Benchmark.

### *Site Generation and Solar Energy*

- No site generation, solar water heating, or solar space heating. All electricity is purchased from the local utility.

## Modeling the Prototype House

The Prototype house is modeled either as designed or as-built, depending on the status of the project. All parameters for the Prototype house model are based on final design specifications or measured data, with the following exceptions and clarifications:

- Natural infiltration rate calculated using blower door measurements in accordance with ASHRAE Standard 119, Section 5.1. If air leakage measurements have not been made, but a target level of natural infiltration has been established as a quality assurance measure, then this target level of infiltration may be used. Otherwise, the natural infiltration is the same as that used in the Regional Standard Practice model.

- Mechanical ventilation must be in compliance with the total cfm requirement specified in ASHRAE Standard 62.2. If the Prototype ventilation system does not meet this standard, then the model shall include a small continuous exhaust or supply ventilation fan (whichever is appropriate for the climate) to make up the difference. The total fan energy is the sum of the installed fan energy and the additional fan energy calculated by using Equation 13. The interactive effects of natural infiltration and the total mechanical ventilation shall be estimated using the guidelines in ASHRAE Standard 136.

  **Equation 13: Additional ventilation fan energy (kWh/yr) = 3.94 x (Additional cfm needed to meet ASHRAE Std 62.2) .**

- The actual site shading conditions are used.

- The default framing factors provided in Table 13 may be used for the Prototype house if the actual framing factors are unknown.

**Table 13. Prototype Default Framing Fractions**

| Enclosure Element | Frame Spacing (inches o.c.) | Default Frame Fraction (% area) |
|---|---|---|
| Walls (standard framing): | | |
| @16" o.c. | 16 | 23% |
| @24" o.c. | 24 | 20% |
| Walls (advanced framing): | | |
| @16" o.c. | 16 | 19% |
| @24" o.c. | 24 | 16% |
| Structural Insulated Panels | 48 | 10% |
| Floors (standard framing): | | |
| @16" o.c. | 16 | 13% |
| @24" o.c. | 24 | 10% |
| Floors (advanced framing): | | |
| @16" o.c. | 16 | 11% |
| @24" o.c. | 24 | 8% |
| Ceilings (standard trusses): | | |
| @16" o.c. | 16 | 14% |
| @24" o.c. | 24 | 11% |
| Ceilings (advanced trusses – "raised heel"): | | |
| @16" o.c. | 16 | 10% |
| @24" o.c. | 24 | 7% |
| Ceilings (conventional framing): | | |
| @16" o.c. | 16 | 13% |
| @24" o.c. | 24 | 9% |

- The installation of energy-saving appliances or other equipment may reduce hot water consumption for certain end uses, reduce the internal sensible and latent loads, or affect the hourly operating profile. Energy savings calculations for the Prototype must take these effects into account, using operating conditions based on rules developed for DOE residential appliance standards (DOE 2003). These DOE rules underlie the hot water usage for the Benchmark. The number of cycles per year specified in the appliance standard for clothes washers is adjusted according to the number of bedrooms and the clothes washer capacity for the Prototype, using Equation 14:

**Equation 14:** **Clothes washer cycles per year = (392) x (½+$N_{br}$/6) x 12.5 lb / $W_{test}$ ,**

where $W_{test}$ = maximum clothes washer test load weight found in 10 CFR part 430, Subpt B, Appendix J1, as a function of the washer capacity in $ft^3$.

A dryer usage factor (DUF) is applied to the clothes washer cycles to determine the number of annual dryer cycles, using Equation 15:

**Equation 15:** **Clothes dryer cycles per year = DUF x Clothes washer cycles per year ,**

where DUF = 0.84.

The dishwasher annual operating cycles are similarly calculated, using Equation 16:

**Equation 16: Dishwasher cycles per year = (215) x (½ + $N_{br}$/6) .**

An appliance spreadsheet posted on the Building America Web site includes two tabs to help analysts calculate energy savings for efficient clothes washers, clothes dryers, and dishwashers. It calculates the split between hot water and machine energy based on the EnergyGuide label, estimates dryer energy savings for clothes washers that reduce remaining moisture content, adjusts energy use for the fact that both hot water and cold water temperatures for the Prototype are different than the test values (140ºF and 60ºF/50ºF), and adjusts for the type of controls present (thermostatic control valves, boost heating, cold water only). Both annual average and monthly average hot water usage are calculated in the spreadsheet.

- Lighting energy use for the Prototype shall be the same as that of the Benchmark unless the team develops a comprehensive set of lighting specifications that addresses both builder- and occupant-controlled lighting. To take credit for lighting energy savings, communications materials must be presented to the homebuyer encouraging the use of energy-efficient lighting in high-use locations and providing guidance for selecting and purchasing lamps. Modifications to the lighting profile due to occupancy sensors or other controls may also be considered for the Prototype, but negative or positive effects on space conditioning load must also be calculated, assuming 100% of interior lighting energy contributes to the internal sensible load.

- Large end uses in the Prototype that are not part of typical houses (such as swimming pools, Jacuzzis, workshops, etc.) are not included in the models for the Prototype or the base cases. The efficiency of these end uses should be addressed in a separate analysis.

- For the Prototype, all site electricity generation is credited regardless of energy source. Residential-scale photovoltaic systems, wind turbines, fuel cells, and micro-cogeneration systems are all potential sources of electricity generated on the site. An offset must be applied to this electricity credit equal to the amount of purchased energy used in the on-site generation process. The credit for site generation shall be tracked separately from the whole-house energy analysis and reported as a separate line in the summary tables (discussed later in this report).

## Operating Conditions

The following operating conditions and other assumptions shall apply to the Prototype house and all three base cases defined in this document. These operating conditions are based on the cumulative experience of the authors through their work on Building America, HERS, Codes and Standards, and other residential energy efficiency programs.

- Thermostat set point for cooling: 78°F with no setup period

- Thermostat set point for heating: 68°F with no setback period

- The natural ventilation schedule shall be set to reflect windows being opened occasionally. In situations in which there is a cooling load, the outdoor temperature is below the indoor temperature, and the window is not already open, then the probability of the window being opened shall be set at a constant 50%. For tools that do not have the capability to calculate air infiltration effects caused by window openings, natural ventilation rates shall be set at 5 ACH unless each living area and bedroom provides at least two openings on different orientations and the net area of openings exceeds 12% of the floor area of the house (cross-ventilation), in which case a natural ventilation rate of 7 ACH shall be used.

- Interior shading multiplier = 0.7 during the cooling season, and 0.85 during the heating season and during swing seasons when both cooling and heating occur. Specific guidelines for defining seasons are presented later in this section.

- Internal loads from lighting, appliances, and other equipment were discussed in previous sections. These loads are not necessarily the same for the Prototype and the three base cases; therefore, they are not considered operating conditions for the purposes of the Building America performance analysis.

- The occupancy schedule is defined with the same level of detail as other internal load profiles. For typical Building America houses, the number of occupants shall be assumed to be equal to the number of bedrooms. Sensible and latent gains shall be accounted for separately, and different loads shall be applied in different space types, as described in Table 14. The occupant heat gains are based on ASHRAE recommendations (ASHRAE 2001). The average hourly occupancy profile is shown in Figure 13, and an example set of detailed hourly occupancy curves is shown in Figure 14. For detailed occupancy profiles for various day types, see the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html). These profiles, which were developed by NREL, were based on the basic ASHRAE occupancy schedule combined with engineering judgment.

**Table 14. Peak Sensible and Latent Heat Gain from Occupants** (ASHRAE 2001)

| | | |
|---|---|---|
| Living Area Sensible Gain: | 230 | BTU/person/hr |
| Bedroom Area Sensible Gain: | 210 | BTU/person/hr |
| Living Area Latent Gain: | 190 | BTU/person/hr |
| Bedroom Area Latent Gain: | 140 | BTU/person/hr |

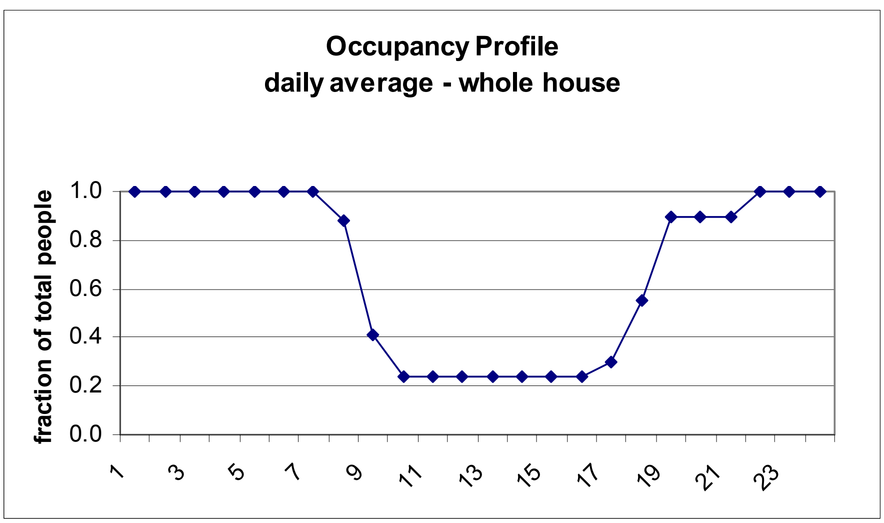



**Figure 13. Average hourly load profile from occupants for all day-types and family types** (16.5 hours/day/person total)

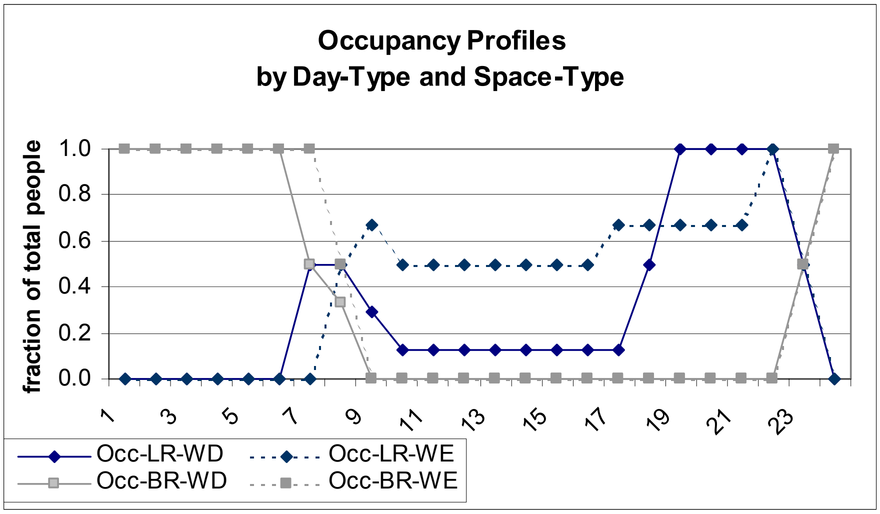



**Figure 14. Detailed hourly load profiles resulting from occupants being in different parts of the house on weekdays (WD) and weekends (WE)**

- The internal mass of furniture and contents shall be equal to 8 lbs/ft$^2$ of conditioned floor space. For solar distribution purposes, lightweight furniture covering 40% of the floor area shall be assumed.

- Weather data shall be based on typical meteorological year (TMY2) data from 1961–1990[14] or equivalent data for the nearest weather station.

- Heating and cooling shall occur only during certain months of the year in accordance with the following guidelines developed by the Florida Solar Energy Center (FSEC), which serve as the basis for defining seasons in the EnergyGauge software. Alternate operating profiles may be acceptable with sufficient justification.

  The heating and cooling seasons shall be determined on the basis of the monthly average temperatures (MAT) and the 99% (annual, not seasonal) winter and summer design temperatures (WDT and SDT, respectively) based on TMY2 data or ASHRAE Fundamentals 2001 for the nearest location, in accordance with the following procedures:

  **Step 1. MAT Basis**
  (I) The heating system shall be enabled for a month in which the MAT is less than 71.5°F.
  (II) The cooling system enabled for a month in which the MAT is greater than 66°F.

  **Step 2. WDT and SDT**
  (I) The heating system shall be enabled in December and January if the WDT is less than or equal to 59°F, regardless of the outcome in Step 1 above.
  (II) The cooling system shall be enabled in July and August regardless of the outcome in Step 1 above.

[14] Analytic Studies Division, National Renewable Energy Laboratory (http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/).

**Step 3. Swing Season Adjustment**

(I) If, based on Steps 1 and 2 above, there are two consecutive months in which the heating system is enabled the first month and the cooling system is enabled the following month, or vice versa, then both the heating system and the cooling system shall be enabled for both these months.

## Reporting Energy Use and Energy Savings

Reporting energy use and energy savings in a consistent format is an important component of Building America analysis. The following tables shall be supplied with the analysis report for every Building America Prototype. The Benchmark version number should be identified in the caption to ensure that the results are interpreted in the correct context and not compared with results obtained using a different version of the Benchmark.

Table 15 shows an example of a site energy consumption report for a hypothetical Prototype in Virginia, along with all relevant base cases. Similar information based on source energy is presented energy in Table 16, along with percent energy savings for each end use. End uses are described in more detail in Table 17.

The "Percent of End Use" columns in Table 16 show the Prototype energy use for each end use as a fraction of the appropriate base case. The "Percent of Total" columns show the contribution of each end use toward an overall energy reduction goal. Note that site generation for the Benchmark is always zero.

Source energy is determined using Equation 17.

**Equation 17:** $$\textbf{Source MBtu} = \textbf{kWh} \bullet \textbf{3.412} \bullet \mathbf{M_e} \,/\mathbf{1000} + \textbf{therms} \bullet \mathbf{M_g} \,/\, \mathbf{10}\ ,$$

where $M_e = 3.16$ = site to source multiplier for electricity (DOE 2002b);
$M_g = 1.02$ = site to source multiplier for natural gas (DOE 1995).

**Table 15. Example Summary of Site Energy Consumption by End Use Using Building America Research Benchmark Version 3.1**

| | Annual Site Energy | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BA Benchmark | | Region Standard | | Builder Standard | | BA Prototype | |
| End Use | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) |
| Space Heating | 11225 | 0 | 11286 | 0 | 11286 | 0 | 4397 | 0 |
| Space Cooling | 2732 | 0 | 2432 | 0 | 2432 | 0 | 902 | 0 |
| DHW | 4837 | 0 | 4838 | 0 | 4838 | 0 | 1351 | 0 |
| Lighting | 3110 | | 3110 | | 3110 | | 1204 | |
| Appliances + Plug | 7646 | 0 | 7646 | 0 | 7646 | 0 | 7436 | 0 |
| OA Ventilation | 400 | | 400 | | 400 | | 400 | |
| Total Usage | 29950 | 0 | 29712 | 0 | 29712 | 0 | 15690 | 0 |
| *Site Generation* | 0 | 0 | 0 | 0 | 0 | 0 | 7402 | 0 |
| *Net Energy Use* | 29950 | 0 | 29712 | 0 | 29712 | 0 | 8289 | 0 |

**Table 16. Example Summary of Source Energy Consumption by End Use Using Building America Research Benchmark Version 3.1**

| | Estimated Annual Source Energy | | | | Source Energy Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Percent of End-Use | | | Percent of Total | | |
| End Use | Benchmark (MBtu/yr) | Region (MBtu/yr) | Builder (MBtu/yr) | Proto (MBtu/yr) | BA Base | Reg Base | Bldr Base | BA Base | Reg Base | Bldr Base |
| Space Heating | 115 | 116 | 116 | 45 | 61% | 61% | 61% | 23% | 23% | 23% |
| Space Cooling | 28 | 25 | 25 | 9 | 67% | 63% | 63% | 6% | 5% | 5% |
| DHW | 50 | 50 | 50 | 14 | 72% | 72% | 72% | 12% | 12% | 12% |
| Lighting | 32 | 32 | 32 | 12 | 61% | 61% | 61% | 6% | 6% | 6% |
| Appliances + Plug | 78 | 78 | 78 | 76 | 3% | 3% | 3% | 1% | 1% | 1% |
| OA Ventilation | 4 | 4 | 4 | 4 | 0% | 0% | 0% | 0% | 0% | 0% |
| Total Usage | 307 | 304 | 304 | 161 | 48% | 47% | 47% | 48% | 47% | 47% |
| *Site Generation* | 0 | 0 | 0 | -76 | | | | 25% | 25% | 25% |
| *Net Energy Use* | 307 | 304 | 304 | 85 | 72% | 72% | 72% | 72% | 72% | 72% |

**Table 17. End-Use Categories**

| End Use | Potential Electric Usage | Potential Gas Usage |
|---|---|---|
| Space Heating | Supply fan during space heating, HP, HP supplemental heat, water boiler heating elements, water boiler circulation pump, electric resistance heating, HP crankcase heat, heating system auxiliary | Gas furnace, gas boiler, gas back-up HP supplemental heat, gas ignition stand-by |
| Space Cooling | Central split-system A/C, packaged A/C (window or through-the-wall), supply fan energy during space cooling, A/C crankcase heat, cooling system auxiliary | Gas absorption chiller (rare) |
| DHW | Electric hot water heater, HP water heater, hot water circulation pumps | Gas hot water heater |
| Lighting | Indoor lighting, outdoor lighting | None |
| Equipment | Refrigerator, electric clothes dryer, gas clothes dryer (motor), cooking, miscellaneous | Cooking, gas clothes dryer |
| OA Ventilation | Ventilation fans, supply air fan during ventilation mode | None |
| Site Generation | Photovoltaic electric generation | None |

Table 18 reports energy savings for individual energy efficiency measures applied to the Prototype, in terms of source energy and energy cost. "Source Energy Savings %" is determined by comparing the source energy for each measure increment to the source energy for the Benchmark (i.e., the first row). In this column, the incremental savings for each measure are added to the savings for all the previous measures. The final row of the column is the overall energy savings achieved for the Prototype house.

When available, actual energy tariffs for the Prototype house shall be used to determine whole-building energy costs. Energy cost and measure savings are compared with the Builder Standard Practice (representing a real design or set of practices that is currently being used by the builder) rather than with the Benchmark. This provides an evaluation of the improvements in the performance of the Prototype compared with that of homes currently being sold by the builder partner.

Peak hourly energy consumption should also be reported for every Prototype. Peak energy 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.

**Table 18. Example Measure Savings Report[15] Using Building America Research Benchmark Version 3.1**

| | Site Energy | | Est. Source Energy | | National Average Energy Cost | | Builder Standard (Local Costs) Energy Cost | | Measure | Package |
|---|---|---|---|---|---|---|---|---|---|---|
| Increment | (kWh) | (therms) | (MBtu) | Savings (%) | ($/yr) | Savings (%) | ($/yr) | Savings (%) | Value ($/yr) | Savings ($/yr) |
| Bldg America Rsch Benchmark | 29950 | 0 | 306.9 | | $ 2,995 | | $ 2,950 | | | |
| Regional Std Practice | 29712 | 0 | 304.4 | 1% | $ 2,971 | 1% | $ 2,927 | | | |
| Builder Std Practice (BSP) | 29712 | 0 | 304.4 | 1% | $ 2,971 | 1% | $ 2,927 | | | |
| BSP + improved walls | 27779 | 0 | 284.6 | 7% | $ 2,778 | 7% | $ 2,736 | 7% | $ 190.4 | $ 190 |
| BSP ++ Low-E Windows | 25810 | 0 | 264.5 | 14% | $ 2,581 | 14% | $ 2,542 | 13% | $ 193.9 | $ 384 |
| BSP ++ Smaller A/C (5 -> 4 tons) | 25420 | 0 | 260.5 | 15% | $ 2,542 | 15% | $ 2,504 | 14% | $ 38.4 | $ 423 |
| BSP ++ Inc. Bsmt Wall Insulation | 25170 | 0 | 257.9 | 16% | $ 2,517 | 16% | $ 2,479 | 15% | $ 24.6 | $ 447 |
| BSP ++ Ground Source HP (+DHW) | 19331 | 0 | 198.1 | 35% | $ 1,933 | 35% | $ 1,904 | 35% | $ 575.1 | $ 1,023 |
| BSP ++ Solar DHW | 17718 | 0 | 181.5 | 41% | $ 1,772 | 41% | $ 1,745 | 40% | $ 158.9 | $ 1,181 |
| BSP ++ Lighting, Appl. & Plug | 15690 | 0 | 160.8 | 48% | $ 1,569 | 48% | $ 1,545 | 47% | $ 199.8 | $ 1,381 |
| *Site Generation* | | | | | | | | | | |
| BSP ++ PV | 8288 | 0 | 84.9 | 72% | $ 829 | | $ 816 | 72% | $ 729.0 | $ 2,110 |

## Important Differences Among Base-Case Definitions

Because each base case 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 19 provides a summary of "blind" and "neutral" features of each of the three base-case definitions. A blind feature is the same for both the Prototype and base case; it indicates an important fundamental feature of the house, and its specifications are usually driven by demands unrelated to energy use, such as architectural appeal, functionality, or comfort. Neutral features are fixed at a specific performance level; energy savings resulting from changes to this level are recognized for the Prototype house. An individual feature may be marked as both neutral and blind in situations where bioclimatic design intent must be considered. If the design change is made for bioclimatic design reasons, the feature is neutral. If the design change is motivated by architectural or other purposes, the feature is blind.

[15] Calculated using national average electric cost = $0.10/kWh and national average gas cost = $0.50/therm.

### Table 19. Summary of Neutral and Blind Features of the Base Cases

| | *Regional Standard Practice* | | *Builder Standard Practice* | | *Research Benchmark* | |
|---|---|---|---|---|---|---|
| **Design Feature** | **Fixed Value (Neutral)** | **Same Value as Prototype (Blind)** | **Fixed Value (Neutral)** | **Same Value as Prototype (Blind)** | **Fixed Value (Neutral)** | **Same Value as Prototype (Blind)** |
| Finished floor area | | ✓ | | ✓ | | ✓ |
| Building footprint | | ✓ | | ✓ | | ✓ |
| Ceiling height | | ✓ | | ✓ | | ✓ |
| Conditioned space boundary of roof system | ✓ | | ✓ | | ✓ | |
| Conditioned space boundary of basement | | ✓ | | ✓ | | ✓ |
| Conditioned space boundary of crawl space | ✓ | | ✓ | | | ✓ |
| U-value of exterior walls | ✓ | | ✓ | | ✓ | |
| U-value of doors | | ✓ | ✓ | | ✓ | |
| U-value of windows | ✓ | | ✓ | | ✓ | |
| U-value of floors over foundation | ✓ | | ✓ | | ✓ | |
| U-value of roof/ceiling | ✓ | | ✓ | | ✓ | |
| Solar absorp. of opaque external surfaces | ✓ | | ✓ | | ✓ | |
| Window area | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Window orientation | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Skylight area | ✓ | | ✓ | | ✓ | |
| Door area | | ✓ | | ✓ | ✓ | |
| Door locations | | ✓ | | ✓ | ✓ | |
| Window frame factor | ✓ | | ✓ | | ✓ | |
| Window solar heat-gain coefficients | ✓ | | ✓ | | ✓ | |
| Overhangs | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Site shading | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Foundation type (slab, crawl space, basement) | | ✓ | ✓ | ✓ | | ✓ |
| Foundation construction/insulation | ✓ | | ✓ | | ✓ | |
| Fuel type | | ✓ | ✓ | | ✓ | ✓ |
| Type of heating/cooling/hot-water system | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Efficiency of heating/cooling/hot-water sys. | ✓ | | ✓ | | ✓ | |
| Capacity of heating/cooling/hot-water system | ✓ | | ✓ | | ✓ | |
| Air handler sizing | ✓ | | ✓ | | ✓ | |
| Distribution system losses | ✓ | | ✓ | | ✓ | |
| Natural infiltration | ✓ | | ✓ | | ✓ | |
| Mechanical ventilation | ✓ | | ✓ | | ✓ | |
| Thermal mass of furniture and contents | | ✓ | | ✓ | | ✓ |
| Thermal mass of interior walls and floors | ✓ | | ✓ | | ✓ | |
| Thermal mass of slab | ✓ | | ✓ | | | ✓ |
| Lights and appliances | ✓ | | ✓ | | ✓ | |
| All other operating conditions | | ✓ | | ✓ | | ✓ |
| Renewable energy | ✓ | | ✓ | | ✓ | |

# Section II. Residential Energy Modeling Approach

## Overview

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 additional recommendations for reporting results. These guidelines and the examples presented are based on NREL's analysis of past and current Building America projects using the DOE-2.2 building simulation tool. The framework for the Building America analysis is presented here. But it is the responsibility of each analyst to use this framework in the most appropriate way for each project. The tools and techniques described in this report are powerful and flexible. Rather than limiting an analyst's options, these tools can give the analyst important insight into the building physics and lead to even more creative and effective designs.

The modeling efforts associated with the Building America project are intended to quantify the energy savings of a wide variety of efficiency measures addressing all end uses. For this reason, Building America energy simulations, as compared with many other residential energy simulations, require a relatively high level of detail in the building shell, building operation, and equipment performance. This section focuses on space conditioning and hot water measures, which constitute the largest fraction of energy efficiency improvements in Building America projects. Additional examples that cover other end uses are provided in Appendix C.

As described in Section I, the base-case building definitions for each Building America house have the same building geometry as the improved case. The *Research Benchmark* house represents typical 1990s construction. It serves as the reference point for establishing programmatic energy savings goals and for tracking progress toward these goals. The *Regional Standard Practice* building uses standard assumptions for building construction materials and heating, ventilating, and air-conditioning (HVAC) performance. These assumptions may vary from region to region and are intended to represent typical construction practices in nearby housing developments. The *Builder Standard Practice* model represents the house that would have built had the builder not participated in the Building America program. Often, the Builder Standard Practice is more energy efficient than Regional Standard Practice, but it may occasionally be less efficient. The *Building America Prototype* house has efficiency levels designed by the Building America team. Savings are determined by comparing the energy use of the Building America Prototype to that of each base case (Figure 15)

Familiarity with the DOE-2 building energy simulation program is needed to create the simulation models required for this analysis. While the examples and sample files included with this report provide a quick start to creating the models with DOE-2.2, building energy simulation requires experience and a background in building thermodynamics, HVAC systems, and, to some degree, computer programming. For those familiar with the DOE-2.1 program, the changes and new features found in the DOE-2.2 program are described in the *DOE-2.2 Basics Manual*.

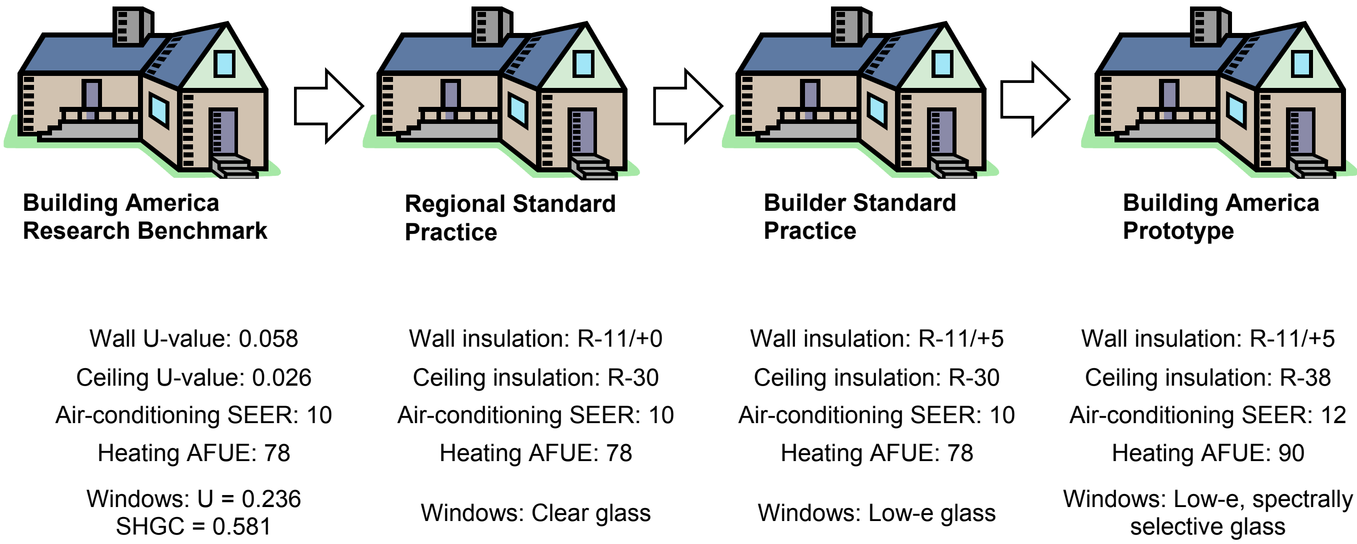



**Figure 15. Comparison of typical Prototype and base-case house features**

## DOE-2 Building Energy Simulation Program

DOE-2 is an hourly building energy simulation tool appropriate for building designers and energy researchers. The program has been developed over the past 25 years by DOE laboratories and by private companies. The program has been continuously upgraded to keep pace with new system types and better algorithms, and it has been established as one of the benchmark energy simulation tools in common use.

In its standard format, the DOE-2 program resembles a highly specialized computer programming language. The building and its energy systems are described using a hierarchical series of commands and keywords listed in a text file. User-defined variables along with simple math and logic functions can be used within the context of the building description. This format allows great flexibility when creating the building simulation model, but it also requires significant effort and expertise from the user.

The latest version of the DOE-2 building energy simulation program is DOE-2.2. Both DOE-2.2 and its predecessor DOE-2.1E are available from J. J. Hirsch and Associates. Information on the programs and how to obtain them can be found on the Internet at www.doe2.com. DOE-2.2 is available in a variety of formats: DOS executable, DOS-32 bit executable, and a Dynamic Linked Library (DLL) version with a simple Windows interface. A compact disc with all of these versions of DOE-2, along with hundreds of weather files for U.S. locations, is available for the cost of shipping and handling.

For DOE-2.2, the text file written by the user that describes the simulation model is first compiled by a stand-alone program called DOEBDL.exe. This program checks the format of the model description, alerts the user to any errors in the model, and even cautions users about possible mistakes in modeling techniques. A second program, DOESIM.exe, then runs the actual hourly simulation of the building thermodynamics. Detailed results are available for almost all aspects of the building simulation, and summary reports provide a quick look at the building's energy performance.

Documentation for the DOE-2.2 program comes as a set of Adobe Acrobat PDF files. The manuals are organized into three sections: DOE-2.2 Basics, DOE-2.2 Dictionary, and DOE-2.2 Topics. The help files that accompany other DOE-2.2 based programs, such as eQUEST or PowerDOE, can also be used as references.

The energy simulation research community is also currently developing an advanced analysis program called EnergyPlus. Currently, it is available as a beta test version at the DOE Web site (see www.eren.doe.gov/buildings/energy_tools/energyplus/).

## Analysis Approach

The analysis approach covered in this document is quite simple. The typical annual energy use of a new building design is compared to a base-case building of the same basic description, only with characteristics defined in Section I of this report. Site energy use, energy costs, and source energy use are all used to compare the buildings. Energy consumption for all end uses is included in these calculations.

Standard operation conditions, such as thermostat setpoints and the use of natural ventilation, are established in this document and used for all the simulations. The base-case building and HVAC characteristics are determined based on the specifications presented in Section I; they are typically a function of the Prototype characteristics and the geographic location.

The three base case simulation models that historically have been created for NREL's Building America analysis—Regional Standard Practice, Builder Standard Practice, and the Benchmark—are all built around the same Building Description Language (BDL) input file as the Prototype. Once the Regional Standard Practice (or other base case) model is established, incremental changes in the model specifications lead to the other models. The following model descriptions are an example of this process.

**Benchmark Model**

- Building geometry is the same as in the Prototype, except
  - window area = 18% of floor area
  - window orientation: 25% of windows on front, back, left and right
  - door area = 40 $ft^2$, facing north
- Wall U-value = 0.058 Btu/hr-$ft^2$-°F
- Window U-value calculated as 0.305 Btu/hr-$ft^2$-°F
- Ceiling U-value = 0.026 Btu/hr-$ft^2$-°F
- Crawl-space Ceiling U-value = 0.05 Btu/hr-$ft^2$-°F
- Natural infiltration = 0.65 ACH
- SEER 10, 2.5-ton air conditioner
- Annual fuel utilization efficiency (AFUE) 78, furnace
- Standard duct loss to attic
- Indoor lighting electricity use = 1895 kWh/yr
- Outdoor lighting electricity use = 350 kWh/yr (inc. garage)
- Appliance/plug energy use = 4034 kWh/yr and 124 therms/yr

**Regional Standard Practice**

- Building geometry same as in the Prototype
- R-11 cavity-filled walls
- Double-pane clear windows with aluminum frames
- R-30 ceiling insulation
- No crawl-space insulation

- Natural infiltration = 0.35 ACH
- SEER 10, 2.5-ton air conditioner
- AFUE 78, furnace
- Standard duct loss to attic
- Indoor lighting, outdoor lighting, and appliance/plug use same as the Benchmark

Increment 1: Change to double-pane, low-e windows with vinyl frames
Increment 2: Add crawl-space wall insulation of R-10 **(**Builder Standard Practice**)**
Increment 3: Lower duct loss by placement within conditioned space
Increment 4: Improve air conditioner to SEER 12
Increment 5: Improved heating system to AFUE 94
Increment 6: Indoor lighting reduced by 40% due to CFLs
Increment 7: Appliance/plug use reduced by 492 kWh/yr due to ENERGY STAR clothes washer & dryer; DHW use reduced by 4 gallons/day due to ENERGY STAR clothes washer. **(**Building America Prototype**)**

The change from the Benchmark model to the Regional Standard Practice model involves significant changes to the simulation model, mainly because the windows and the shell constructions have to be treated differently. Once the Regional Standard Practice model is established, seven relatively minor increments lead to the Prototype model. For this example, the Builder Standard Practice house is modeled by changing two components of the Regional Standard Practice model—the window type and the crawl-space insulation.

## The 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 process described here is merely an outline, the details of which will be unique to each project.

The major steps in the modeling process are identified below and described in the following sections.

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 and the Prototype description to define the benchmark characteristics.
8. **Regional and Builder Standards.** Use knowledge of local building practice to define the building characteristics of the Regional and Builder Standard Practice.
9. **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.

10. **DOE-2 simulation and design verification.** Use the DOE-2 simulation results to verify both the simulation model and building design.
11. **Energy efficiency measure analysis and reporting results.** Use the results of all the DOE-2 simulations to analyze each component of the building improvements.

### *1. Thermal Zoning*

An important consideration when creating residential energy models is the number of separate thermal zones that will be modeled. For some studies, a simple residence modeled as a single zone is adequate for assessing overall loads or overall changes in loads. However, when a simulation includes the performance of actual HVAC systems, most residences need multiple zones to capture the thermodynamic diversity that occurs when the systems are both on and off.

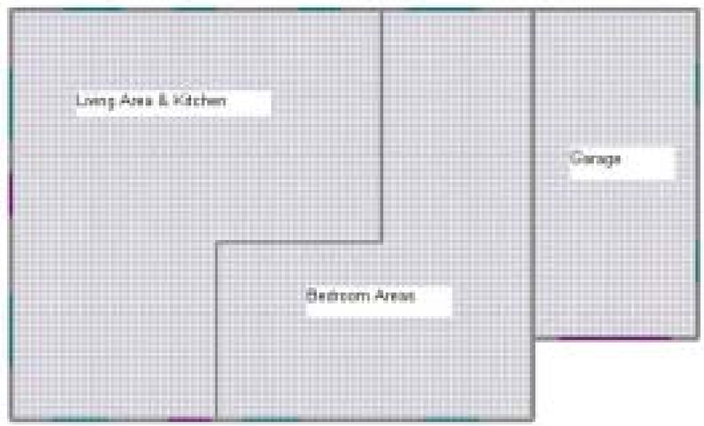



**Figure 14. Example house floor plan containing two conditioned zones** (Source: eQUEST)

The maximum number of conditioned zones appropriate to model is a function of the floor plan and the HVAC system layout for a house. Another important consideration is the type of questions that the simulation model is expected to answer. Unless the model is also being used to help design supply airflow rates to each register, well-connected spaces and spaces that are thermodynamically similar can, and should, be combined into single zones. This is especially true of the zone that contains the thermostat. The thermostat zone should be well connected to the spaces around it so that it responds properly to the changing conditions of the space.

A typical house might have two conditioned zones: a living area and the bedroom areas. With a two-story house, this might correspond to the first floor and the second floor. Houses designed for passive solar heating may require additional zones. When possible, thermally well-connected spaces should be modeled as single zones (Figure 16).

Unconditioned zones typically include garages, crawl spaces, basements, and attics. These zones must be modeled separately for an accurate simulation.

### *2. Floor Plan Take-offs*

The key to modeling the building geometry of a residence lies in properly describing the building floor plans. The floor plans are described using a feature of DOE-2.2 called *polygons*. Polygons can be used to describe the layout of spaces and floors, and they are also used to describe any irregularly shaped wall or roof surface. For the residential models, they are especially useful in describing the floor plan of the house and each individual zone.

> "You define polygons by specifying the coordinates of the vertices, an x-y coordinate system that is local to the polygon. You can then position this local polygon coordinate system in the parent coordinate system by setting appropriate values for X, Y, Z, Azimuth and Tilt of the wall, space or floor. You must specify the vertices in counter-clockwise order, as seen when you face the polygon." (DOE-2.2 Help File)

An example of a simple (rectangular) polygon in BDL:

```
KitchenPoly = POLYGON
   V1       = ( 0 , 35 )
   V2       = (19 , 35 )
   V3       = (19 , 49.8 )
   V4       = ( 0 , 49.8 )    ..
```

In this case, the origin of the polygon is far from its vertices. As a shortcut when creating the polygons, the 19-ft x 14.8-ft rectangle shares the origin with the house polygon.

The advantage of using polygons to describe the floor plans is especially evident when entering the required data for exterior walls. Instead of specifying the X and Y coordinates of the wall—along with the height, the width, and the azimuth of the wall—the only entry needed is the vertex of the space polygon that locates the wall.

1. *The reHABITAT Guide for Energy- and Resource-Efficient Retrofit Strategies* seeks to advance the goal of the U.S. Department of Energy's Existing Residential Buildings Program (ERBP): to develop approaches that will enable the housing retrofit industry to deliver energy-efficient housing improvements and to ensure that energy-efficient retrofit technologies incorporated into projects are viable over conventional approaches. This guide was developed for Habitat for Humanity International and is the result of lessons learned from demonstration retrofit projects undertaken by Habitat for Humanity affiliates in Newburgh, New York; Baltimore, Maryland; and Philadelphia, Pennsylvania; with building systems consulting and technical assistance provided by Steven Winter Associates, Inc. (SWA).

An example of an exterior wall specification when polygons are used:

```
K-EXT1 = EXTERIOR-WALL
  LOCATION = SPACE-V3 ..
```

This command places a wall between the third and fourth vertices of the space polygon. The wall height will default to the height of the space.

Polygons should be created for each floor of the house. These floor polygons will include all spaces on the floor, including conditioned and unconditioned spaces. An attached garage, for example, should be included in the first-floor polygon. In addition, space polygons should be created for each space that will be a separate zone in the DOE-2 model.

Placement of separate internal and external walls should be considered when creating the space polygons. In Figure 17, the "Great Room" polygon could be defined using four vertices. However, because six separate walls will be defined for this floor plan (three internal and three external), the polygon used to describe the space should be defined with the six vertices shown.

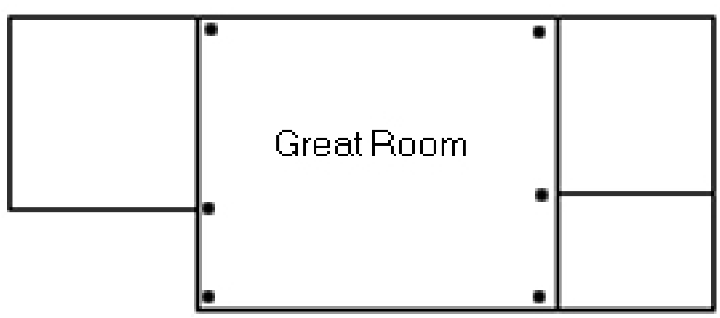



**Figure 17. Definition of vertices for typical floor plan**

### *3. Building Shell Take-Offs*

The building shell take-offs involve identifying the location and size of all windows, doors, interior walls, exterior walls, and underground walls. As shown above, placement of exterior walls is simplified when polygons are used to describe the floor plan (using the LOCATION keyword under the EXTERIOR-WALL command).

Placement of doors and windows is accomplished by specifying the X and Y coordinates within the appropriate exterior wall. Placement of the windows is especially important, so that shading of the building and site is properly accounted for. Below is an example of a window specification.

```
"MB Win2"          = WINDOW
GLASS-TYPE        = mainglass[]
HEIGHT            = #[70  / 12]
WIDTH             = #[35  / 12]
X                 = 3.5
Y                 = #[7 - #[70 / 12]]    $window height = 7'
..
```

In this case, the window was measured as 70 in. high by 35 in. wide, including the frame. The X value places the window 3.5 ft from the left side of the preceding wall definition. The Y value places the top of the window 7 ft from the bottom of the wall.

Doors containing a significant amount of glazing should be separated into an opaque area (specified using the DOOR command) and a window area. Sliding glass doors are treated as windows.

To capture the correct surface orientations of roof surfaces and attic end walls, trapezoidal and triangular polygons are often needed. Figure 18 shows a three-dimensional representation of a DOE-2.2 model with fairly accurate roof geometry. The roof is composed of six polygons, all part of the attic space.

**Figure 18. Building geometry of a simple residence** (Source: eQUEST)

### *4. Building Constructions*

#### *Wall Constructions*

There are a number of ways to model wall constructions within the DOE-2 program. *Quick Walls* have no mass and are capable of steady-state heat transfer only. For the purposes of Building America, these types of walls are used only for lightweight door constructions, such as garage doors. Massive walls, built up from descriptions of the individual material components, provide a much more accurate model of heat transfer.

The following BDL code is an example of how to define an exterior wall with the proper mass and overall thermal resistance for both the Benchmark and Prototype houses. The first section defines the construction of a frame wall given the Frame Type (2x4, 2x6, engineered 2x6) along with the cavity and sheathing insulation values. The second section creates a frame wall based on a specified overall U-value, as is needed for the reference house. Both of these constructions create realistic walls with respect to building materials, mass, and overall thermal resistance, but with a simplifying homogeneous middle layer made up of framing and insulation.

```
$-----------------------------------------------------------------------------------------
$ Exterior Wall Definition Start ========================================================
$
$
$ Defines "EXT-WALL", based on either specified Wall insulation and wall type or overall
$   wall U-value.
$
$ Required material definitions:
$
$    PW02, GP01
$
$ Required macros:
$
$    WallAbs
$    WallIns & SheathIns & FramType
$     or WallU
$    WallMethod  (SpecIns or SpecU)
$
 ##if #[WallMethod[] EQS SpecIns]
  $
  $ This wall construction assumes that "WallIns" and "SheathIns" are specified along with the
  $  FrameType (2x4Frame, 2x6Frame or SIPS).  Overall Wall U-value is determined based on these
  $  inputs.  Actual effective ceiling insulation r-value is used as well.
  $
  ##SET1 CEILTH #[CeilRval[] / 40]        $ WALL INSULATION THICKNESS IN FT.
  CEILINS  = MAT TYPE=PROPERTIES TH=CEILTH[] COND=0.0250  DENS=0.6  S-H=0.2 ..

  ##if #[FramType[] EQS "2x4Frame"]
   ##set1 cavitydep   #[3.5 / 12]                $ cavity depth, feet
   ##set1 maxcavR     10.8                       $ filled cavity R-value
   ##set1 FramFact    0.23
   ##set1 framerval   #[15 * cavitydep[]]        $ pine framing R-15 per ft
   ##set1 framedens   32.0                       $ pine framing 32 lbs/ft3
   ##set1 cavityrval  WallIns[]
  ##elseif #[FramType[] EQS "2x6Frame"]
   ##set1 cavitydep   #[5.5 / 12]                $ cavity depth, feet
   ##set1 maxcavR     17.0                       $ filled cavity R-value
   ##set1 FramFact    0.20
   ##set1 framerval   #[15 * cavitydep[]]        $ pine framing R-15 per ft
   ##set1 framedens   32.0                       $ pine framing 32 lbs/ft3
   ##set1 cavityrval  WallIns[]
  ##elseif #[FramType[] EQS "Eng2x6"]
   ##set1 cavitydep   #[5.5 / 12]                $ cavity depth, feet
   ##set1 maxcavR     17.0                       $ filled cavity R-value
   ##set1 FramFact    0.13                       $ Reduced Framing Factor
   ##set1 framerval   #[15 * cavitydep[]]        $ pine framing R-15 per ft
   ##set1 framedens   32.0                       $ pine framing 32 lbs/ft3
   ##set1 cavityrval  WallIns[]
  ##else
   ##ABORT - framing type not defined
  ##endif

  ##if #[cavityrval[] LT maxcavR[]]  $air gap in wall
   ##set1 cavityrval #[cavityrval[] + 0.9]
  ##endif
  ##if #[cavityrval[] GT maxcavR[]]
   ##set1 cavityrval maxcavR[]
  ##endif
  ##set1 ffill #[WallIns[] / maxcavR[]]
  ##if #[ffill[] GT 1]
   ##set1 ffill 1
  ##endif
  ##set1 cavitydens  #[#[0.6 * ffill[]] + #[0.016 * #[1 - ffill[]]]]
                                                     $Fiberglass @0.6lbs/ft3, air@62.5 ft3/lb

  $ Net exterior wall values:
  ##set1 wallrval  #[#[1 / cavityrval[]] * #[1 - FramFact[]]]
  ##set1 wallrval  #[wallrval[] + #[ #[1 / framerval[]] * FramFact[]]]
  ##set1 wallrval  #[1 / wallrval[]]
```

```
 ##else  $Wall Method = SpecU
  $
  $ For this method, overall Wall U-value is specified (WallU) instead of insulation R-value
  $ This U-value includes inside and outside film coefficients.  Ceiling structure (inc. attic)
overall
  $  u-value is used to calculate an equivalent ceiling insulation level.
  $
  $ Construction is standard 2x4Frame, with exterior sheathing as needed.

  ##set1 CeilRval #[1 / CeilU[]]
  ##set1 CeilRval #[CeilRval[] - 3.16]    $ 3.16 = Rval of other materials and attic space (T-24)
  ##SET1 CEILTH #[CeilRval[] / 40]        $ WALL INSULATION THICKNESS IN FT.
  CEILINS  = MAT TYPE=PROPERTIES TH=CEILTH[] COND=0.0250  DENS=0.6  S-H=0.2 ..

  $##if #[FramType[] EQS "2x4Frame"]
   ##set1 cavitydep   #[3.5 / 12] $ cavity depth, feet
   ##set1 maxcavIns   10.8        $ filled cavity R-value
   ##set1 FramFact    0.23
   ##set1 FrameRval   #[15 * cavitydep[]]        $ pine framing R-15 per ft
   ##set1 framedens   32.0                       $ pine framing 32 lbs/ft3
   ##set1 NonInsRval  2.32  $ = 0.47 * 2 (pw02) + 0.45 (gp01) + 0.68 (in) + 0.25 (out)
  $##endif

  ##set1 WallR     #[1 / WallU[]]                   $required wall construction R-value
  ##set1 WallCavR  #[WallR[] - NonInsRval[]]        $required wall cavity composite R-value

  ##set1 CavIns    #[#[1 / WallCavR[]] - #[FramFact[] / FrameRval[]]]  $required Insulation R-
value
  ##set1 CavIns    #[#[1 - FramFact[]] / CavIns[]]                     $ of cavity

  ##if #[CavIns[] GT maxcavIns[]]
   ##set1 CavIns maxcavIns[]
  ##endif

  ##set1 wallrval  #[#[1 / CavIns[]] * #[1 - FramFact[]]]              $actual cavity R-value
  ##set1 wallrval  #[wallrval[] + #[ #[1 / FrameRval[]] * FramFact[]]]
  ##set1 wallrval  #[1 / wallrval[]]

  ##set1 SheathIns #[WallCavR[] - wallrval[]]
  ##set1 cavitydens  0.6     $ fiberglass, 0.6 lbs/ft3

##endif

##set1 walldens  #[cavitydens[] * #[1 - FramFact[]]]
##set1 walldens  #[walldens[] + #[framedens[] * FramFact[]]]

$wall insulation material is a combination of insulation and wood
WALLINSM =MAT TYPE=PROPERTIES    TH = cavitydep[]
                               COND = #[cavitydep[] / wallrval[]]
                               DENS = walldens[]
                                S-H = 0.2 ..

$exterior wall: siding, insulation, plywood, cavity and gypboard
##if #[SheathIns[] GT 0.3]
 SHEATHINS =MAT TYPE=PROPERTIES TH = #[0.02 * SheathIns[]]
                                COND = 0.02 DENS = 1.8 S-H = 0.29 ..
  LAY-1               =LAYERS  MAT=(PW02,SHEATHINS,PW02,WALLINSM,GP01)
                               I-F-R = 0.68 ..
##else
  LAY-1               =LAYERS  MAT=(PW02,PW02,WALLINSM,GP01)
                               I-F-R = 0.68 ..
##endif
EXT-WALL =CONS      TYPE=LAYERS  LAYERS=LAY-1  ROUGHNESS=6 ABS=WallAbs[]  ..


$ End of Exterior Wall definition -----------------------------------------------
$ ==============================================================================
```

This type of conglomerate wall construction makes it possible to use polygons to place exterior wall sections. An alternative method of describing frame walls is to create separate wall types for the cavity and framing section. In the latter case, rather complicated polygons need to be specified for each floor plan, or the traditional X and Y coordinate system needs to be used to place exterior walls.

### *Foundations*

There are a number of ways to model the heat flow through foundation walls connected to the underground. When possible, the method described by Fred Winkelman (Winkelman 1998) should be used. This perimeter heat-loss method uses predetermined conduction factors that relate the heat loss rate of an underground surface to the exposed perimeter of the surface as well as the construction and insulation levels. The method applies to slab-on-grade floors, basement walls, and crawl-space walls.

It is very important not to model underground surfaces using the standard DOE-2 construction command combined with a standard underground wall command. Though this may seem reasonable, the model assumes a constant ground temperature (versus a ground temperature that is influenced by the building heat loss), and losses can be greatly overpredicted.

**Slab-on-Grade Floors.** The perimeter heat-loss method requires that a separate slab construction be defined for each space that has a slab floor. Each construction includes a fictitious insulating layer based on the area, exposed perimeter, and construction of the slab. The following BDL code defines the slab floor construction for one space:

```
$ Great Room Slab Definition, based on perimeter losses, F2 = 0.77,
$   R-Value of airfilm + carpet + slab = 3.5
##set1 Reff_gr #[GR_area[] / #[0.77 * GR_perim_t[]]]
##set1 Rfic_gr #[Reff_gr[] - 3.5]

$ SLAB FICTICIOUS INSULATING LAYERS
"MAT-FIC-CORE GR" = MATERIAL
   TYPE             = RESISTANCE
   RESISTANCE       = Rfic_gr[]  ..

"Slab Layer Core GR" = LAYERS
   MATERIAL  = ("MAT-FIC-CORE GR", "Soil", CC03,
                "Carpet & Rubber Pad (CP02)") ..

"Floor Slab Cons GR" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "Slab Layer Core GR" ..
```

Soil properties are defined as:

```
SOIL  = MAT TYPE=PROPERTIES TH=2.0  COND=1.0  DENS=115  S-H=0.26 ..
```

This construction, as well as the effective R-value of the slab (Reff_gr) is referenced when defining the slab floor as an underground wall within the space command.

```
GR-SLAB  = UNDERGROUND-WALL
           LOCATION     = BOTTOM
           TILT         = 180
           U-EFFECTIVE  = #[1 / Reff_gr[]]
           CONSTRUCTION = "Floor Slab Cons GR"  ..
```

**Crawl Spaces and Basements**. Crawl space and basement walls are modeled in much the same way as slab floors, with the location specified by a polygon vertex. Floors for basements and crawl spaces are described in a similar fashion using DOE-2, only the "R-eff" is set to a high value and the U-effective is set to zero. For a more detailed description, see the complete article by Winkelman.

### *Windows*

Windows can be modeled using the DOE-2.2 window library or by specifying the shading coefficient and overall glass U-value. The window library method is more accurate but might not be readily applied to the Benchmark model, which specifies a fixed SHGC and a variable U-value. For consistency between the various models being compared, we suggest using the same calculation method for all models.

## *5. Shading*

Shading is an important consideration when evaluating fenestration measures—as important as the glazing type. Shading can be caused by a variety of sources, all of which should be properly accounted for when modeling the Prototype, Regional Standard Practice, or Builder Standard Practice (the Benchmark is modeled without shading).

### *Site Shading*

Shading caused by nearby buildings, fences, and vegetation falls under this category. This type of shading is modeled using the BDL Building-Shade command. A transmittance value can also be added if vegetation partially shades the house.

```
BUILDING-SHADE      X=40   Y=55   Z=0
$right bldg$        H=13   W=55
                    AZ=270 TILT=90 ..
```

(Note: Site shading normally is fixed at typical levels for purposes of comparing Prototype and base-case houses.)

### *Overhangs/Self-Shading*

Roof overhangs can be modeled as separate BUILDING-SHADE commands or as an exterior wall that is part of the attic space. It is usually much simpler to model the overhang as a building shade, as in the example below:

```
BUILDING-SHADE      X=0    Y=50  Z=wallht[]
$left  soffit$      H=1.5  W=44
                    AZ=270 TILT=180 ..
```

The height where the shading surface begins, the Z coordinate, is specified using the user-specified macro for the house wall height. The location of shading surfaces relative to the house should be checked using eQUEST or PowerDOE, as misplaced shading surfaces can have a large impact on the heating and cooling loads.

Walls of the building that could shade other surfaces can be specified as shading surfaces by adding the SHADING-SURFACE = YES keyword to the EXTERIOR-WALL command.

```
GR-EXT1  = EXTERIOR-WALL
        LOCATION         = SPACE-V1
        SHADING-SURFACE  = YES  ..
```

The modeler can cause all exterior walls to become shading surfaces by using the SET-DEFAULT command for EXTERIOR-WALL, but this slows down the simulation time unnecessarily. Note that the guidelines in Section I of this report recommend that self shading *not* be used for comparing the Prototype with the Benchmark.

### 6. Measure Design

This step involves assessing how the Prototype model differs from the base-case models and determining how best to incorporate all the changes. Macros, as either single variables or entire sets of BDL commands and key words, are established for each incremental change.

The types of measures and BDL modifications that are identified in this step will help determine how the modeling details of the base cases will take shape.

### 7. Defining the Building America Benchmark

#### Building Shell

As mentioned previously, the base-case models are created from the construction documents for the Prototype building using the guidelines set forth in Section I. The only differences in the building shell between the Prototype and the Benchmark models are the window and door areas by orientation. The Benchmark model has equal window areas facing in each direction, and a total area specified as a function of the conditioned floor area. In the BDL, macros can help with these definitions:

```
##if #[WindowAreaMeth[] EQS Reference]
       "BAwindow GR1"   = WINDOW
        GLASS-TYPE     = WinGlassBA
        HEIGHT           = 4
        WIDTH            = #[BA_AreaEachWinow[] / 4]
        X                = 2
        ..
##else
       "4040 Win-1"   = WINDOW
       GLASS-TYPE     = SouthGlass
        ##set1 fw        #[FrameWid[] * 1.2]  $slider
        HEIGHT           = #[#[WinHt[] - #[fw[] * 2]] / 12]
        WIDTH            = #[#[40 - #[fw[] * 2]] / 12]
        FRAME-WIDTH      = #[fw[] / 12]
        SPACER-TYPE      = BUTYL/METAL
        FRAME-ABS        = 0.7
        FRAME-CONDUCT    = FrameCond[]
        X                = 1
        ..
       "4040 Win-2"   = WINDOW
        LIKE "4040 Win-1"
        X                = 7.5 ..
       "4040 Win-3"   = WINDOW
        LIKE "4040 Win-1"
        X                = 12.33 ..
##endif
```

#### Cooling Equipment Performance/Sizing

Sizing and performance of the Benchmark cooling equipment were outlined earlier. The SEER can be translated to energy efficiency ratio (EER) as outlined for California's Title 24[13]:

```
$ Title-24 SEER/HP-HIR Calculation ====================
##SET1 EERb    = #[SEER[] / 0.985]
##SET1 EER95s   = #[0.855 * EERb[]]
##SET1 FAN-KW = supplykw[]
```

```
##SET1 STDFAN_KW = 0.000365               $ ARI conditions
##SET1 SUPPLY_DT = #[FAN-KW[] * 3160]   $ 3413/1.08
##SET1 EIRn = #[#[1 / EER95s[]] - #[33.333 * STDFAN_KW[]]]
##SET1 EIRd = #[0.2930 + #[33.333 * STDFAN_KW[]]]
##SET1 EIRa = #[EIRn[] / EIRd[]]
```

The “supplykw” value will be set to 0.00055 kW/cfm. This value is typical of a number of Building America test houses, including both the base-case and Prototype houses. At a minimum, the following cooling equipment parameters will be specified under the SYSTEM command:

```
SUPPLY-KW         = FAN-KW[]
SUPPLY-DELTA-T    = SUPPLY_DT[]
COOLING-EIR       = EIRa[]
```

It is also possible to use the equipment manufacturer’s extended ratings to model the equipment’s part-load performance and performance as a function of ambient and indoor conditions. In this case, NREL can supply a set of detailed performance curves to use with the Benchmark model.

### *Heating Equipment Performance/Sizing*

As described in Section I, heating equipment representing both the Benchmark and Regional Standard Practice is a furnace with an AFUE of 78 if the main heating fuel for the Prototype is natural gas. If the main heating fuel is electricity, the heating equipment will be an air-source heat pump with heating seasonal performance factor (HSPF) of 6.8. The heat pump will be sized based on the cooling capacity and will have electric resistance backup. Supply fan power will be the same as described for the cooling equipment.

```
##SET1 COP47s = #[#[0.4813 * hspf[]] - 0.2606]
##SET1 HIRn = #[#[1 / #[COP47s[] * 3.413]] - #[33.333 * FAN_KW[]]]
##SET1 HIRd = #[0.2930 - #[33.333 * FAN_KW[]]]
##SET1 HP-HIR = #[HIRn[] / HIRd[]]
##if #[FurnAFUE[] GT 83.5]
  ##SET1 FURN-HIR = #[ 1 / #[#[1.1116 * #[FurnAFUE[] / 100]] - 0.098185]]
##else
  ##SET1 FURN-HIR = #[ 1 / #[#[0.2907 * #[FurnAFUE[] / 100]] + 0.5787]]
##endif
```

### *Water Heating Equipment Performance*

Because the typical efficiency specification of hot-water systems is the energy factor, which accounts for annual average burner efficiency and tank losses, the domestic hot water (DHW) model in DOE-2 is very nearly disabled in favor of the simplified algorithm: Energy (Btu) = hot-water load (Btu) / EF. The hot-water volume is determined using Table 9, and the set point is 120°F. The DOE-2 part-load performance curve for DHW equipment must be overridden with a curve that eliminates any efficiency dependency on partial loads, and tank losses must be set to zero. The entire DOE-2 DHW model is shown below:

```
$ DHW Monthly Inlet temperatures for Boulder, CO
MAINS-T-SCH = SCHEDULE  TYPE=TEMPERATURE
              THRU JAN 31 (ALL) (1,24) (46.9)
              THRU FEB 28 (ALL) (1,24) (45.6)
              THRU MAR 31 (ALL) (1,24) (47.0)
              THRU APR 30 (ALL) (1,24) (50.6)
              THRU MAY 31 (ALL) (1,24) (55.6)
              THRU JUN 30 (ALL) (1,24) (60.6)
              THRU JUL 31 (ALL) (1,24) (64.4)
              THRU AUG 31 (ALL) (1,24) (66.0)
              THRU SEP 30 (ALL) (1,24) (64.8)
              THRU OCT 31 (ALL) (1,24) (61.4)
              THRU NOV 30 (ALL) (1,24) (56.4)
              THRU DEC 31 (ALL) (1,24) (51.3)  ..
```

```
DHWLoop = CIRCULATION-LOOP
   TYPE             = DHW
   $dhwuse in gallons per day, converted to gallons per hour via schedule:
   PROCESS-SCH      = "DHW Schedule"
   $dhwuse in gallons per hour, converted to gallons per minute:
   PROCESS-FLOW     = #[dhwuse[] / 60 ]
   HEAT-SETPT-T     = 120             $120 F hot-water supply temp.
   DHW-INLET-T-SCH  = MAINS-T-SCH     $Monthly mains water temperature
   ..

NoPLR = CURVE-FIT                  $eliminates the dependence on part-load
   TYPE             = LINEAR
   INPUT-TYPE       = COEFFICIENTS
   COEFFICIENTS     = (0,1)
   ..

DHWheater = DW-HEATER
   TYPE             = GAS               $ GAS
   HIR              = #[1 / DHWeff[]]   $ EIR = #[1 / DHWeff[]]
   HIR-FPLR         = NoPLR             $ EIF-FPLR = NoPLR
   DHW-LOOP         = DHWLoop
   TANK-UA          = DHWTankUA[]
   TANK-VOLUME      = DHWVolume[]
   LOCATION         = ZONE
   ZONE-NAME        = BasementZ   ..
```

## *8. From Regional Standard Practice to Prototype*

Once the Regional Standard Practice building is modeled, the Prototype model is created by changing the characteristics of each component that is not the same in the two houses. 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 improvement is analyzed by simulating the new combination of measures and comparing the energy performance to the previous combination of measures.

The order 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 a hypothetical unvented attic measure and a duct improvement measure. We assume the duct improvement measure, which lowers the air-loss rate to the attic from 15% to 3%, has approximately the same added cost as the unvented attic strategy, which moves the insulation from the attic floor to the attic roof. If the unvented attic measure is added first, the results in Table 20 are possible.

**Table 20. 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) | **Source Energy 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;

therefore, it should come first, according to this analysis. When the measure order is reversed, the results in Table 21 are possible.

**Table 21. 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) | Source Energy 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% |

Here, the unvented attic is projected to have a negative impact on energy use if the duct measure is implemented first. When measures are highly interactive, it is important to explore the sensitivity of the savings to the order of the measures, and results should be presented in multiple sequences to illustrate this sensitivity and clarify the B/C analysis.

One convenient way of modeling the incremental changes from a base case to the Prototype is to use macros that progressively add in measures as the value of an "EEM level" (energy efficiency measure level) variable increases. The following BDL code is used in the sample input file:

```
##set1 mainglass StdGlass $ Dbl-clear
##set1 framecond 3.037    $ aluminum frames
##set1 ceilrval  26.2  $ R-value if insulation is in ceiling, nominal R-30

$ EEM 1, changes  ================================
$                 eemlvl = 1 or above
$
$ EEM description:  better windows
 ##if #[eemlvl[] GT 0.5]
  ##set1 mainglass AndersonGlass
##endif

$ EEM 2, changes  ================================
$                 eemlvl = 2 or above
$
$ EEM description:  Inc. Ceiling Insulation
 ##if #[eemlvl[] GT 1.5]
  ##set1 ceilrval  34
 ##endif
```

If the value of the "eemlvl" macro is zero, then the changes associated with "EEM 1" and "EEM 2" are skipped. As the value of "eemlvl" increases, more and more components are changed to reflect the Prototype design.

## *9. DOE-2 Simulation and Design Verification*

The results of the base-case and Prototype simulations need to be examined carefully to ensure that the building systems are well-designed and that the buildings are modeled as intended.

### *Input Verification*

We cannot overstate importance of verifying that the inputs to the model are as intended. Given the flexible nature of the inputs, the use of macros to calculate many input values and the potential complexity of the building geometry, opportunities abound for misplaced decimal points and misplaced walls.

The easiest way to verify the building geometry is to import the BDL input file into one of the DOE-2.2-based simulation tools discussed later in this report. These tools will show all the building surfaces in a three-dimensional format. Misplaced or incorrectly sized surfaces can thus be quickly identified.

DOE-2 produces a series of verification reports that summarize and list all of the important inputs for a surface, a space, or the whole building. Reports LV-B and LV-C are particularly useful to verify building construction inputs. Report LV-B should be examined to verify the area and volume of each defined space. Report SV-A summarizes the major system characteristics. Supply airflow rates to each space are listed, as is the total heating and cooling capacity of the systems.

It is also useful to examine the component loads of the various building components by using a report like LS-C. This report shows the peak load associated with each major building component. Errors in the simulation model can often be caught by comparing the peak component heat flows with the analyst's expectations.

### *Performance Verification*

Another important quality control effort is to ensure that HVAC systems are performing as intended. The best indicator of this could be the comfort level maintained in the house. Report SS-K reports monthly average temperatures during cooling, heating, and floating hours. SS-R reports the part-load operation of the equipment and how many hours any particular zone was underheated or undercooled. The temperature profile in each zone can be quickly assessed with the SS-O reports for each zone. (Time saver: searching for the word "below" within the DOE-2 output file will quickly take you to the bottom of each temperature profile.)

For many residential systems, it is not unusual for some of the zones to float past the control temperature; this occurs fairly often. Because the thermostat is in only one zone (typically), other zone temperatures will float until the zone with the thermostat calls for heating or cooling. If some zones are almost always too hot or too cold, this could indicate that the zone with the thermostat is not properly "connected" with the spaces around it or that the supply airflow to the zones is not well designed.

### ***10. Analysis and Reporting of Results***

Consistent reporting of the analysis is important for the proper and timely interpretation of results. Guidelines for reporting results are provided in Section I. However, additional data may be of interest, depending on the application, and they should be supplied in a separate spreadsheet.

The process of extracting results for the DOE-2.2 simulation file for the series of runs required for the Building America analysis can be performed quite simply by using the BA-Run22 program, which is discussed in more detail in the Support Programs section of this report.

## Modeling Topics

There is rarely only one way to model a particular thermal component of an energy simulation exercise. Varying levels of detail are usually available, and the greatest level of detail is not always the most appropriate choice. Efforts should be directed toward the areas that most influence the final answers. The following sections present methods for modeling infiltration, unvented attics, and HVAC systems. These discussions are based on experience with past projects and should be considered a starting point for further research and refinement.

### 1. Infiltration

Infiltration of outdoor air into a house is caused by a number of mechanisms—occupant behavior (opening doors and windows), natural infiltration caused by wind and the temperature difference between the house and the outdoors, mechanical ventilation of bathrooms and kitchens, and the infiltration caused by the operation of the HVAC system. The latter mechanism may be intentional or caused by leaks from supply ducts into unconditioned spaces.

Each of these mechanisms should be considered when creating the simulation model. There are a number of ways to model infiltration in DOE-2. Some of these methods and their common application in the Building America context are described below.

#### Infiltration Caused by Occupant Behavior

There are at least two aspects of infiltration caused by occupant behavior. The more predictable aspect occurs when occupants open windows, and possibly doors, because there is a perceived cooling load and the outdoor temperature is cooler than the indoor temperature. In DOE-2 BDL, this is called *natural ventilation*. This is not an unusual situation, especially in desert climates where evening temperatures, even in the middle of the cooling season, can drop well below 70°F.

The DOE-2 simulation program accounts for this type of infiltration by allowing for a specific additional amount of air exchange based on the hourly indoor and outdoor temperature, the estimated air-exchange rate when windows are open, and the probability that an occupant will open the windows if they are closed. The modeler must also consider other aspects of the local climate when modeling this type of infiltration. For example, it might be impractical to open windows, even during cool evenings, in windy and dry (i.e., dusty) conditions.

An example of the BDL code under the SYSTEM command used to specify natural ventilation is as follows:

```
$NATURAL VENTING system variables:
  VENT-METHOD      = AIR-CHANGE
  NATURAL-VENT-SCH = VOPSCH   $when windows are allowed open
  VENT-TEMP-SCH    = VTSCH    $temp. below which windows closed
  OPEN-VENT-SCH    = WINDOPER $probability of window being open
  NATURAL-VENT-AC  = 10       $peak air-changes per hour
```

The natural vent schedule (natural-vent-sch) is set to allow the windows to be opened anytime during the day or season. The ventilation temperature schedule (vent-temp-sch) is set to a constant 68°F, forcing the windows closed if the indoor temperature falls below this value. Given that 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 open is set at a constant 50%. Any changes from these assumptions should be documented.

Another aspect of occupant-induced infiltration is doors opened for entry and windows opened for reasons not based on temperature considerations (i.e., for fresh air). Opening doors for entry typically leads to very small amounts of infiltration and is usually considered “lost in the noise” of the overall infiltration rate. As such, no explicit accounting is made of this. Also, no special considerations are given to unpredictable and atypical infiltration caused by occupant behavior.

*Natural Infiltration*

Natural infiltration is caused by air passages between the house and the outdoors, pressure differences caused by wind, and the temperature difference between the indoors and outdoors.

Blower door measurements lead to estimates for the leakage area of the house and the natural infiltration rate. Whereas DOE-2 includes an infiltration model based on leakage area, it is applicable only to single-zone models. A simple ACH model is usually an acceptable alternative. The disadvantage of an ACH model is that it does not capture increased infiltration during periods of very high and low outdoor temperatures, when the load resulting from the infiltration is also higher.

An example of the BDL code under the SPACE command used to specify natural infiltration:

```
INF-METHOD        = RESIDENTIAL
RES-INF-COEF      = (0.35,0,0)   $  const, wind ,deltaT coefficients
```

The coefficients (0.35, 0.0) sets the infiltration air-exchange rate to a constant value of 0.35 ACH.

An alternative method that captures the variation in infiltration rate due to wind and temperature, but which requires considerable more effort to create, is an adjusted leakage area model. The concept is to use the Sherman-Grimsrud (S-G) leakage area method for all conditioned zones, but adjust the leakage area so the resulting annual average infiltration rate is the estimated natural infiltration rate. In this way, the S-G method will provide hourly variations in the infiltration rate while still relying on the natural infiltration calculations of the blower door test.

A similar approach could be taken using the infiltration method described for occupant behavior. In either case, it is important to review the profile of hourly infiltration rates calculated by the program using DOE-2's hourly reports before accepting the results.

*Spot Ventilation in Bathrooms and Kitchens*

If mechanical ventilation is specifically used to supply outside air to the house, either continuously or with a fixed schedule, the increased infiltration and electric usage of the fan must be accounted for. On the other hand, if occupants turn on kitchen and bathroom exhaust fans intermittently to control humidity or odors (i.e., spot ventilation), the unpredictable increase in infiltration and electricity does not need to be included in the model.

Unfortunately, the residential system in DOE-2 does not include exhaust fans, and the associated increase in outdoor air must be accounted for in the overall house infiltration. The electric usage of the fan should not be included in the indoor loads, because nearly all of the heat generated by the fan is exhausted. Instead, outdoor electric loads can be added to the main electric meter command in DOE-2, or electric usage can be added after the DOE-2 simulation.

*Infiltration Based on Hourly Measurements*

This method is potentially the most accurate way to characterize the hourly infiltration rate caused by natural infiltration and HVAC system operation. Its application is limited, however, because of the data needed to establish the proper inputs.

Hourly data are needed for actual infiltration rate, HVAC system run-time, local wind speed, average indoor temperature, and outdoor temperature. The time period for the hourly data must span a variety of wind speeds and outdoor temperatures in order to produce reliable regression coefficients. These data are typically collected under test conditions for a period ranging from several days to two weeks.

If the proper data are available, a simple linear regression can produce an equation that predicts the infiltration rate as a function of wind speed and the indoor-outdoor temperature difference:

$$\text{Infiltration} = c0 + c1 * \text{wind speed} + c2 * |T_{in}-T_{out}| ,$$

where c0, c1, and c2 are regression coefficients, $T_{in}$ is the indoor temperature, and $T_{out}$ is the outdoor temperature.

When extrapolating the simulation model to a full year using standard weather files, it is important to adjust the average wind speed measured at the site to the average wind speed for the same period in the yearly weather data used for the annual simulation.

In this case, these inputs are used in the DOE-2 input file:

```
INF-METHOD       = RESIDENTIAL
RES-INF-COEF     = (infconst[],infwind[],infdeltat[])
                 $  const, wind ,deltaT  coefficients
```

The three coefficients are input with macros set elsewhere in the BDL code, so that they can be easily changed based on the specific model being simulated.

## 2. Building Operation

Typically, levels of confidence vary in the many inputs required to model the house properly. The most variable component, by far, is the building operation. Building operation includes most of the occupant-controlled aspects of energy use, including thermostat set points, window management, hot-water usage, and natural ventilation. Earlier, this document recommended a set of standard schedules, set points, and variables associated with the building and equipment operation that should be used for the base cases and the Prototype. Any deviations from these standards must be clearly pointed out in the modeling report and justification should be documented.

### Internal Gain Schedules

These vary the amount of heat gain from appliances and lights throughout the day. The single internal gain schedule used in the original version of this report has been replaced with individual schedules for occupants, lighting, and plug & appliance loads.

**Occupancy schedules** control when people are in various spaces. The following schedules define different occupancy patterns for bedrooms and nonbedroom areas, and they vary from weekday to weekend.

```
$ Schedule for people in the Living Room:
PEOP-LR-WD =DAY-SCHEDULE   TYPE = FRACTION  $PEOPLE Weekday
  ( 1) (0.00)  ( 2) (0.00)  ( 3) (0.00)  ( 4) (0.00)
  ( 5) (0.00)  ( 6) (0.00)  ( 7) (0.50)  ( 8) (0.33)
  ( 9) (0.33)  (10) (0.33)  (11) (0.33)  (12) (0.33)
  (13) (0.33)  (14) (0.33)  (15) (0.33)  (16) (0.33)
  (17) (0.33)  (18) (0.33)  (19) (1.00)  (20) (1.00)
  (21) (1.00)  (22) (1.00)  (23) (0.50)  (24) (0.00)
   ..
PEOP-LR-WE =DAY-SCHEDULE   TYPE = FRACTION  $PEOPLE Weekend
  ( 1) (0.00)  ( 2) (0.00)  ( 3) (0.00)  ( 4) (0.00)
```

```
  ( 5) (0.00)  ( 6) (0.00)  ( 7) (0.00)  ( 8) (0.50)
  ( 9) (0.67)  (10) (0.67)  (11) (0.67)  (12) (0.67)
  (13) (0.67)  (14) (0.67)  (15) (0.67)  (16) (0.67)
  (17) (0.67)  (18) (1.00)  (19) (1.00)  (20) (1.00)
  (21) (1.00)  (22) (1.00)  (23) (0.50)  (24) (0.00)
  ..

$ Schedule for people in the Bedrooms:
PEOP-BR-WD =DAY-SCHEDULE   TYPE = FRACTION  $PEOPLE Weekday
  ( 1) (1.00)  ( 2) (1.00)  ( 3) (1.00)  ( 4) (1.00)
  ( 5) (1.00)  ( 6) (1.00)  ( 7) (0.50)  ( 8) (0.33)
  ( 9) (0.00)  (10) (0.00)  (11) (0.00)  (12) (0.00)
  (13) (0.00)  (14) (0.00)  (15) (0.00)  (16) (0.00)
  (17) (0.00)  (18) (0.00)  (19) (0.00)  (20) (0.00)
  (21) (0.00)  (22) (0.00)  (23) (0.50)  (24) (1.00)
   ..

PEOP-BR-WE =DAY-SCHEDULE   TYPE = FRACTION  $PEOPLE Weekend
  ( 1) (1.00)  ( 2) (1.00)  ( 3) (1.00)  ( 4) (1.00)
  ( 5) (1.00)  ( 6) (1.00)  ( 7) (1.00)  ( 8) (0.50)
  ( 9) (0.00)  (10) (0.00)  (11) (0.00)  (12) (0.00)
  (13) (0.00)  (14) (0.00)  (15) (0.00)  (16) (0.00)
  (17) (0.00)  (18) (0.00)  (19) (0.00)  (20) (0.00)
  (21) (0.00)  (22) (0.00)  (23) (0.50)  (24) (1.00)
  ..

PEOP-LR-SCH =SCHEDULE TYPE = FRACTION THRU DEC 31 (WD)  PEOP-LR-WD
                                                 (WEH)  PEOP-LR-WE  ..

PEOP-BR-SCH =SCHEDULE TYPE = FRACTION THRU DEC 31 (WD)  PEOP-BR-WD
                                                 (WEH)  PEOP-BR-WE  ..
```

The actual number of people in each space is specified in the SPACE-CONDITIONS command. The standard number of people in the house is the number of bedrooms. Because the schedules defined above do not overlap, the total number of people specified for all of the bedrooms should equal this number, and the total number of people in the other spaces should equal this number, as well.

**Lighting schedules** are defined for various levels of modeling detail in the lighting spreadsheet posted on the Building America Web site. The most important aspect of these schedules is that they merely assign a profile to lighting use. The schedules must be used along with the modeled lighting power densities to arrive at the required annual lighting energy use. To keep this as simple as possible, the supplied lighting schedules always average to a daily total of 1.0 for a given space type.

```
$ Lighting Schedule, average for all WEEKDAYS of the year, LIVING SPACES ONLY
Ltg-LR-WD-DS =DAY-SCHEDULE   TYPE = FRACTION
(1,24)   (0.0081,0.0081,0.0081,0.0081,0.0161,0.0322,0.0380,0.0361,
          0.0161,0.0161,0.0161,0.0161,0.0161,0.0161,0.0161,0.0341,
          0.0742,0.1066,0.1268,0.1329,0.1208,0.0644,0.0322,0.0161)  ..

$ Lighting Schedule, average for all WEEKEND days of the year, BEDROOM SPACES ONLY
Ltg-BR-WD-DS =DAY-SCHEDULE   TYPE = FRACTION
(1,24)   (0.0092,0.0092,0.0092,0.0092,0.0366,0.0800,0.0867,0.0731,
          0.0275,0.0092,0.0092,0.0092,0.0092,0.0092,0.0092,0.0114,
          0.0251,0.0366,0.0686,0.1099,0.1374,0.1191,0.0641,0.0275)  ..

$ Lighting Schedule, average for all WEEKDAYS of the year, LIVING SPACES ONLY
Ltg-LR-WE-DS =DAY-SCHEDULE   TYPE = FRACTION
(1,24)   (0.0081,0.0081,0.0081,0.0081,0.0161,0.0322,0.0362,0.0362,
          0.0242,0.0242,0.0242,0.0242,0.0242,0.0242,0.0242,0.0362,
          0.0722,0.0943,0.1267,0.1369,0.1208,0.0805,0.0483,0.0161)  ..

$ Lighting Schedule, average for all WEEKEND days of the year, BEDROOM SPACES ONLY
Ltg-BR-WE-DS =DAY-SCHEDULE   TYPE = FRACTION
(1,24)   (0.0092,0.0092,0.0092,0.0092,0.0366,0.0807,0.0877,0.0738,
          0.0275,0.0092,0.0092,0.0092,0.0092,0.0092,0.0092,0.0117,
          0.0253,0.0365,0.0685,0.1098,0.1374,0.1191,0.0771,0.0275)  ..
```

```
Ltg-LR-SCH =SCHEDULE TYPE = FRACTION
         THRU DEC 31 (WD)   Ltg-LR-WD-DS
                     (WEH)  Ltg-LR-WE-DS  ..


Ltg-BR-SCH =SCHEDULE TYPE = FRACTION
         THRU DEC 31 (WD)   Ltg-BR-WD-DS
                     (WEH)  Ltg-BR-WE-DS  ..
```

When specifying the lighting intensity for the living area, the specified lighting (kW) is merely the annual lighting (kWh) for the living area divided by the total number of days (365).

```
LIGHTING-SCHEDULE = Ltg-LR-SCH
LIGHTING-KW       = #[AnnLtgLR[] / 365]
```

**Plug and appliance schedules** are dealt with in much the same way as the lighting schedules. The following schedule used for appliance and plug loads sums to 1.0 over the course of a day:

```
$ Appliance & Plug Load Schedule, average for all days of the year, all
spaces
$ Daily sum = 1.0,  Peak schedule value = 0.0588
ApplPlug-DS =DAY-SCHEDULE   TYPE = FRACTION
(1,24)   (0.0335,0.0288,0.0288,0.0270,0.0270,0.0335,0.0447,0.0523,
          0.0523,0.0482,0.0417,0.0417,0.0376,0.0341,0.0341,0.0341,
          0.0429,0.0347,0.0588,0.0588,0.0564,0.0564,0.0506,0.0417)  ..

ApplPlug-SCH =SCHEDULE TYPE = FRACTION
          THRU DEC 31 (ALL)  ApplPlug-DS  ..
```

When specifying the plug/appliance intensity, the specified "equipment kW" is merely the annual plug/appliance kWh divided by the total number of days (365).

```
EQUIPMENT-SCHEDULE = (ApplPlug-SCH
EQUIPMENT -KW       = #[AnnPlugAppl_kWh[] / 365]
```

**Thermostat schedules** are defined for heating and cooling. The cooling schedule uses a set point of 78°F, and the heating schedule uses a set point of 68°F. Space heating and cooling are made available on a monthly basis according to the rules in Section I. These rules are easily translated into BDL code for any location using the appliance and DHW spreadsheet on the Building America Web site.

```
$ Heating and Cooling Availability for Boulder, CO
 HEATING-AVAIL = SCHEDULE  TYPE=ON/OFF
              THRU JAN 31 (ALL) (1,24) (1)
              THRU FEB 28 (ALL) (1,24) (1)
              THRU MAR 31 (ALL) (1,24) (1)
              THRU APR 30 (ALL) (1,24) (1)
              THRU MAY 31 (ALL) (1,24) (1)
              THRU JUN 30 (ALL) (1,24) (1)
              THRU JUL 31 (ALL) (1,24) (1)
              THRU AUG 31 (ALL) (1,24) (1)
              THRU SEP 30 (ALL) (1,24) (1)
              THRU OCT 31 (ALL) (1,24) (1)
              THRU NOV 30 (ALL) (1,24) (1)
              THRU DEC 31 (ALL) (1,24) (1)  ..

 COOLING-AVAIL = SCHEDULE  TYPE=ON/OFF
              THRU JAN 31 (ALL) (1,24) (0)
              THRU FEB 28 (ALL) (1,24) (0)
```

```
                THRU MAR 31 (ALL) (1,24) (0)
                THRU APR 30 (ALL) (1,24) (0)
                THRU MAY 31 (ALL) (1,24) (0)
                THRU JUN 30 (ALL) (1,24) (1)
                THRU JUL 31 (ALL) (1,24) (1)
                THRU AUG 31 (ALL) (1,24) (1)
                THRU SEP 30 (ALL) (1,24) (1)
                THRU OCT 31 (ALL) (1,24) (0)
                THRU NOV 30 (ALL) (1,24) (0)
                THRU DEC 31 (ALL) (1,24) (0)  ..

SYSTEM-1   = SYSTEM
          TYPE             = RESYS2

          COOLING-SCHEDULE = COOLING-AVAIL
          HEATING-SCHEDULE = HEATING-AVAIL
          … etc.
```

### *3. Systems*

The DOE-2 "RESYS2" system type is used for most residential systems. An alternative residential system type is available in later versions of DOE-2. The RESVVT system delivers variable temperature and variable volumes of air to individually controlled zones. More on this system type can be found in the DOE-2.2 documentation.

The RESYS2 system type can simulate split system and unitary cooling systems, as well as direct and indirect evaporative cooling. Heating can be supplied from a gas furnace, electric resistance, or air-source heat pump. More sophisticated systems configurations, with ground loop heat exchangers, combined hydronic water heating, and other features can be modeled using the circulation loop approach described in the DOE-2.2 HVAC documentation.

Sample system BDL code is included for each of the examples posted on the Building America Web site (see www.eere.energy.gov/buildings/building_america/benchmark_def.html), providing comprehensive models for most system types likely to be encountered.

### *4. Modeling an Unvented Attic*

An accurate model of the attic is essential to capture the difference between a vented and unvented attic. Figure 19 shows the basic components for the vented attic model.

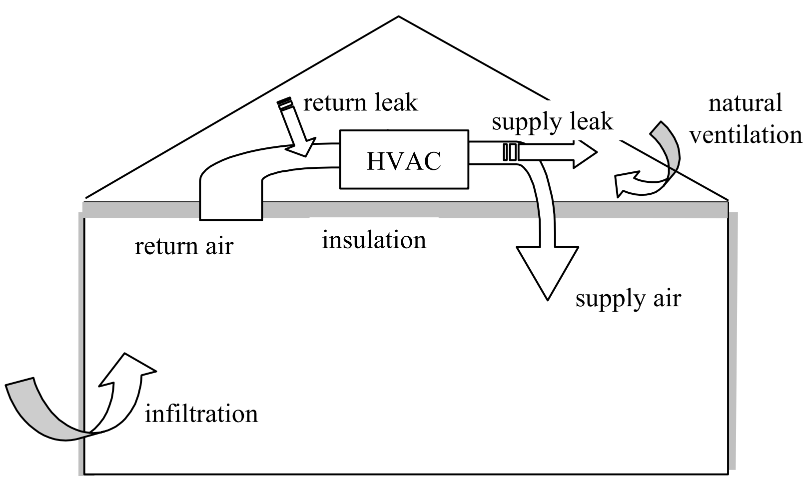



**Figure 19. Vented attic scenario**

For the vented scenario, the attic is modeled as an unconditioned space. The attic air-exchange rate is specified as 1.5 ACH and the duct UA is calculated using R-5 duct insulation. Return leaks add air from the attic to the return air stream. The difference between the supply leakage and return leakage is made up to the space with outside air (increased infiltration).

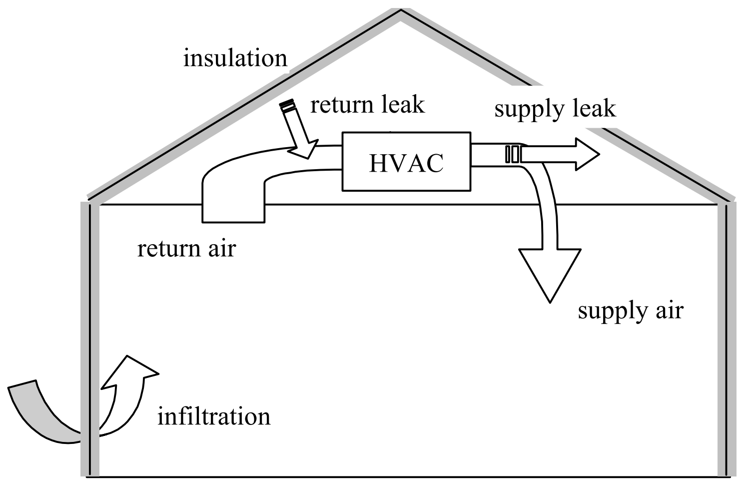



**Figure 20. Unvented attic scenario**

In the unvented attic model depicted in Figure 20, the insulation is in the roof portion of the attic, creating a much tighter space and minimizing natural ventilation. For the DOE-2 simulation, the attic is modeled as a conditioned space, with a supply cfm specified equivalent to the duct leakage. The assumption is that the negative pressure in the house and positive pressure in the attic caused by duct leakage are balanced by exchange between the attic and house, rather than by inducing increased outdoor airflow to the house. By modeling the space as conditioned and assigning a supply airflow rate, additional outside air will not be modeled.

The case of the unvented roof as compared with a traditional vented roof is an example of rather complicated thermodynamics that cannot be entirely modeled using the standard options of DOE-2. It is important to test the sensitivity of each assumption and identify a range of possible results or areas in which further research would be helpful.

## Support Programs

### 1. PowerDOE and eQUEST

PowerDOE and eQUEST are Microsoft Windows$^{TM}$-based programs that provide a graphical interface to the DOE-2.2 program. Both programs provide on-line help and a three-dimensional view of the modeled building. These programs can be used to create and simulate the residential models for Building America, because they provide complete access to all of the DOE-2.2 features. However, using these programs will not necessarily make the process any easier or faster.

eQUEST is a freeware program and features a "building creation wizard" that helps the user create a complex commercial building with relatively few inputs. However, this approach is not geared toward residential buildings. eQUEST can read DOE-2.2 input files and is a very handy tool for checking the geometry of walls, windows, and floor plans of existing simulation models. Most of the graphics included in this report were generated by eQUEST.

eQUEST can be downloaded, at no cost, from www.doe2.com. After installing the program, it is quite easy to import DOE-2.2 input files:

1. From the top menu, choose File – New – Blank Slate
2. From the top menu, choose Import
3. Choose Import File type of *.INP
4. Browse to your DOE-2.2 input file.

eQUEST will compile your input file and report any errors it finds. Press the Building Geometry button to view your building in two or three dimensions. In the three-dimensional view, you can zoom in and out by holding down the Control key and right mouse button while moving the mouse forward and backward. You can rotate the building by holding down the Control key and left mouse button while moving the mouse.

The help files included with both PowerDOE and eQUEST contain detailed command and key-word explanations as well as topic discussions. These help files can be used independently or from within the program.

### 2. PRC Tools

The Partnership for Resource Conservation (PRC) has created some useful tools that are available to Building America contractors; they can run DOE-2.2 and extract results from the program.

PRC-Run22 allows the user to define all of the runs for a Building America analysis by entering the macros and parameters that define each run into a spreadsheet-like interface. All required simulations for the analysis can then run with the push of a single button. The program will also grab specified results from each output file and copy them to a common output file, formatted for easy import into a spreadsheet program. This process enables consistent reporting and facilitates updates of existing projects.

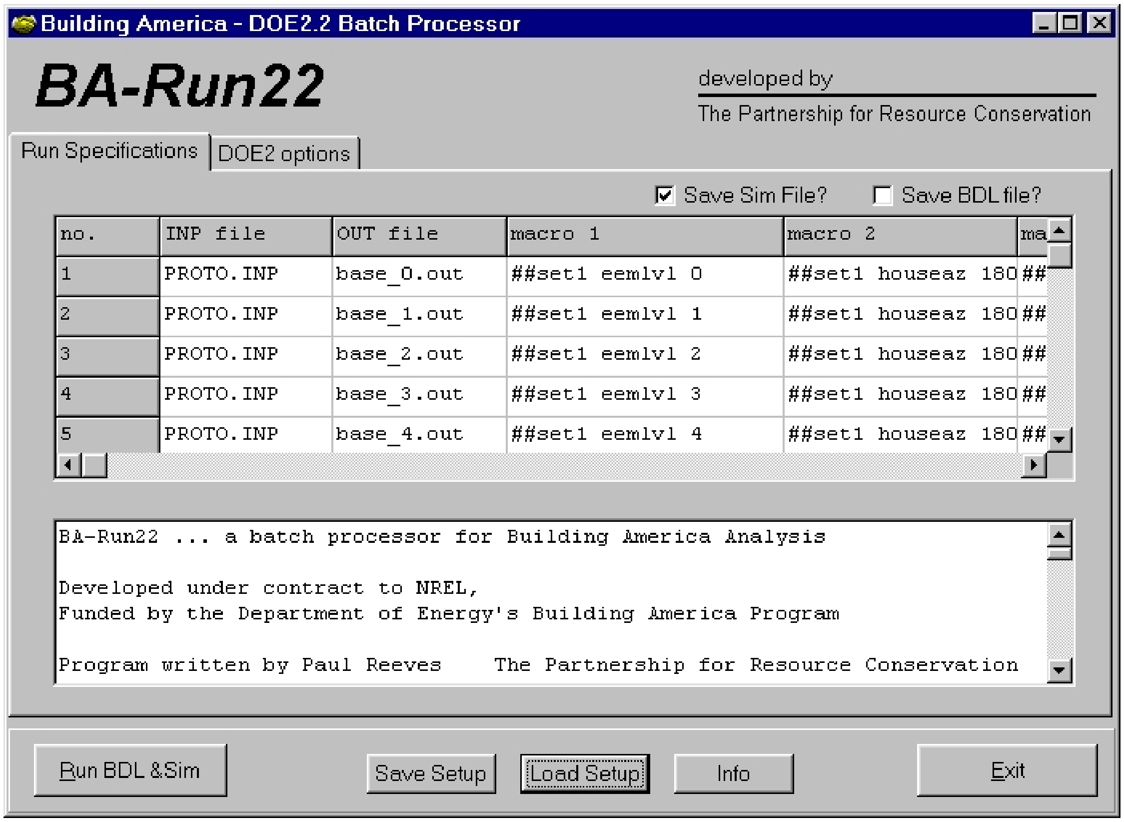



**Figure 21. PRC's BA-Run22 main input screen**

All program specifications can be saved to, and loaded from, a text file. This allows the user to save the specifications for an analysis and use them to reproduce or modify the entire analysis later. The program remembers the last executed analysis and loads that information at start-up.

The BA-Run22 program must reside in the same directory as the WinDOE-2 program supplied with the latest DOE-2.2 installation. This is typically the "DOE2DLL" subdirectory underneath the main DOE-2 directory (Figure 21).

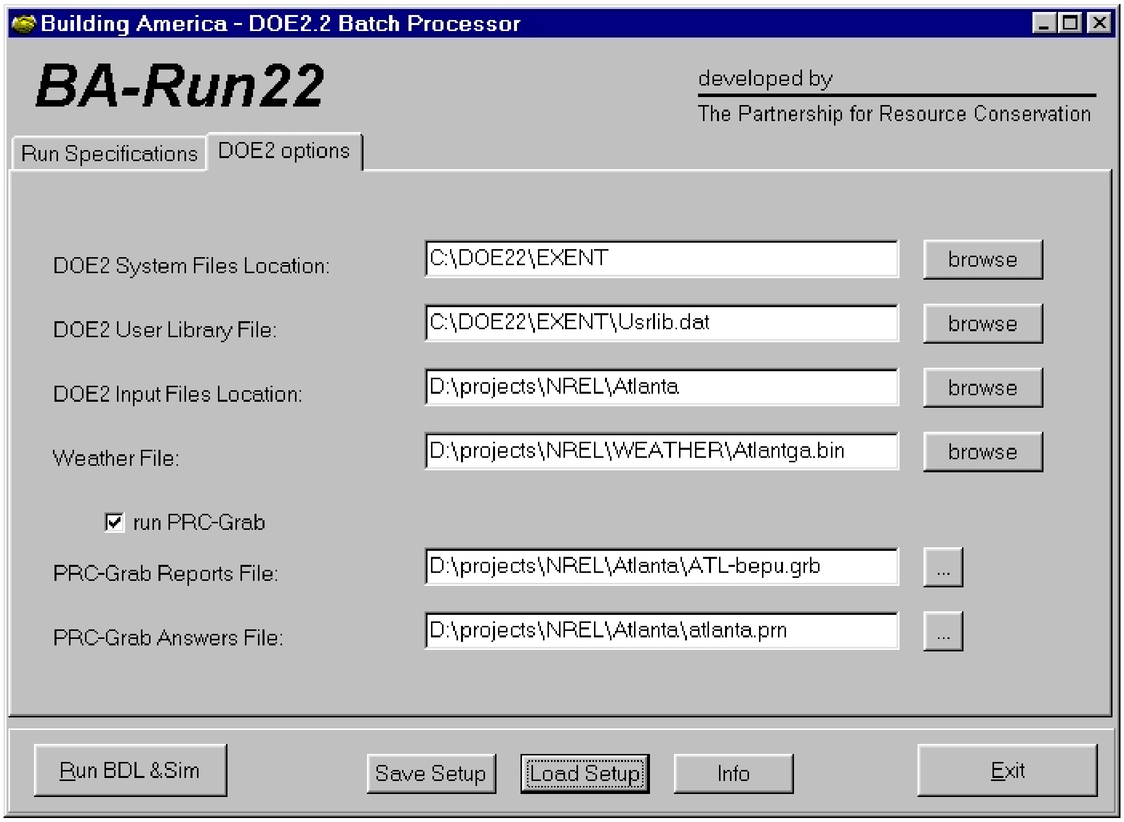



**Figure 22. PRC's BA-Run22 options screen**

The second tab of the main screen configures the program for the local machine's DOE-2 program, as well as the current project (Figure 22). The "DOE2 System Files Location" should point to the EXENT subdirectory created when DOE-2.2 was installed. The User Library File can specify a custom library file or the standard "usrlib.dat" file supplied with the DOE-2 program. The "Input Files Location" is the subdirectory of the current project; the input file of interest must reside in this directory. Finally, the weather file must be specified for the current analysis.

The full functionality of another tool, PRC-Grab, is integrated into BA-Run22. When the "run PRC-Grab" box is checked, the user can enter a "grab" file that specifies the results needed and a common file to write the results to. PRC-Grab will extract any number of results from the DOE-2 output and append it to a common file.

### *Grab File Description*

The grab file contains information regarding which answers are to be extracted from the DOE-2 output. You must specify in which DOE-2 report the answers are located and then indicate which line of the report contains the answer. The line can be specified as either a certain number of lines from the top of the report or a line that contains a unique string of text.

Here is an example grab file; you can use these lines as a starting point for your own grab file.

```
REPORT: SV-A
Line/Column: 13 12
L/C: "HVAC Zone 1" 26
L/C: "HVAC Zone 3" 26
L/C: "HVAC Zone 5" 26
L/C: "HVAC Zone 7" 26
REPORT: BEPS
L/C: 8    15
L/C: 8    24
L/C: 8    33
L/C: 8    42
L/C: 11   15
L/C: 11   24
L/C: 11   33
L/C: 11   42
```

Note: If you want to skip to the third SV-A report, add a “3” after the SV-A report name (i.e., REPORT: SV-A 3).

If you want to add two values together before saving, add “PLUS” to the end of the first value’s line. The following example adds the values found in columns 15, 24, and 33 in line 8 of the BEPS report before saving the value to the Answer file. “PLUS” can span across reports, as well:

```
REPORT: BEPS
L/C: 8    15 PLUS
L/C: 8    24 PLUS
L/C: 8    33
```

The next example adds values from three different SV-A reports. If you want to multiply a value by a constant before saving it, add “TIMES” and a value after the specification:

```
REPORT: SV-A 5
L/C:  6  55    PLUS
REPORT: SV-A 6
L/C:  6  55    PLUS
REPORT: SV-A 7
L/C:  6  55
```

This example adds up the cooling capacities from nine zonal systems. Four of the systems have space multipliers of 3; therefore, they are multiplied before being added to the total.

```
REPORT: SV-A 1
L/C:  20 79    PLUS
L/C:  21 79    PLUS
L/C:  22 79 TIMES 3  PLUS
L/C:  23 79 TIMES 3  PLUS
L/C:  24 79 TIMES 3  PLUS
L/C:  26 79 TIMES 3  PLUS
L/C:  27 79    PLUS
L/C:  28 79    PLUS
L/C:  29 79
```

The following is an example of a grab file used in a typical Building America analysis.

### *3. Sample Building America Analysis Grab File*

```
REPORT: BEPU
L/C: 8    51   cooling kWh
L/C: 11   42   heating therm

'Fan energy by heating/cooling available from SS-L
REPORT: SS-L
L/C: 38   12   cooling fan kWh
L/C: 38   24   heating fan kWh

REPORT: BEPU
L/C: 11  105   DHW therm

'temperature summaries for each zone, June July August under cooled hours:
REPORT: SS-F 1
L/C: 25  123  PLUS
L/C: 27  123  PLUS
L/C: 29  123

REPORT: SS-F 2
L/C: 25  123  PLUS
L/C: 27  123  PLUS
L/C: 29  123

REPORT: SS-F 3
L/C: 25  123  PLUS
L/C: 27  123  PLUS
L/C: 29  123

REPORT: SS-F 4
L/C: 25  123  PLUS
L/C: 27  123  PLUS
L/C: 29  123

REPORT: SS-F 5
L/C: 25  123  PLUS
L/C: 27  123  PLUS
L/C: 29  123
```

## Appendix A
## CHAPTER THREE
## RESNET
## NATIONAL ENERGY RATING TECHNICAL STANDARD

### A. GENERAL PROVISIONS

1. **Purpose.** The provisions of this document are intended to establish national residential energy efficiency rating Guidelines, consistent with the provisions of the Energy Policy Act of 1992, which any provider of home energy ratings may follow to produce uniform energy efficiency ratings for residential buildings.
   a. Relationship to other Guidelines. These Guidelines are a companion document to the "National Accreditation Procedures for Home Energy Rating Systems" as promulgated and maintained by the National Association of State Energy Officers (NASEO) and the Residential Energy Services Network (RESNET), and recognized by the mortgage industry.
   b. Relationship to State Law. These Guidelines specifically recognize the authority of each state that has a state law or regulation that requires certification or licensing of home energy rating systems. To the extent that such state laws or regulations differ from these Guidelines, state law or regulation shall govern.
2. **Scope.** These Guidelines apply to existing or proposed, site-constructed or manufactured, one- and two-family residential buildings, or other residential buildings three stories or less in height, excepting hotels and motels.
3. **Definitions and acronyms**

   *Accreditation Procedures* - The set of standards and procedures entitled "Mortgage Industry National Accreditation Procedures for Home Energy Rating Systems" as published and maintained by NASEO and RESNET.

   *Adiabatic* - A condition wherein heat neither enters nor leaves a system

   *Annual Fuel Utilization Efficiency* or *AFUE* - The ratio of annual output energy to annual input energy that includes any non-heating season pilot input loss.

   *Climate zone* - A geographical area defined as having similar long-term climate conditions.

   *COP* - Coefficient of Performance, which is the ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete heat pump system under designated operating conditions.

   *Conditioned space boundary* - The continuous planes of the building envelope that comprise the primary thermal and air flow barrier between the directly or indirectly conditioned space and either the outdoors or an adjacent unconditioned space.

   *Confirmed Rating* - An energy rating accomplished using data gathered from an on-site audit inspection and, if required, performance testing of the physical building and its installed systems and equipment.

*Data analyst* - A person trained to enter the information compiled by a data collector into the rating tool and to produce the energy efficiency rating of a home.

*Data collector* - A person trained to evaluate the minimum rated features of a home on site and collect all the information required to create a rating.

*Detached one- and two-family dwelling* - A building with one or two independent dwelling units with an individual or central HV AC system.

*Directly Conditioned space* - An enclosed space having heating equipment with a capacity exceeding 10 BTU/hr-ft2, or cooling equipment with a capacity exceeding to 10 BTU/hr-ft2. An exception is if the heating and cooling equipment is designed and thermostatically controlled to maintain a process environment temperature less than 65° Fahrenheit or greater than 85° Fahrenheit for the whole space the equipment serves.

*Distribution System Efficiency* - A system efficiency factor, not included in manufacturer's performance ratings for heating and cooling equipment, that adjusts for the energy losses associated with the delivery of energy from the equipment to the source of the load, such energy losses associated with heat transfer across duct or piping walls and air leakage to or from forced air distribution systems.

*Energy analysis tool-* A calculation procedure for determining a home's energy efficiency rating and estimating annual purchased energy consumption and cost.

*EER* - Energy Efficiency Ratio, which is the ratio of net equipment cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions.

*Energy efficiency rating or rating* - An unbiased indication of a home's relative energy efficiency based on consistent inspection procedures, operating assumptions, climate data and calculation methods.

*Energy factor* - A measure of water heater energy efficiency as determined under Department of Energy Regulations, 10 CFR 430.23(e)(2)(ii).

*Energy saving measure or feature* - Any material, component, device, system, construction method, process or combination thereof that will result in a reduction of energy use.

*EPAct* - The U.S. Energy Policy Act of 1992.

*Estimated annual energy cost savings* - Positive dollar difference between estimated annual energy costs for a home with energy saving measures and estimated annual energy costs of the same home in its current condition.

*Exposed wall* - Walls subjected to heat loss or gain.

*Fenestration* - A glazed opening and its associated sash and framing that is installed into a building.

*Guidelines* (HERS Guidelines) - Minimum criteria that a HERS Provider must meet in order to receive accreditation.

*HERS* - Home energy rating system.

*HERS-BEST EST* - The Home Energy Ratings System Building Energy Simulation Test published in NREL Report No. NREL/TP-472-7332.

*HERS provider* - A person or organization that develops, manages, and operates a home energy rating system.

*Home* - A one- or two-family dwelling or multi-family dwelling of three stories or less.

*Home energy rater or rater* - The person trained to perform the functions of both a data collector and a data analyst, and to inspect a home to evaluate the minimum rated features and prepare an energy efficiency rating (see also Data collector and Data analyst).

*Home Energy Rating System or HERS* - The materials and procedures needed to operate a home energy rating program including but not limited to: marketing materials, training materials, publications, rating tool, quality control, data bases collection and maintenance, agreements, data collection sheets, home owner reports, and other related materials and services.

*HSPF* - Heating Seasonal Performance Factor that is the total heating output of a heat pump during its normal annual usage period for heating, in Btu, divided by the total electric energy input during the same period, in watt-hours.

*HVA*C - Heating, Ventilating, and Air Conditioning

*Indirectly Conditioned space* - Enclosed space that is not directly conditioned

(1) With area weighted heat-transfer coefficient (U-value) to directly conditioned space exceeding that to the outdoors or to unconditioned spaces; or

(2) through which air to or from directly conditioned spaces is transferred at a rate exceeding three air changes per hour.

*Internal gains* - The heat gains within a home attributable to lights, people, and miscellaneous equipment including domestic hot water equipment losses.

MEC '93 - the Model Energy Code as promulgated by the Council of American Building Officials (CABO) in 1993 as amended in 1994.

*NASEO* - National Association of State Energy Officers

*NREL* - National Renewable Energy Laboratory

*Projected Rating* - A rating performed prior to the construction of a new building or prior to implementation of energy-efficiency improvements to an existing building.

*Purchased energy* - The portion of the total energy requirement of a home purchased from a utility or other energy supplier.

*Rated Home* - The specific home being evaluated using the rating procedures and Guidelines contained in this document.

*Rating tool*- A procedure for calculating a home's energy efficiency rating, annual energy consumption, and annual energy costs.

*Reference Home* - A hypothetical home configured in accordance with the specifications set forth in Section B.4 of these Guidelines.

*RESNET*- Residential Energy Services Network.

*R-value* - thermal resistance value measured in h-ft$^2$-F/Btu.

*SEER* - Seasonal Energy Efficiency Ratio, which is the total cooling output of an air conditioner during its normal annual usage period for cooling, in Btu/h, divided by the total electric energy input during the same period, in watt-hours.

*Thermal boundary wall-* Any wall that separates directly or indirectly conditioned space from unconditioned space or ambient conditions.

*Above-grade thermal boundary wall* is any thermal boundary wall not in contact with soil.

*Thermal storage mass* - Materials or equipment incorporated into a home that will store heat, produced by renewable or nonrenewable energy, for release at a later time.

*Typical Meteorological Year or TMYData* - Hourly climate data published by the National Climatic Center, Asheville, North Carolina, based on historical climate data in 216 locations.

*V-value* - Thermal transmittance value measured in Btu/h-ft$^2$-F.

## B. TECHNICAL REQUIREMENTS FOR CONDUCTING RATINGS

### 1. Rating Procedure

a. To determine the energy efficiency rating of a home, all HERS provider shall:

   (1) If rating an existing home, visit the home to collect the data needed to calculate the rating;

   (2) If rating a new, to-be-built home, follow the procedures set forth in Section B.8 of these Guidelines to collect the data needed to calculate the rating;

   (3) Use the collected data to estimate the annual purchased energy consumption for heating, cooling and water heating for both the Rated Home and the Reference Home as defined in Section B.4 of these Guidelines.

   (4) If the energy efficiency rating is conducted to evaluate proposed energy conserving improvements to the home, calculate additional estimates of annual purchased energy consumption with the home reconfigured to include those improvements sufficient to consider interactions among improvement options.

b. Estimates completed by all HERS providers under paragraphs a.(3) and a.(4) of this section must be

   (1) Based on the minimum rated features set forth in Section B.5 of these Guidelines.

   (2) Conducted using the standard operating assumptions established in Section B.6 of these Guidelines.

   (3) Conducted using an energy analysis (rating) tool that has been certified for accuracy under Section C.l of these Guidelines.

c. All HERS providers shall compare the estimates provided under paragraph B.l.a. of this section to determine the energy efficiency rating of the home and, if applicable, the energy efficiency rating of the home with proposed conservation measures installed.

d. To encourage the use of energy efficient lights and appliances, HERS providers may provide additional information on estimated lights and appliance energy consumption in the Rated Home. This information shall not change the rating score set forth in Section B.2.a. of these Guidelines.

## 2. Rating Point Score and Star Rating

a. Point score. The Reference Home shall have a point score of 80 points on a 0-to-100 point scale. Each 5% increase or decrease in the relative energy efficiency potential of the Rated Home with respect to the Reference Home shall constitute a 1-point increase or decrease, respectively (from 80), in the Rated Home's score. The method used to calculate the score shall be approved by the accreaiting body and be consistent for each HERS provider operating within a state. Except in states or territories whose laws or regulations require a specific alternative method, which shall control, equations 1 and 2 shall be used in a two-step process to calculate the point score for the Rated Home, as follows:

Step (1) Calculate the individual normalized Modified End Use Loads (nMEUL) for heating, cooling, and hot water using equation 1:

$$nMEUL = REUL * (nEC\_x / EC\_r) \qquad \text{(Eq. 1)}$$

where:

nMEUL = normalized Modified End Use Loads (for heating, cooling or hot water).

REUL = Reference Home End Use Loads (for heating, cooling or hot water) as computed using accredited simulation tools.

nEC_x = normalized Energy Consumption for Rated Home's end uses (for heating, cooling or hot water).

EC_r = estimated Energy Consumption for Reference Home's end uses (for heating, cooling or hot water) as computed using accredited simulation tools.

and where:

$$nEC\_x = (a * EEC\_x - b)*(EC\_x * EC\_r * DSE\_r) / (EEC\_x * REUL)$$

where:

EC_x = estimated Energy Consumption for the Rated Home's end uses (for heating, cooling or hot water) as computed using accredited simulation tools.

EEC_x = Equipment Efficiency Coefficient for the Rated Home's equipment, such that EEC_x equals the energy consumption per unit load in like units as the load, and as derived from the Manufacturer's Equipment Performance Rating (MEPR) such that EEC_x equals 1.0 / MEPR for AFUE, COP or EF ratings, or such that EEC_x equals 3.413/ MEPR for HSPF, EER or SEER ratings.

DSE_r = REUL/EC_r * EEC_r

For simplified system performance methods, DSE_r equals 0.80 for heating and cooling systems and 1.00 for hot water systems (see Section B.4.a [17]). However, for detailed modeling of heating and cooling systems, DSE_r may be less than 0.80 as a result of part load performance degradation, coil air flow degradation, improper system charge and auxiliary resistance heating for heat pumps. Except as otherwise provided by these Guidelines, where detailed systems modeling is employed, it must be applied equally to both the Reference and the Rated Homes.

EEC_r = Equipment Efficiency Coefficient for the Reference Home's equipment, such that EEC_r equals the energy consumption per unit load in like units as the load, and as derived from the Manufacturer's Equipment Performance Rating (MEPR) such that EEC_x equals 1.0 / MEPR for AFUE, COP or EF ratings, or such that EEC_x equals 3.413 / MEPR for HSPF, EER or SEER ratings.

and where the coefficients 'a' and 'b' are as defined by Table 1:

**Table 1. Coefficients 'a' and 'b'**

| Fuel Type and End Use | a | b |
|---|---|---|
| Electric space heating | 1.9924 | 0 |
| Natural gas space heating | 1.2544 | 0.6082 |
| Fuel oil space heating | 2.4321 | 2.1180 |
| Electric air conditioning | 2.9301 | 0 |
| Electric water heating | 0.8800 | 0 |
| Natural gas water heating | 0.9404 | 0.7415 |
| Fuel Oil water heating | 1.5569 | 1.9376 |

Step (2) Determine the point score using equation 2:

$$\text{Point score} = 100 -«TnML / TRL) * 20) \qquad \text{(Eq. 2)}$$

where:

$TnML = nMEUL_{HEAT} + nMEUL_{COOL} + nMEUL_{HW}$~ (Total of all normalized Modified End Use Loads as calculated using equation 1).

$TRL = REUL_{HEAT} + REUL_{COOL} + REUL_{HW}$ (Total of all Reference Home End Use Loads).

b. Star rating. The Rated Home will be given a star rating between one and five-plus stars, determined by the numerical score and the corresponding number of stars depicted in Table 2:

**TABLE 2. Score, Star, and Efficiency Scales for Rated Homes**

| Score Range | Stars | Relative Efficiency Change (with respect to Reference Home) |
|---|---|---|
| ≥0 and <20 | * | ≥ -400% and < |
| ≥20 and <40 | *+ | -300% |
| ≥40 and <50 | ** | ≥ -300% and < |
| ≥50 and <60 | **+ | -200% |
| ≥60 and <70 | *** | ≥ -200% and < |
| ≥70 and <80 | ***+ | -150% |
| ≥80 and <83 | **** | ≥ -150% and < |
| ≥83 and <86 | ***** | -100% |
| ≥86 and <90 | *****+ | ≥ -100% and < |
| ≥90 and ≤100 | | -50% |
| | | ≥ -50% and <0% |
| | | ≥ 0% and <15% |
| | | ≥ 15% and <30% |
| | | ≥ 30% and |
| | | ≤ 50% |
| | | ≥ 50% |

## 3. Rating Report

a. For each rating conducted under this part, a report shall be prepared containing, at a minimum, the following information:

(1) The numerical rating score determined in Section B.2.a of these Guidelines,

(2) The star rating determined in Section B.2.b of these Guidelines, except that all plus (+) ratings other than 5+ are optional;

(3) The estimated annual purchased energy consumption for space heating, space cooling, domestic hot water, and all other energy use, and the total of these four estimates;

(4) The estimated annual energy cost for space heating, space cooling, domestic hot water, and all other energy use, and the total of these four estimates;

(5) The unique physical location (full street address or recorded real property identifier) of the Rated home;

(6) The name of the individual accomplishing the rating;

(7) The date the rating was accomplished; and

(8) The rating tool (including version number) used to calculate the rating;

b. If ratings are conducted to evaluate energy saving improvements to the home, in addition to the information set forth under paragraph B.3.a of this section, each rating report must include:

(1) The estimated annual energy cost savings for the home reconfigured to include those improvements;

(2) The discount rate applied to, and present worth value of the energy cost savings; and

(3) The financing interest rate and the life of the measures used by the HERS provider to determine the present worth value.

c. The rating report must also provide either:

(1) The estimated lights and appliance energy consumption of the Rated Home: or

(2) Information that additional energy savings related to lights and appliance use may be attainable and that the information available on Energy Guide labels and from other recognized sources may be used to consider the energy efficiency of appliances.

d. If a Projected Rating conducted under Section B.8.a of these Guidelines, the Rating shall be identified as a Projected Rating.

e. For each rating conducted under these Guidelines, the following items are to be prominently displayed on all reports and labels:

(1) Date of the rating;

(2) Annual estimated energy costs for heating, cooling, water heating and all other use;

(3) Rating point score; and

(4) Star rating;

(5) As an alternative to reporting the rating point score and star rating, any home achieving a rating score of 86 or greater may, at the request of the person for whom the rating is being conducted, be labeled an ENERGY STAR® Home.

## 4. Reference Home Configuration

a. All HERS providers shall establish a Reference Home used in an annual purchased energy consumption comparison with the Rated Home. The Reference Home is a hypothetical home having the following characteristics -

(1) The same shape and size as the Rated Home;

(2) The same area of surfaces bounding Conditioned Space as the Rated Home,

(3) All enclosure elements that meet, but not exceed, the requirements, expressed as U and $U_o$ values, of Paragraph 502.2 of MEC '93 with the components that meet the $U_a$ requirement for walls determined by:

(a) For detached one and two family homes, the U-values for wall assemblies from Table 3a; or

(b) For attached homes, the U-values for wall assemblies from Table 3b; and for all homes.

(c) The U-values for fenestration calculated using Equation 3 or U = 1.3, whichever is less;

$$U_F = [(Uo \times Ao)-(Uw \times Aw)-8]/AF \qquad \text{(Eq. 3)}$$

Where:

$U_F$ = Required average U-value of the fenestration systems.

$U_o$ = Average U-value requirement for walls from paragraph 502.2 of MEC '93.

$A_o$ = Gross exposed wall area, not including basement walls, of the Rated Home.

$V_w$ = Value from Table 2a or 2b based on HDD65 criteria of Rated Home location.

$A_w$ = Net opaque wall area, calculated as: $A_o$ - $A_p$ - 40.

$A_F$ = Area of fenestration calculated using the gross area calculated under Section B.4.a.7. of these Guidelines.

Note: For walls of attached homes, the U-value calculation in paragraph (3) above is completed using the fenestration, area calculated as $A_F$ in Section B.4.a.7 of these Guidelines and the actual area of walls that experience heat loss or gain. Areas of common walls that separate homes are not included in $A_o$, Equation 3.

**Table 3a. Opaque Wall U-values ($U_w$) for Detached Homes**

| Heating degree days base 65 (HDD65) from nearest location listed in Chapter 9 of ASHRAE Standard 90.2 | $U_w$ air to air includes framing |
|---|---|
| > 13000 | 0.038 |
| 9000-12999 | 0.046 |
| 6500-8999 | 0.052 |
| 4500-6499 | 0.058 |
| 3500-4499 | 0.064 |
| 2600-3499 | 0.076 |
| <2600 | 0.085 |

**Table 3b. Opaque Wall U-values ($U_w$) for Attached Homes**

| Heating degree days base 65 (HDD65) from nearest location listed in Chapter 9 of ASHRAE Standard 90.2 | $U_w$ air to air includes framing |
|---|---|
| >9000 | 0.064 |
| 7100-8999 | 0.076 |
| 3000-7099 | 0.085 |
| 2800-2999 | 0.100 |
| 2600-2799 | 0.120 |
| <2600 | 0.140 |

(4) The same foundation type as the Rated Home, where:

(a) For Rated Homes on ventilated crawl spaces, assume for the Reference Home, insulation of the floor above the crawl space meeting the requirements of MEC '93;

(b) For Rated Homes on non-ventilated crawl spaces, assume for the Reference Home, insulation of the crawl space walls meeting the requirements of MEC '93;

(c) For Rated Homes on basements that are directly or indirectly conditioned spaces, assume for the Reference Home, insulation of the basement walls meeting the requirements of MEC '93;

(d) For Rated Homes with slab on grade construction, assume insulation of the slab edge meeting the requirements of MEC '93;

(5) Solar absorptivity of opaque areas of exterior walls of 0.50 and of opaque areas of roofs of 0.75;

(6) An area of exterior doors of 40 square feet, facing north, and with the door U-value at 0.20.

(7) Vertical fenestration area ($A_F$) is determined-

(a) for one- and two-family detached homes, by equation 4;

(b) for attached homes, by equation 5.

$$A_F = 0.18 \text{ X } A_{FL} \text{ x } F_A \qquad \text{(Eq. 4)}$$

$$A_F = 0.18 \text{ X } A_{FL} \text{ x } F_A \text{ x } F \qquad \text{(Eq. 5)}$$

Where:

$A_F$ = Total fenestration area.

$A_{FL}$ = Total floor area of directly conditioned space.

$F_A$ = (Above-grade thermal boundary wall area)/(total thermal boundary wall area).

F = (Above-grade thermal boundary wall area)/(above-grade thermal boundary wall area + common wall area) $\geq$ 0.56

And where:

*Thermal boundary wall* is any wall that separates directly or indirectly conditioned space from unconditioned space or ambient conditions.

*Above-grade thermal boundary wall* is any thermal boundary wall not in contact with soil.

(8) Vertical fenestration distributed-

(a) For detached homes, equally in each of the four cardinal directions, north, south, east, and west; and

(b) For attached homes, equally in each of the four cardinal directions, north, south, east, and west, which if necessary may require fenestration facing the same direction as common walls;

(9) A frame factor equal to 27% of the gross fenestration area calculated under Section B.4.a.7. of these Guidelines;

(10) The glazed area of the fenestration with a shading coefficient (SC) of 0.70 assumed during the cooling season, which represents the combined SC of the glazing and the use of nonwhite draperies; and with a SC of 0.88, representing the SC of the glazing only, assumed at all other times;

(11) No external shading assumed at any time;

Note: For the calculation of solar gains from all fenestration areas determined under Section B.4.a.7. of these Guidelines, the values in Table 4 are used to represent the combined effect of the framing factor in Section B.4.a.9. of these Guidelines and the glazed area shading coefficients in Section B.4.a.l0. of these Guidelines.

(12) The same fuel type for heating, cooling and water heating as used in the Rated Home.

(13) One each heating, cooling and hot water system of the same type as in the Rated Home except as required by the exceptions in Section B.4.a.14. of these Guidelines;

(14) If the Rated home contains multiple heating, cooling, or water-heating systems using different fuel types, then the applicable Reference Home system capacities and fuel types shall be weighted in accordance with the loads distribution (as calculated by accepted engineering practice for that equipment and fuel type) of the subject multiple systems.

**Table 4. Shading and Solar Heat Gain Coefficients**

| Season | SC[a] | SHGC[b] |
|---|---|---|
| Heating | 0.675 | 0.581 |
| Cooling | 0.541 | 0.466 |

[a] For calculation tools using shading coefficients

[b] For calculation tools using solar heat gain coefficients as defined by NFRC 200

Table 5. Reference Home Equipment Efficiencies

| Rated Home Fuel | Function | Reference Home Device |
|---|---|---|
| Electric | Heating | 6.8 HSPF Air Source Heat Pump |
| Non-Electric Warm Air Furnace | Heating | 78% AFUE Gas Furnace |
| Non-Electric Boiler | Heating | 80% AFUE Gas Boiler |
| Any Type | Cooling | 10 SEER Electric Air Conditioner |

(15) The minimum NAECA efficiency in effect on January 1, 1992, for the same type of HVAC equipment found in the Rated Home, except that the efficiencies given in Table 5 will be assumed when;

(a) A type of device not covered by NAECA is found in the Rated Home;

(b) The Rated Home is heated by electricity using a device other than an air source heat pump; or

(c) The Rated Home does not contain one or more of the required HVAC equipment systems. (16) The sizing of HV AC equipment determined in accordance with accepted engineering practice for that equipment and fuel type.

(17) A distribution system efficiency of 0.80, which is to be multiplied by the equipment efficiencies determined under Section B.4.a.15. of these Guidelines.

(18) The efficiency of the water heater;

(a) For Rated Homes with a storage type water heater, the minimum NAECA Energy Factor in effect on January 1, 1992, for the fuel type and size found in the Rated Home;

(b) For Rated Homes with a non-storage type water heater, the minimum NAECA Energy Factor in effect on January 1, 1992, is used to provide domestic hot water in the Rated Home.

[c] For Rated Homes without water heaters, the minimum NAECA Energy Factor in effect on January 1, 1992, for a 40-gallon storage-type water heater using the same fuel as the predominant heating fuel type in the Rated Home shall be used for the purpose of calculating the HERS Score. (Note: This energy use may be excluded from the purchased energy cost estimate for the Rated Home.)

(19) An annual average air change rate as determined from normalized building leakage (nL) using Equation 6.

$$ach = nL \times W \qquad \text{(Eq. 6)}$$

where:

ach = average annual air changes per hour
nL (normalized leakage) = 0.57 for the Reference Home.
W = Weather factor fromW Tables in ASHRAE Standard 136 for the site most climatologically representative of the Rated Home's location.

(20) An internal mass for furniture and contents of 8 pounds per square foot of floor area;

(21) Only the structural mass and associated heat capacitance calculated as follows:

(a) For masonry floor slabs, as found in the Rated Home;

(b) For masonry basement walls, as found in the Rated Home, but with any basement wall insulation as required under paragraph (3) assumed to be located on the interior side of the basement walls;

(c) For walls other than basement walls, for ceilings, floors, and interior partition walls, using equivalent areas to the Rated Home assuming light frame construction.

## 5. Minimum Rated Features

a. All HERS providers shall calculate the estimated annual purchased energy consumption for heating, cooling and water heating set forth in Section B.l of these Guidelines using the energy loss and gain associated with the minimum rated features set forth in Table 7.

b. For existing homes, the envelope thermal characteristics of building elements 1 through 7 set forth in Table 7 are determined by site observation.

c. If data for the minimum rated features set forth in paragraph (b) of this Section cannot be obtained by observation or without destructive disassembly of the home, all HERS providers shall use default values. The default values are determined from the following sources listed in the preferential order of use:

(1) for manufactured homes, available manufacturer's data

(2) current and historical local building practices; or

(3) current and historical local building codes.

d. Default values set forth in paragraph (c) of this section shall be established or approved by the accrediting body and be consistent for all HERS providers operating within a state.

e. For existing homes, the determination of air leakage and duct leakage values set forth as building elements 10 and 11 in Table 7 are determined by data collected on site using the following procedures listed in preferential order of use:

(1) current on-site diagnostic tests conduced in accordance with nationally accepted pressurization test standards; or

(2) observations of the condition of the building and duct system made by the HERS provider. Based on these observations values used will be.

(a) for envelope air leakage, a minimum normalized leakage rate of nL = 0.67, where nL may be converted to an air change rate using Equation 6 of Section B.4.a(19) to compute average annual air changes per hour(ach); and

(b) for distribution system efficiency, default values in accordance with Table 6, below.

(3) The energy efficiency of the mechanical equipment set forth as building elements 12 through 14 in Table 7 is determined by data collected on site using the following sources listed in preferential order of use:

(a) current on-site diagnostic test data as corrected using the following equation:

$$Eff,rated = Eff,listed * Es,measured / Es,listed$$

where:

Eff,rated = annual efficiency to use as input to the rating

Eff,listed = listed annual efficiency by manufacturer or directory

Es,measured = measured steady state efficiency of system

Es,listed = manufacturer's listed steady state efficiency, under the same operating conditions found during measurement

(b) name plate data;

(c) manufacturer's data sheet; or

(d) equipment directories.

## Table 6. Default Values[1] for Distribution System Efficiencies

| Distribution System Configuration and Condition | Forced Air Systems | | Hydronic System[2] | |
|---|---|---|---|---|
| | Heating | Cooling | Heating | Cooling |
| ***Observable leakage pathways***[3] with distribution system components located in unconditioned space | 0.70 | 0.70 | | |
| ***Observable leakage pathways*** with entire distribution system located in conditioned space[4] | 0.75 | 0.75 | | |
| Distribution system components located in | 0.80 | 0.80 | 0.95 | 0.95 |
| Entire distribution system located in *conditioned space* | 0.85 | 0.85 | 1.00 | 1.00 |
| ***Proposed***[5] "leak-free" with entire air distribution system located in the conditioned space | 1.00 | 1.00 | | |
| ***Proposed*** "leak-free" air distribution system with components located in the unconditioned space | 0.95 | 0.95 | | |
| "Ductless"[6] systems | 1.00 | 1.00 | | |

***Table 6 Notes:***

1 *Default values* given by this table are for distribution systems that have been visually inspected only, and which meet MEC '93 minimum requirements for duct system insulation. Visual inspection is not the recommended method of determining forced air distribution system leakage. The recommended and preferred method of determining forced air distribution system leakage is through pressurization testing accomplished in accordance with Section B.5.e.(1) of this Guideline.

2 *Hydronic systems* shall mean those systems that distribute heating and cooling energy directly to individual spaces using liquids pumped through closed loop piping and that do not depend on ducted, forced air flows to maintain space temperatures.

3 *Observable leakage pathways* shall mean that elements of the air distribution system (including joints, seams, connection flanges, collars, boots, panned ducts, construction cavities used as airflow pathways, and other like system components) can be visually determined to contain one *or* more flaws through which unconditioned air may be forced into or out of the designated air duct system.

4 *Entire system in conditioned space* shall mean that no component of the distribution system, including the air handler unit, is located outside of the plane of the conditioned space boundary. Conditioned space shall mean any building space directly or indirectly heated or cooled in accordance with the definitions provided

in section A.3. of this Guideline. Any other air distribution system condition results in *system components located in unconditioned space.*

5 *Proposed" leak free"* shall mean *substantially leak free* as defmed by the 1998 IECC (International Energy Conservation Code) to be a leakage rate of not more than 5% of the rated fan flow rate at a pressure differential of 25 Pascal across the entire system, including the manufacturer's air handler enclosure. This *proposed condition is reserved for Projected Ratings* and must be specified as the required performance in the construction documents. This proposed condition *requires confirmation through field testing* of installed systems.

6 Ductless systems may have forced air flow across a coil but shall not have any ducted air flows external to the manufacturer's air handler enclosure.

f. If the Rated Home does not utilize at least one each heating, cooling and hot water system, the Reference Home equipment efficiencies as specified in section B.4.a.(15) shall be assumed for the relevant missing system(s) in the Rated Home for the purposes of calculating the rating.

g. If the Rated Home utilizes multiple heating, cooling or hot water systems, the operating conditions specified in Section B.6 of these Guidelines shall be used for each system and the relevant purchased energy consumption calculations shall be appropriately weighted by system capacity in accordance with the loads distribution as calculated by accepted engineering practice for that equipment and fuel type.

h. If information on the energy efficiency of mechanical equipment cannot be determined from the sources listed in paragraph (3) of this section, the values set forth in Tables 8 and 9 shall be used.

i. Any HERS provider may base annual purchased energy consumption estimates for the Rated Home on additional features if the HERS provider's energy analysis tool is capable of doing so.

**Table 7. Minimum Rated Features**

| Building Element | Minimum-rated Features |
|---|---|
| Floor Foundation Assembly | Construction type (slab-on-grade, crawl space, insulation (edge, under slab, cavity, sheathing), vented or unvented (crawl space), capacitance (if slab or basement receives appreciable solar gain). |
| Walls | Walls Construction type, insulation value (cavity, sheathing); capacitance, color (light, medium, or dark). |
| Roof/Ceiling Assembly | Construction type, insulation value (cavity, sheathing), roof color (light, medium, or dark). |
| Rim Joist | Insulation value (cavity, sheathing) |
| Doors | Construction type, insulation value. |
| Windows | Construction type, orientation, tilt, V-value (of comp assembly), heat gain coefficient, shading |
| Skylights | Construction type, orientation, tilt, U-value of complete assembly, solar heat gain coefficient, shading |
| Passive Solar System (Direct Gain system) | Solar type, collector type and area, orientation, tilt, efficiency, storage tank size, pipe insulation value |
| Solar Domestic Hot Water Equipment | System type, collector type and area, orientation, tilt, efficiency, storage tank size, pipe insulation value |
| Air Leakage | Air leakage measurement type (default estimate, blower door test, tracer gas test), volume of conditioned space. |
| Distribution System | System type, location, insulation value (duct and pipe), air leakage measurement type (default estimate, duct blaster, pressure pan threshold, blower door subtraction) |
| Heating Equipment | Equipment type, location, efficiency (AFUE, HSPF) |
| Cooling Equipment | Equipment type, location, efficiency (SEER, COP) |
| Domestic Hot Water Equipment | Equipment type, location, energy factor or seasonal efficiency, extra tank insulation value, pipe insulation |
| Control Systems | Thermostat type |

## Table 8. Default Values for Mechanical System Efficiency (Age-based)

| Mechanical Systems | Units | Pre-1960 | 1960-69 | 1970- 74 | 1975-83 | 1984-8 | 1988-91 | 1992 to present |
|---|---|---|---|---|---|---|---|---|
| **Heating:** | | | | | | | | |
| Gas Furnace | AFUE | 0.60 | 0.60 | 0.65 | 0.68 | 0.68 | 0.76 | 0.78 |
| Gas Boiler | AFUE | 0.60 | 0.6 | 0.65 | 0.65 | 0.70 | 0.77 | 0.80 |
| Oil Furnace or Boiler | AFUE | 0.60 | 0.65 | 0.72 | 0.75 | 0.80 | 0.80 | 0.80 |
| Air-Source Heat Pump | HSPF | 4.50 | 4.50 | 4.70 | 5.50 | 6.30 | 6.80 | 6.80 |
| Ground-Water Geothermal Heat Pump | COP | 2.70 | 2.70 | 2.70 | 3.00 | 3.10 | 3.20 | 3.50 |
| Ground-coupled Geothermal Heat Pump | COP | 2.30 | 2.30 | 2.30 | 2.50 | 2.60 | 2.70 | 3.00 |
| **Cooling:** | | | | | | | | |
| Air-Source Heat Pump | SEER | 5.00 | 6.10 | 6.50 | 7.40 | 8.70 | 9.40 | 10.00 |
| Ground-Water Geothermal Heat Pump | EER | 10.00 | 10.00 | 10.00 | 13.00 | 13.00 | 14.00 | 16.00 |
| Ground-Coupled Geothermal Heat Pump | EER | 8.00 | 8.00 | 8.00 | 11.00 | 11.00 | 12.00 | 14.00 |
| Central Air Conditioner | SEER | 5.00 | 6.10 | 6.50 | 7.40 | 8.70 | 9.40 | 10.00 |
| Room Air Conditioner | EER | 5.00 | 6.10 | 6.10 | 6.70 | 7.70 | 8.10 | 8.50 |
| **Water Heating:** | | | | | | | | |
| Storage Gas | EF | 0.47 | 0.47 | 0.47 | 0.49 | 0.55 | 0.56 | 0.56 |
| Storage Oil | EF | 0.47 | 0.47 | 0.47 | 0.48 | 0.49 | 0.54 | 0.56 |
| Storage Electric | EF | 0.79 | 0.80 | 0.80 | 0.81 | 0.83 | 0.87 | 0.88 |

**Table 9. Default Values for Mechanical System Efficiency (not Age-based)**

| Item | Units | Rating |
|---|---|---|
| **Heating** | | |
| Gas Wall Heater (Gravity) | SE | 0.65 |
| Gas Floor Furnace | SE | 0.60 |
| Gas Water Heater (Space Heating) | AFUE | 0.75 |
| Electric Furnace | HSPF | 3.413 |
| Electric Radiant | HSPF | 3.413 |
| Heat Pump Water Heater (Space) | HSPF | 5.11 |
| Electric Water Heater (Space) | HSPF | 2.73 |
| **Cooling:** | | |
| Electric Evaporative Cooling | EER | 30 |
| Gas Absorption Cooler | COP | 0.40 |
| **Water Heating:** | | |
| Heat Pump | COP | 2.00 |
| Instantaneous Electric | EF | 0.87 |
| Instantaneous Gas | EF | 0.75 |
| Solar (Use SRCC Adjustment Procedures) | EF | 2.00 |

## 6. Operating Condition Assumptions

a. Alternate operating conditions assumptions shall only be used where authorized by state law or regulation. Alternate operating condition assumptions shall be applied equally to both the Reference Home and the Rated Home and shall be consistent for all HERS providers operating within the state.

b. All HERS providers shall estimate the annual purchased energy consumption for heating, cooling, and hot water for both the Rated Home and the Reference Home using the following assumptions-

(1) Temperature control set points for heating and cooling of 68° F and 78° F, respectively;

(2) Where programmable offsets are available in the Rated Home, 5°F temperature control point offsets with an 11 p.m. to 7 a.m. schedule for heating and a 9 a.m. to 3 p.m. schedule for cooling, and with no offsets assumed for the Reference Home;

(3) Internal heat gains from lights, people and equipment of 72,000 Btu/day for detached homes and 36,000 Btu/day for attached homes;

(4) When calculating annual purchased energy for cooling, internal latent gains assumed as 0.20 times sensible internal heat gains;

(5) Estimated hot water usage based on Equation 7.

$$\text{Gallons/day} = 30 \text{ gallons} + (10 \text{ gallons} * \text{number of bedrooms}) \qquad \text{(Eq. 7)}$$

(6) The climatologically most representative TMY or equivalent climate data, which may be interpolated between climate sites if interpolation is established or approved by the accrediting body and consistent for all HERS providers operating within a state.

(7) Corrections for climate conditions and mis-sizing of equipment, using correction factors to HSPF, SEER, and AFUE that are established or approved by the accrediting body and consistent for all HERS providers operating within a state.

(8) Local residential energy or utility rates that-

(a) Are revenue-based and include customer service and fuel charges;

(b) Are updated at least annually; and

(c) Are confirmed by the accrediting body.

## 7. Non-rated Energy Consuming Devices

Consistent with Section B.3.a.(3) and (4) of these Guidelines all HERS providers shall calculate and report the annual purchased energy consumption and energy cost for the operation of all non-rated energy consuming devices in the Rated and Reference Homes. Actual efficiency of these devices is not considered and usage estimates are based on Table 10. The data in Table 10 may be modified if they are established or approved by the accrediting body consistent for all HERS providers operating within the state.

## Table 10. Annual Energy Use for Non-Rated Features

| End use | Units/Year | Energy estimate | Applicability |
|---|---|---|---|
| Ceiling Fan | kWh | 220/ea | If present |
| Dishwasher | kWh | 299/per cooking area | If present or if space is area dedicated for DW. |
| Dryer, electric | kWh | 875/ea | If present or if 220V wiring is present at dryer location |
| Dryer, gas | Therms<br>kWh | 60/ea<br>100/ea | If present or if gas piping is at dryer location |
| Lights | kWh | 940 | All homes |
| Microwave Oven Built-in | kWh | 191/per cooking | If permanently installed |
| Miscellaneous Plug Loads | kWh | 500 | All homes |
| Pool Pump | kWh | 1700/ea | If present |
| Range/Oven Combo-electric | kWh | 450/per cooking | If present, or if 220V wiring is present at range location |
| Range/Oven Combo-gas w/ Pilot | Therms | 44/per cooking area | If present, or if gas piping is present at range location |
| Range/Oven Combo-gas w/o Pilot | Therms | 22/per cooking area | If present |
| Refrigerator | kWh | 1150 | Each one present |
| Television | kW\h | 720 | All homes |
| Washer, clothes | kWh | 99/ea | If present, or facilities present for washer |
| Well pump | kWh | 288 / ea | If present |

## 8. Projected Ratings for To-be-Built or To-be-Improved Homes

a. A HERS provider may calculate the Projected Rating of a to-be-built or to-be-improved home based on architectural drawings with material, mechanical and electrical specifications for a to-be-built home, or based on a site audit for a to-be-improved home; and by:

(1) Using either the envelope leakage rate specified as the required performance by the construction documents, the site-measured envelope leakage rate, or a default value for normalized leakage of nL = 0.67, where nL may be converted to an air change rate using Equation 6 of Section B.4.a(19) to compute average annual air changes per hour(ach);

(2) Using either the distribution system efficiency specified as the required performance by the construction documents, the site-measured distribution system efficiency, or a default distribution system efficiency value from Table 6; and

(3) Using the planned location and orientation of the proposed home, or if the proposed orientation is unknown, calculating ratings for the home facing each of the four cardinal directions, north, south, east, and west, and using the lowest rating score as the Projected Rating.

b. Upon completion of construction and verification of the proposed specifications, all rated features of the home shall be confirmed using site inspections and envelope air leakage rates and distribution system efficiencies derived from on-site diagnostic tests conducted in accordance with Section B.5.e.(I) of this Guideline, and the actual orientation of the home.

# C. ADMINISTRATION OF A HOME ENERGY RATING SYSTEM

## 1. Energy Analysis Tool Requirements

a. In order to be certified for the purpose of providing home energy ratings under these Guidelines, an energy analysis (rating) tool must:

(1) Demonstrate the ability to calculate annual purchased energy consumption for each building type which ratings are provided;

(2) Estimate the total annual purchased energy consumption associated with minimum rated features set forth in Section B.5 of these Guidelines;

(3) Calculate energy use of non-rated energy consuming devices as set forth in Section B.7 of these Guidelines;

(4) Reflect the operating condition assumptions described in Section B.6 of these Guidelines; and

(5) Pass all tests in Tier 1 and Tier 2 of the Home Energy Ratings System Building Energy Simulation Test (HERS BESTEST) NREL Report no. NREL/TP-472-7332, which is administered by, and has pass-fail criteria set by the accrediting body.

b. Future guideline requirements. On or before September 30, 2003, all HERS providers accredited under these Guidelines, shall have updated their energy analysis tool to be capable of rating the following additional features-

(1) Thermostat set-back and set-up;

(2) Effects of part load and weather conditions on HVAC systems;

(3) Demand and time of use utility rates;

(4) Solar water heating;

(5) Sunspaces; and

(6) Whole house fans.

c. Energy analysis tools certified under paragraph (a)(5) of this section must be retested and recertified if a new version of the tool is released that includes changes to the engineering algorithms.

2. Site data collection manual. All HERS providers shall provide data collectors with a manual containing procedures for the on-site collection of data that are:

   a. Consistent with those provided in Appendix A as extracted from Guideline No. 10 of the Home Energy Rating Systems Council Guidelines;

   b. Established or approved by the Accrediting Body and updated as supplemental or revised information becomes available.

3. Training home energy raters. Each person seeking a position as a full rater, data collector, or data analyst for any HERS provider shall receive training by an accredited rater training organization prior to performing rating tasks without supervision. The training shall be conducted in accordance with a syllabus developed by all HERS providers. The syllabus must specify subjects applicable to each position (i.e., rater, data collector, or data analyst) and must include the following:

(a) Classroom training. Each rater shall receive classroom training on

(1) Basic principles of building science (i.e., viewing the home as a system)

(2) Thermal resistance of insulation materials

(3) The minimum rated features for buildings

(4) Blower door testing procedures

(5) Duct leakage testing procedures

(6) Variations in construction types and their ramifications

(7) Types and efficiencies of windows

(8) Types and efficiencies of heating, cooling, water heating, and lighting systems

(9) Types and characteristics of space conditioning and domestic hot water distribution systems

(10) Types of thermostatic controls

(11) Determination of azimuth

(12) Determination of air leakage

(13) Determination of fuels used by major appliances

(14) Utility rate structures

(15) On-site inspection procedures

(16) Producing a scaled and dimensioned drawing of a home

(17) Calculating the area of rectangles, triangles, circles, ovals and combinations of these shapes

(18) Calculating the volume of boxes, pyramids, spheres, and other geometric shapes

(19) Completing a home energy rating checklist or entering data into a home energy rating software program;

(20) Completing a home energy improvement analysis or entering data into a home energy rating software program that performs improvement analysis

(21) Basic knowledge of financial incentive programs and energy efficient mortgages

(22) Communicating the benefits of energy saving measures and practices to the consumer; and

(23) Quality assurance.

b. Written examination. Each rater shall be given a written examination that evaluates the rater's understanding of the subjects in paragraph (a) of this section.

c. Field training. Each rater shall perform two ratings (or portions of ratings for those seeking to be data collectors or data analysts), including software operations, in the presence of trainers.

d. Probationary period. Each rater shall complete a probationary period where close supervision is provided. This period covers a minimum of five ratings, after which the supervisor shall determine if additional training is needed.

e. Challenge test. A challenge test may be taken, which, if passed in all competencies, will waive the classroom training requirement. The requirements of paragraphs (c) and (d) of this section may not be waived.

f. Continuing education. Each rater shall complete a minimum of 12 hours of approved continuing education during each 3-year period of certification.

## 4. Quality Control

a. All HERS providers shall establish a quality assurance plan that includes-

(1) Periodic peer review and reevaluation of raters

(2) Random auditing of each rater's work;

(3) Evaluation of the training program by raters after field experience;

(4) Customer evaluation of rating services;

(5) Random review of the inputs into the rating tool to ensure that they are consistent with the data collected in the field; and

(6) Verification of the accuracy and completion of the input forms and output of the first five ratings performed by each rater.

b. All HERS providers shall maintain a permanent quality assurance file that is updated at least every two years or when changes to the system are made, and contains:

(1) A description of local rate structure for electricity, gas and other locally used fuels;

(2) A description of climatological data (including interpolation methods) used;

(3) A description of the data storage and maintenance systems including:

(a) Software for database,

(b) Training for data entry personnel, and

(c) Data quality assurance procedures that will be exercised;

(4) A description of each rating tool that the HERS provider uses including a list of which home types the tool supports;

(5) The results and date of the certified accuracy test conducted for the rating tool;

(6) An example of the rating outputs produced;

(7) The materials and tests used to provide training for home energy raters;

(8) The materials used to document the site data collection procedures; and

(9) A description of the individual elements of the quality assurance plan set forth in paragraph (a) of this section.

c. All HERS providers shall maintain an electronic database of information for each home rated. The minimum content of the database is -

(1) A unique file reference of ill number

(2) Date of on-site inspection

(3) Raters name;

(4) Tool name and version:

(5) Identification of climate data used for the rating

(6) Type of rating, either projected or confirmed

(7) Use of rating, either-

(a) Time of sale rating;

(b) Pre-home improvement rating;

(c) Post home improvement rating; or

(d) Information only rating

(8) Address of Rated Home

(9) Home type;

(10) Floor area of conditioned space;

(11) Fuel types used by building heating, cooling and water heating systems;

(12) Minimum rated feature energy efficiency data used to determine the rating;

(13) In the four categories of heating, cooling, water heating and all other uses, the

(a) Estimated annual purchased energy consumption in total;

(b) Estimated annual purchased energy consumption by fuel;

(c) Estimated annual energy costs in total; and

(d) Estimated annual energy cost by fuel.

(14) Estimated total annual energy cost for all uses; and

(15) Rating score of the Rated Home on 0-100 points scale and 1- 5+ stars category

(16) To extent allowed by state statute, all HERS providers shall for 10% or for 500 of the homes rated annually, whichever is less, maintain a database of the following -

(a) Homeowners authorization for the release of consumption information by utility companies;

(b) Climate data site used for energy estimation;

(c) Any energy efficiency improvements made to the home and date of completion.

## 5. Guideline Compliance.

a. Full accreditation. Any HERS provider may be accredited as being in full compliance with these Guidelines if it demonstrates that it can

(1) Conducts ratings in accordance with the provisions of Section B.l of these Guidelines;

(2) Reports the results of ratings in accordance with the provisions of Section B.3 of these Guidelines;

(3) Produces documentation of a correctly configured Reference Home in accordance with the provisions of Section B.4 of these Guidelines;

(4) Provides documentation that their energy analysis tool is certified in accordance with the Accreditation Procedures as having passed HERS-BESTEST.

(5) Provides training in accordance with the provisions of Section C.3 of these Guidelines;

(6) Provides documentation of a quality control plan and a permanent quality assurance file in accordance with the provisions of Section C.4 of these Guidelines;

(7) Provides documentation of a monitoring and evaluation program in accordance with the provisions of Section C.5 of these Guidelines;

b. Basic compliance. Any exiting HERS provider may be accredited for a period of up to two years, as being in basic compliance with these Guidelines, by demonstrating that it meets all the provisions of paragraph (a) of this section except that it may -

(1) Use a simplification of utility rate structures;

(2) Rate only the features set forth by Section B.5 of these Guidelines that may be rated with its existing system capabilities;

(3) Use only those standard operating conditions set forth in Section B.6 of these Guidelines that can be handled by their existing energy analysis tool;

(4) Pass only the Tier I set of HERS-BESTEST tests;

(5) Meet the training requirements of Section C.3 of these Guidelines by -

(a) Verification that each person with responsibilities in the conduction of ratings has completed classroom training on all items set forth in Section C.3.a of these Guidelines;

(b) Verification that each person with responsibilities for the conduction of ratings has received field training;

(c) Verification that all personnel have successfully passed a-written objective examination in all areas applicable to their designated job descriptions; and

(d) Verification of a probationary period set forth in Section C.3.d of these Guidelines; and

(6) Use an existing program to monitor and evaluate the accuracy of ratings.

## 6. Accreditation

a. All HERS providers operating in voluntary compliance with these Guidelines shall be accredited only by a State or by an other independent Accrediting Body authorized by the state to:

(1) Establish and coordinate consistent adjustments to these Guidelines within a State for

(a) default values for minimum rated features set forth in Section B.5 of these Guidelines;

(b) operating condition assumptions and local climatic data interpolation set forth in Section B.6 of these Guidelines;

(c) alternate standard operating condition assumptions set forth in Section B.5 of these Guidelines.

(2) administer the procedures for certification of energy analysis tools established by HERS-BESTEST set forth in the NREL Report No. NREUTP-472- 7332 referenced in Section C.l of these Guidelines;

(3) evaluate the training of home energy raters set forth in Section C.3 *of* these Guidelines

(4) review and evaluate the quality control procedures set forth in Section C.4 *of* these Guidelines; and

(5) evaluate the site data collection manual and monitoring and evaluation program set forth in Sections C.2 and C.5 of these Guidelines.

b. The accreditation process shall be conducted fully consistent with the "Mortgage Industry National Accreditation Procedures for Home Energy Rating Systems" and with applicable state law, included but not limited to statutes and regulation related to home energy rating systems and to the state's required administrative procedures. In cases where the national Accreditation Procedures and state law or regulation differ, the state law or regulation shall govern.

c. Any Lender or agency in a mortgage business who offers mortgage or loan incentives for energy efficiency on the basis *of* a home energy rating should require that such ratings be conducted in accordance with these Guidelines and that the rating provider is accredited in accordance with the "Mortgage Industry National Accreditation Procedures for Home Energy Rating Systems."

# Appendix B. Standard Reference House Definitions

Several organizations have attempted to define standard construction practices in such documents as the Model Energy Code (MEC 1995), International Energy Conservation Code (IECC 2003), National Home Energy Rating System (HERS) Technical Guidelines, and ASHRAE Standard 90.2. The technical guidelines developed by some of these organizations are summarized in Table B-1; climate-dependent variables are calculated for three diverse locations (Fargo, Baltimore, and Houston).

### Table B-1. Comparison of Important Reference Houses (New Detached Single-Family Houses)

| House Features | City | MEC 93 | HERS 1999 | IECC 2003 | DOE IECC Proposal | BA Research Benchmark (Version 3.1) |
|---|---|---|---|---|---|---|
| Energy end uses included in comparison | All | All end uses | Space conditioning and hot water | All end uses | Space conditioning and hot water | All end uses |
| Basis of comparison | All | Site energy | Normalized modified end use load method | Site energy | Energy cost (or site energy at discretion of local jurisdiction) | Site energy, source energy, and energy cost |
| Thermal envelope boundary (volume of conditioned space) | All | Same as proposed | Same as proposed | Same as proposed | Same as proposed except attic is always unconditioned | Same as proposed except attic is always unconditioned |
| Opaque Wall U-value | Fargo | Unspecified | 0.046 (9254 HDD) | 0.046 (9254 HDD) | 0.057 (Zone 7) | 0.046 (9254 HDD) |
| | Baltimore | Unspecified | 0.058 (4707 HDD) | 0.058 (4707 HDD) | 0.082 (Zone 4) | 0.058 (4707 HDD) |
| | Houston | Unspecified | 0.085 (1599 HDD) | 0.085 (1599 HDD) | 0.082 (Zone 2) | 0.085 (1599 HDD) |
| Window U-value | Fargo | Unspecified | ~ 0.32 (Depending on size/shape of house) | 0.26 | 0.35 | ~ 0.32 (Depending on size/shape of house) |
| | Baltimore | Unspecified | ~ 0.44 (Depending on size/shape of house) | 0.30 | 0.40 | ~ 0.44 (Depending on size/shape of house) |
| | Houston | Unspecified | ~ 0.64 (Depending on size/shape of house) | 0.47 | 0.80 | ~ 0.64 (Depending on size/shape of house) |
| Total Wall/Window/ Door U-value | Fargo | 0.110 | 0.110 | ~ 0.098 | ~ 0.130 | 0.110 |
| | Baltimore | 0.146 | 0.146 | ~ 0.116 | ~ 0.162 | 0.146 |
| | Houston | 0.211 | 0.211 | ~ 0.173 | ~ 0.262 | 0.211 |
| Wall Construction | All | Unspecified | Light frame wood | Unspecified | Wood frame | Light frame wood, 23% framing factor |
| Wall Absorptivity | All | Unspecified | 0.5 | Unspecified | 0.75 | 0.5 |
| Wall Emittance | All | Unspecified | Unspecified | Unspecified | 0.90 | 0.90 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Window Area | All | Unspecified | 18% of conditioned floor area x fraction of walls above grade | 18% of conditioned floor area | 18% of conditioned floor area, modified for conditioned basements | 18% of conditioned floor area x fraction of walls above grade |
| Window Area Distribution | All | Unspecified | Equal in each of 4 cardinal directions | Equal in each of 8 directions (NE,N,etc.) | Equal in each of 4 cardinal directions | Equal in each of 4 cardinal directions |
| Door U-value | Fargo | Unspecified | 0.2 | 0.2 | 0.35 | 0.2 |
| | Baltimore | Unspecified | 0.2 | 0.2 | 0.40 | 0.2 |
| | Houston | Unspecified | 0.2 | 0.2 | 0.80 | 0.2 |
| Door Area | All | Unspecified | 40 $ft^2$, facing north | Same as proposed | 40 $ft^2$, facing north | 40 $ft^2$, facing north |
| Window SHGC (including framing) | Fargo | Unspecified | 0.581 | 0.68 | 0.55 | 0.581 |
| | Baltimore | Unspecified | 0.581 | 0.68 | 0.55 | 0.581 |
| | Houston | Unspecified | 0.581 | 0.40 | 0.40 | 0.581 |
| Opaque Roof U-value | Fargo | Unspecified | Unspecified | 0.026 | 0.026 | 0.026 |
| | Baltimore | Unspecified | Unspecified | 0.032 | 0.030 | 0.030 |
| | Houston | Unspecified | Unspecified | 0.041 | 0.035 | 0.035 |
| Skylight U-value | Fargo | Unspecified | Unspecified | No skylights | No skylights | No skylights |
| | Baltimore | Unspecified | Unspecified | No skylights | No skylights | No skylights |
| | Houston | Unspecified | Unspecified | No skylights | No skylights | No skylights |
| Total Roof/Ceiling U-value | Fargo | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 |
| | Baltimore | 0.032 | 0.032 | 0.032 | 0.030 | 0.030 |
| | Houston | 0.041 | 0.041 | 0.041 | 0.035 | 0.035 |
| Ceiling Construction | All | Unspecified | Light frame wood | Unspecified | Wood frame | Light frame wood, 11% framing factor |
| Roof Absorptivity | All | Unspecified | 0.75 | Unspecified | 0.75 | 0.75 |
| Roof Emittance | All | Unspecified | Unspecified | Unspecified | 0.90 | 0.90 |
| Floor Over Unconditioned Space U-value | Fargo | 0.05 | 0.05 | 0.05 | 0.033 | 0.05 |
| | Baltimore | 0.05 | 0.05 | 0.05 | 0.047 | 0.05 |
| | Houston | 0.07 | 0.07 | 0.07 | 0.064 | 0.07 |
| Floor Construction | All | Unspecified | Light frame wood | Unspecified | Wood frame | Light frame wood, 13% framing factor |
| Unvented Crawl Space Wall U-value | Fargo | 0.060 | 0.060 | 0.060 | 0.057 | 0.060 |
| | Baltimore | 0.069 | 0.069 | 0.069 | 0.065 | 0.069 |
| | Houston | 0.150 | 0.150 | 0.150 | 0.477 | 0.150 |
| Basement Wall U-value | Fargo | 0.060 | 0.060 | 0.060 | 0.041 | 0.060 |
| | Baltimore | 0.099 | 0.099 | 0.099 | 0.059 | 0.099 |
| | Houston | 0.168 | 0.168 | 0.168 | 0.360 | 0.168 |
| Basement Insulation Location | All | Unspecified | Interior | Unspecified | Interior | Interior |
| Slab-On-Grade Insulation (Unheated Slab) | Fargo | R-7.2, 4 ft depth | R-7.2, 4 ft depth | R-7.2, 4 ft depth (except high termite infestation areas) | R-15, 4 ft depth | R-7.2, 4 ft depth |
| | Baltimore | R-4.1, 2 ft depth | R-4.1, 2 ft depth | R-4.1, 2 ft depth | R-10, 4 ft depth | R-4.1, 2 ft depth |
| | Houston | None | None | None | None | None |

| | | | | | | |
|---|---|---|---|---|---|---|
| Slab Covering | All | Unspecified | Unspecified | Unspecified | 80% R-2 carpet/pad, 20% directly exposed | 80% R-2 carpet/pad, 20% directly exposed |
| Sunrooms | | Same as proposed | Same as proposed | Same as proposed | None | None |
| Structural Mass | All | Unspecified | Same as proposed, except consistent w/ light frame const. for above-grade walls, ceilings, floors | 3.5 lb/ft$^2$ | Same as proposed | Same as proposed, except consistent w/ light frame construction for above-grade walls, ceilings, floors |
| External Shading | All | Unspecified | None | None | None | None |
| Heating System Type (if heating system is present in Prototype/ proposed house) | All | Same as proposed | Same as proposed, except heat pump for any electric system not covered by NAECA, and gas furnace for any non-electric system not covered by NAECA | Same as proposed | Same as proposed, except heat pump for any electric system not covered by NAECA, and gas furnace for any non-electric system not covered by NAECA | Same as proposed, except heat pump for any electric system not covered by NAECA, and gas furnace for any non-electric system not covered by NAECA |
| Heating System Type (if no heating system is present in Prototype/ proposed house) | All | Unspecified | Heat pump if electricity used for water heating, gas furnace if gas or other fuel is used for water heating | Unspecified | Heat pump if electricity used for water heating, gas furnace if gas or other fuel is used for water heating | Air source heat pump if heating is required for at least one month |
| Heating Fuel | All | Same as proposed | Same as proposed, except gas for any non-electric heating in Rated Home | Same as proposed | Same as proposed, except gas for any non-electric heating in Rated Home | Same as proposed, except gas for any non-electric heating in Rated Home |
| Heating System Efficiency | All | 78% AFUE for Gas Furnace, 80% AFUE for Gas Boiler, 6.8 HSPF for Heat Pump (others listed in Tables 503.4.2a-503.4.3c) | 78% AFUE for Gas Furnace, 80% AFUE for Gas Boiler, 6.8 HSPF for Heat Pump (others per NAECA) | 78% AFUE for Gas Furnace, 80% AFUE for Gas Boiler, 6.8 HSPF for Heat Pump (others per NAECA or ASHRAE 90.1) | Prevailing federal minimum effficiency (NAECA) | 78% AFUE for Gas Furnace, 80% AFUE for Gas Boiler, 6.8 HSPF for Heat Pump (others per NAECA) |
| Heating System Sizing | All | Per ASHRAE Hndbk of Fundamentals | Per acceptable engineering practice | Per ASHRAE Hndbk of Fundamentals | Per ACCA Manual J | Per ACCA series of manuals |

| | | | | | | |
|---|---|---|---|---|---|---|
| Cooling System Type (if cooling system is present in Prototype/ proposed house) | All | Same as proposed | Same as proposed, except electric air conditioner for any system not covered by NAECA | Same as proposed | Electric air conditioner | Same as proposed, except electric air conditioner for any system not covered by NAECA |
| Cooling System Type (if no cooling system is present in Prototype/proposed house) | All | Unspecified | Electric air conditioner | Unspecified | Electric air conditioner | Electric air conditioner |
| Cooling Fuel | All | Same as proposed | Electric | Same as proposed | Electric | Electric |
| Cooling System Efficiency | All | 10 SEER electric air conditioner (others listed in Tables 503.4.5a-503.4.6) | 10 SEER electric air conditioner, 6.8 HSPF heat pump (others per NAECA) | 10 SEER electric air conditioner, 6.8 HSPF heat pump (others per NAECA or ASHRAE 90.1) | 10 SEER electric air conditioner, 6.8 HSPF heat pump (others per NAECA) | 10 SEER electric air conditioner, 6.8 HSPF heat pump (others per NAECA) |
| Cooling System Sizing | All | Per ASHRAE Handbook of Fundamentals | Per acceptable engineering practice | Per ASHRAE Handbook of Fundamentals | Per ACCA Manual J | Per ACCA series of manuals |
| Hot Water Type | All | Same as proposed | Same as proposed | Same as proposed | Standard storage type | Standard electric or gas water heater |
| Hot Water Fuel | All | Same as proposed | Same as proposed | Same as proposed, except gas or electric used if a solar energy system in proposed design provides 100% of hot water | Same as proposed | Same as proposed, except same as space heating system if fuel other than electricity or gas is used for proposed |
| Hot Water Efficiency | All | 75% recovery efficiency and standby loss (%/hr) = 2.3+67/V for gas or oil; 75% thermal efficiency for gas; 80% combustion efficiency for oil; standby loss = 0.17Btu/hr/ft$^2$/°F for electric; R-12.5 tank insulation | EF = 0.93-(0.00132xV) for electric; EF = 0.62-(0.0019xV) for gas (others per 1992 NAECA) | EF = 0.93-(0.00132xV) for electric; EF = 0.62-(0.0019xV) for gas (others in Table 504.2) | EF = 0.93-(0.00132xV) for electric; EF = 0.62-(0.0019xV) for gas (others per current NAECA) | EF = 0.93-(0.00132xV) for electric; EF = 0.62-(0.0019xV) for gas |

| | | | | | | |
|---|---|---|---|---|---|---|
| Hot Water Sizing (V) | All | Same as proposed | Same as proposed | Same as proposed | Unspecified | Per ASHRAE HVAC Applications Handbook |
| Hot Water Tank Location | All | Unspecified | Unspecified | Unspecified | Unspecified | Same as proposed |
| DHW Pipe Insulation | All | Dependent on pipe size, pipe location, and climate | Unspecified | Dependent on pipe size, pipe location, and climate | Unspecified | Unspecified |
| Infiltration | Fargo | Unspecified (basic air sealing measures required) | 0.63 ACH (includes conditioned basement) | 0.63 ACH (includes conditioned basement) | 0.53-0.65 ACH (depending on # stories, ACH includes conditioned basement) | 0.41-0.82 ACH (depending on foundation type, ACH includes conditioned basement) |
| | Baltimore | | 0.47 ACH | 0.47 ACH | 0.39-0.48 ACH | 0.31-0.62 ACH |
| | Houston | | 0.46 ACH | 0.46 ACH | 0.39-0.48 ACH | 0.30-0.61ACH |
| Duct Leakage | All | Unspecified (basic duct sealing measures required) | Unspecified | Unspecified | Unspecified | 10% of total air handler flow (6.5% supply, 3.5% return) |
| Duct Insulation | All | R-3.3 to R-8 depending on whether ducts are in conditioned space | Unspecified | Unspecified | Unspecified | R-3.3 or R-5 depending on whether ducts are in conditioned space |
| Duct Location | All | Same as proposed | Unspecified | Same as proposed | Unspecified | Depends on air handler location and climate |
| Total Duct Energy Loss | All | Unspecified | 0.8 distribution efficiency | 0.8-1.0 distribution efficiency depending on fraction of ducts in conditioned space | 0.8 distribution efficiency | Calculated (approximately 0.8 distribution efficiency on average) |
| Whole-House Ventilation Fan Energy | All | Unspecified | Unspecified | Unspecified | kWh/yr = 0.03942xCFA + 29.565x(Nbr+1) if proposed design has mech. ventilation | kWh/yr = 0.03942xCFA + 29.565x(Nbr+1) if proposed design has mech. ventilation |
| Lighting Energy | All | Same as proposed | Not relevant | Same as proposed | Not relevant | 2245 kWh/yr for typical 1800 $ft^2$ house, including exterior lighting |
| Appliance and Other Plug Load Energy | All | Same as proposed | Not relevant | Same as proposed | Not relevant | Fixed energy use for individual appliances, fixed total energy use for other plug loads |

| | | | | | | |
|---|---|---|---|---|---|---|
| Site Generation | All | Credit for renewable energy systems that include storage | Unspecified | Unspecified | Unspecified | No site generation |
| ***Operating Conditions*** | | | | | | |
| Thermostat Settings | All | Same as proposed, which is undefined | 68ºF Heating 78ºF Cooling | 68ºF Heating 78ºF Cooling | 68ºF Heating 78ºF Cooling | 68ºF Heating 78ºF Cooling |
| Thermostat Setback/Setup for Proposed House | All | Undefined | 5ºF set-back for heating 11pm-7am, 5ºF set-up for cooling 9am-3pm if programmable thermostat | Up to 5ºF set-back for up to 6 hours in heating mode, up to 5ºF set-up for up to 6 hours in cooling mode | None | None |
| Thermostat Setback/Setup for Reference House | All | Same as proposed | None | 5ºF set-back for 6 hours in heating mode, 5ºF set-up for 6 hours in cooling mode | None | None |
| Internal Sensible Load | All | Same as proposed, which is undefined | 3000 Btu/hr total | ~3000 Btu/hr total, depending on house size and number of bedrooms | ~3000 Btu/hr total, depending on house size and number of bedrooms | ~450 Btu/hr for occupants, ~1740 Btu/hr for appliance and plug loads, ~740 Btu/hr for lighting |
| Internal Latent Load | All | Same as proposed, which is undefined | 600 Btu/hr total | Not distinguished from sensible load | Not distinguished from sensible load | ~340 Btu/hr for occupants, ~340 Btu/hr for appliances |
| Internal Thermal Mass | All | Same as proposed, which is undefined | 8 lb/ft$^2$ floor area for reference house only | 8 lb/ft$^2$ floor area | 8 lb/ft$^2$ floor area for reference house only, plus additional thermal storage elements of proposed design | 8 lb/ft$^2$ floor area for reference house only, plus additional thermal storage elements of proposed design |
| Window Operation | All | Same as proposed, which is undefined | None | None | None | 50% probability during cooling season if outside temperature is below indoor, 5-7 ACH due to open windows |
| Window Shading Multiplier | All | Same as proposed, which is undefined | 0.8 during cooling season, 1.0 during other seasons | 0.7 in summer, 0.9 in winter (seasons undefined) | 0.7 for hours with cooling, 0.85 for hours with heating (0.95 for proposed design with passive solar) | 0.7 during cooling season, 0.85 during heating/swing seasons |

| | | | | | | |
|---|---|---|---|---|---|---|
| Hot Water Usage | Fargo | Same as proposed, which is undefined | 60 gal/day for 3 Bedroom | 60 gal/day for 3 Bedroom | 60 gal/day for 3 Bedroom | 58.0 gal/day for 3 Bedroom |
| | Baltimore | | | | | 55.8 gal/day for 3 Bedroom |
| | Houston | | | | | 52.6 gal/day for 3 Bedroom |
| Hot Water Set Point | All | Same as proposed, which is undefined | Unspecified | 120ºF | 120ºF | 120ºF |
| Water Mains Temperature | All | Same as proposed, which is undefined | Unspecified | Unspecified | Unspecified | Function of climate and day of year |
| ***Constraints on Model of Proposed Design*** | | | | | | |
| Air Infiltration | | No minimum specified | No minimum specified | No credit for air tightness below 0.35 ACH | No credit for air tightness below 0.35 ACH if no ventilation, no credit below 0.01xCFA+7.5x(Nbr+1) cfm if ventilation included | No minimum, but combined ventilation and infiltration must meet ASHRAE 62.2 guidelines |
| Duct Leakage | | As measured or using default values of distribution efficiency | As measured or using default values of distribution efficiency | Credit for duct improvements allowed only if duct blaster verifies < 5% leakage at 25 Pa (no credit for ducts in conditioned space) | Credit for duct improvements allowed only if duct blaster verifies < 3cfm/100ft2 leakage to outside at 25 Pa, or if ducts are in conditioned space | As measured or as-designed |

*Note: For definitions of acronyms and abbreviations listed above, please see the List of Terms in the front of this report.*

# Appendix C.  Performance Analysis Examples

Each residential design for a Building America project is unique.  However, the processes used in creating the models within the context of DOE-2.2 are always fairly similar.  Houses can vary from single-story ones with slab-on-grade foundations to two-story ones with basements, but that range is actually small with respect to the range of building types that can be modeled using DOE-2.  This fact allows the analyst to create new models relatively quickly and efficiently.  The starting point for a new model is almost always a previous project that was similar in number of stories or foundation type.

NREL has conducted several detailed energy performance simulations using DOE-2.2 over the past few years.  Two examples are presented here to further illustrate the process described in this document: EcoVillage in Cleveland, Ohio, and the Solar Patriot Home in Purcellville, Virginia.  Other sample DOE-2.2 input files are posted on the Building America Web site (see http://www.eere.energy.gov/buildings/building_america/benchmark_def.html).

The sample files serve to both illustrate examples of modeling techniques and act as a template for new projects.  Much of the structure of the DOE-2 input file is arbitrary—the title section can come at the end of the file, the reports sections can come at the beginning, command and key-word abbreviations can be used or they can be spelled out completely.  However, using a consistent format for the model description will save all parties much time and effort.

## *EcoVillage, Cleveland, Ohio*

The objective of this analysis was to quantify the energy performance of attached townhouses in a three-story building constructed by Building Science Consortium (BSC) partner DAS Construction in a community called EcoVillage in Cleveland, Ohio.  The analysis was based on a combination of field testing and building energy simulation using DOE-2.2.  The evaluated units are part of Building A, a four-unit building designed to have very high energy performance and numerous "green" design features (see Figure C1).  Key features include well-insulated building envelopes, low-e windows, ducts and air handlers in conditioned space, high-efficiency furnaces, large south-facing bay windows, and 2- or 4-kW PV arrays.

The units in each building are significantly different in size and shape.  Unit 2 was finished at the time of the test and was being used as a sales model, but the other three were not fully finished pending the selection of final options by the purchaser (cabinets, carpeting, etc.).  Unit 4 was not available for testing because some finishing work was being done by the builder. Unit 1 included two separate living areas, one two-story floor plan above grade and the other in the basement, each with its own space-conditioning equipment.

**Figure C1. EcoVillage Building A (Cleveland, Ohio, December 2002)**

An annual energy analysis of EcoVillage Building A was performed by NREL using the DOE-2.2 building simulation software. The geometry of the model was illustrated using eQUEST, as shown in Figure C2. All four units were included in one simulation so that interactions between units would be captured. Below-grade and above-grade portions of the basement were included. The analysis was conducted and reported in accordance with the original published Building America Performance Analysis Procedures (September 2001) and the Building America Research Benchmark Version 2.1 (July 2003). The specific inputs used in the models are summarized in Table C1.

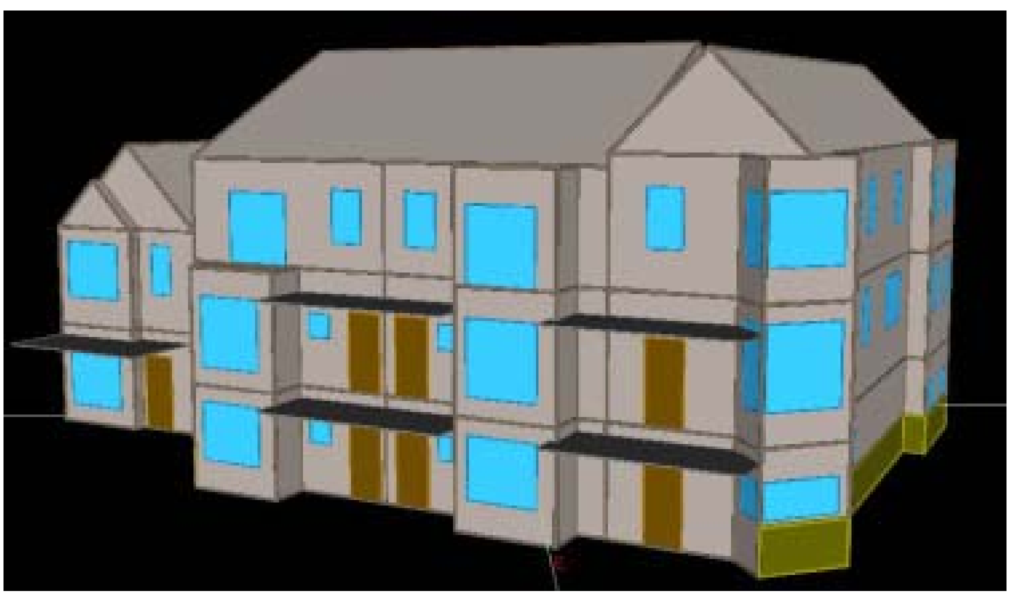


**Figure C2. EcoVillage energy simulation model geometry using eQUEST**

## Table C1.  Annual Energy Simulation Inputs

| Component | | BA Benchmark | Region Standard | Builder Standard | Prototype |
|---|---|---|---|---|---|
| A/C size | Unit 1 | 3 | 3 | 3 | 2.5 |
| | Unit 2 | 3 | 3 | 3 | 2.5 |
| | Unit 3 | 3 | 3 | 3 | 2.5 |
| | Unit 4 | 2.5 | 2.5 | 2.5 | 2 |
| A/C SEER | | 10 | 10 | 10 | 12 |
| Furnace AFUE | | 80 | 80 | 80 | 90 |
| Wall Type | | 2x6 | 2x4 | 2x4 | 2x6 |
| Wall Insulation | | Overall R=16.7 | Filled Cavity | Filled Cavity | Filled Cavity + R5 |
| Ceil Insulation | | R-33.3 (nominal R38) | R-38 nominal | R-38 nominal | R-38 nominal |
| Bsmt Wall Insulat | | R-17 | R-10 | R-10 | Filled Cavity + R5 |
| Glass Type | | U=0.35, SHGC=0.55 | U=0.46, SHGC=0.76 | U=0.46, SHGC=0.76 | U=0.36, SHGC=0.45 |
| Window Frame | | aluminum frame | aluminum frame | aluminum frame | aluminum frame |
| Slab Insulation | | none | none | none | R-10, 4ft perim |
| Gas DHW | Unit 1 | 40 gallon, EF = 0.54 | 40 gallon, EF = 0.54 | 40 gallon, EF = 0.54 | 40 gallon, EF=0.59 |
| | Unit 2 | 40 gallon, EF = 0.54 | 40 gallon, EF = 0.54 | 40 gallon, EF = 0.54 | 40 gallon, EF=0.59 |
| | Unit 3 | 40 gallon, EF = 0.54 | 40 gallon, EF = 0.54 | 40 gallon, EF = 0.54 | 40 gallon, EF=0.59 |
| | Unit 4 | 30 gallon, EF = 0.56 | 30 gallon, EF = 0.56 | 30 gallon, EF = 0.56 | 40 gallon, EF=0.59 |
| Mech Ventilation | | BA minimum kWh | BA minimum kWh | BA minimum kWh | see Air-Cycler tab |
| Infiltration | Unit 1 | 0.64 ACH | 0.64 ACH | 0.64 ACH | 0.30 + $0.05_{mech}$ ACH |
| | Unit 2 | 0.64 ACH | 0.64 ACH | 0.64 ACH | 0.30 + $0.05_{mech}$ ACH |
| | Unit 3 | 0.64 ACH | 0.64 ACH | 0.64 ACH | 0.30 + $0.05_{mech}$ ACH |
| | Unit 4 | 0.57 ACH | 0.57 ACH | 0.57 ACH | 0.30 + $0.05_{mech}$ ACH |
| Supply Duct Desc. | Unit 1 | all internal | 25% ext. walls | 25% ext. walls | all internal |
| | Unit 2 | all internal | 10% in ext. walls | 10% in ext. walls | all internal |
| | Unit 3 | all internal | 10% ext. walls | 10% ext. walls | all internal |
| | Unit 4 | all internal | 25% in ext. walls | 25% in ext. walls | all internal |
| Return Duct Desc. | Unit 1 | all internal | all internal | all internal | all internal |
| | Unit 2 | all internal | all internal | all internal | all internal |
| | Unit 3 | all internal | all internal | all internal | all internal |
| | Unit 4 | all internal | all internal | all internal | all internal |
| Duct Htg/Clg Seasonal Efficiency | Unit 1 | 99 / 99 % | 99 / 99 % | 99 / 99 % | 99 / 99 % |
| | Unit 2 | 99 / 99 % | 99 / 99 % | 99 / 99 % | 99 / 99 % |
| | Unit 3 | 99 / 99 % | 99 / 99 % | 99 / 99 % | 99 / 99 % |
| | Unit 4 | 99 / 99 % | 99 / 99 % | 99 / 99 % | 99 / 99 % |

**Utility Rates for Cleveland:**

| Electric (\$/kWh) | Gas (\$/therm) |
|---|---|
| 0.07 | 0.65 |

Annual site energy consumption by end use for each EcoVillage Town House (BA Prototype) and its corresponding Building America Benchmark, Regional Standard Practice, and Builder Standard Practice house is summarized in Tables C2-C5. Because of the unique nature of the builder for this project, Regional Standard Practice and Builder Standard Practice are assumed to be equivalent. The space heating end use includes supply fan energy used during heating, and the space cooling end use includes supply fan energy used during cooling. Lighting end use includes both interior and exterior lighting.

Significant energy savings are predicted for all four units in the major end-use categories, including heating, cooling, and hot water. Mechanical ventilation adds a significant energy penalty because of the additional air handler use associated with the AirCycler approach. However, the PV arrays are expected to offset a large fraction of total electricity use, including all of the additional fan power. There is also a small amount of energy savings in the Appliances and Plug Loads category because of the ENERGY STAR dishwashers in the Prototypes.

**Table C2. Annual Site Energy Use for Ecovillage Unit 1 and Base Cases (Benchmark Version 2.1)**

| Unit 1 | Annual Site Energy | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 story, Bsmt unit | BA Benchmark | | Region Standard | | Builder Standard | | BA Prototype | |
| End-Use | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) |
| Space Heating | 536 | 870 | 708 | 979 | 708 | 979 | 425 | 547 |
| Space Cooling | 1339 | 0 | 2034 | 0 | 2034 | 0 | 1035 | 0 |
| DHW | 0 | 212 | 0 | 223 | 0 | 223 | 0 | 201 |
| Lighting | 2658 | | 2658 | | 2658 | | 2658 | |
| Appliances + Plug | 4892 | 124 | 4892 | 124 | 4892 | 124 | 4842 | 124 |
| OA Ventilation | 180 | | 180 | | 180 | | 911 | |
| Total Usage | 9604 | 1206 | 10472 | 1326 | 10472 | 1326 | 9871 | 872 |
| *Site Generation* | 0 | 0 | 0 | 0 | 0 | 0 | 4271 | 0 |
| *Net Energy Use* | 9604 | 1206 | 10472 | 1326 | 10472 | 1326 | 5600 | 872 |

**Table C3. Annual Site Energy Use for Ecovillage Unit 2 and Base Cases (Benchmark Version 2.1)**

| Unit 2 | Annual Site Energy | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 story, Bsmt | BA Benchmark | | Region Standard | | Builder Standard | | BA Prototype | |
| End-Use | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) |
| Space Heating | 341 | 572 | 383 | 558 | 383 | 558 | 193 | 265 |
| Space Cooling | 1010 | 0 | 1427 | 0 | 1427 | 0 | 734 | 0 |
| DHW | 0 | 221 | 0 | 221 | 0 | 221 | 0 | 200 |
| Lighting | 2703 | | 2703 | | 2703 | | 2703 | |
| Appliances + Plug | 4985 | 124 | 4985 | 124 | 4985 | 124 | 4935 | 124 |
| OA Ventilation | 182 | | 182 | | 182 | | 1113 | |
| Total Usage | 9221 | 917 | 9680 | 903 | 9680 | 903 | 9678 | 589 |
| *Site Generation* | 0 | 0 | 0 | 0 | 0 | 0 | 4271 | 0 |
| *Net Energy Use* | 9221 | 917 | 9680 | 903 | 9680 | 903 | 5407 | 589 |

**Table C4. Annual Site Energy Use for Ecovillage Unit 3 and Base Cases (Benchmark Version 2.1)**

| Unit 3<br>3 story, Bsmt | Annual Site Energy | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BA Benchmark | | Region Standard | | Builder Standard | | BA Prototype | |
| End-Use | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) |
| Space Heating | 344 | 578 | 392 | 571 | 392 | 571 | 197 | 271 |
| Space Cooling | 954 | 0 | 1450 | 0 | 1450 | 0 | 738 | 0 |
| DHW | 0 | 213 | 0 | 222 | 0 | 222 | 0 | 200 |
| Lighting | 2679 | | 2679 | | 2679 | | 2679 | |
| Appliances + Plug | 4936 | 124 | 4936 | 124 | 4936 | 124 | 4886 | 124 |
| OA Ventilation | 181 | | 181 | | 181 | | 1131 | |
| Total Usage | 9094 | 915 | 9638 | 917 | 9638 | 917 | 9631 | 595 |
| *Site Generation* | 0 | 0 | 0 | 0 | 0 | 0 | 4271 | 0 |
| *Net Energy Use* | 9094 | 915 | 9638 | 917 | 9638 | 917 | 5360 | 595 |

**Table C5. Annual Site Energy Use for Ecovillage Unit 4 and Base Cases (Benchmark Version 2.1)**

| Unit 4<br>2 story, slab | Annual Site Energy | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BA Benchmark | | Region Standard | | Builder Standard | | BA Prototype | |
| End-Use | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) | (kWh) | (therms) |
| Space Heating | 319 | 531 | 380 | 542 | 380 | 542 | 219 | 291 |
| Space Cooling | 599 | 0 | 983 | 0 | 983 | 0 | 488 | 0 |
| DHW | 0 | 188 | 0 | 188 | 0 | 188 | 0 | 176 |
| Lighting | 1996 | | 1996 | | 1996 | | 1996 | |
| Appliances + Plug | 3451 | 116 | 3451 | 116 | 3451 | 116 | 3401 | 116 |
| OA Ventilation | 118 | | 118 | | 118 | | 843 | |
| Total Usage | 6483 | 835 | 6927 | 846 | 6927 | 846 | 6947 | 583 |
| *Site Generation* | 0 | 0 | 0 | 0 | 0 | 0 | 2672 | 0 |
| *Net Energy Use* | 6483 | 835 | 6927 | 846 | 6927 | 846 | 4275 | 583 |

Source energy consumption and energy savings by end use relative to the three base cases are shown in Tables C6-C9. The "Percent of End Use" column shows how effective the Prototype building is at reducing energy use in each end-use category. The "Percent of Total" columns show how the energy reductions in each end-use category contribute to overall savings. Space heating is clearly the dominant load in Cleveland, and efficiency measures targeting this load have the greatest impact on overall energy savings. The predicted source energy savings resulting from energy efficiency improvements ranges from 15% to 17% on a whole-house basis compared to Version 2.1 of the Building America Research Benchmark. When the PV systems are included, the predicted source energy savings increase to a range of 32% to 38%.

**Table C6. Annual Source Energy Savings for Ecovillage Unit 1**
**(Benchmark Version 2.1)**

| Unit 1<br>3 story, Bsmt Unit | Annual Source Energy | | | | Source Energy Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Percent of End-Use | | | Percent of Total | | |
| | BA Bench | Region | Builder | Proto | BA | Reg | Bldr | BA | Reg | Bldr |
| End-Use | (MBtu/yr) | (MBtu/yr) | (MBtu/yr) | (MBtu/yr) | Base | Base | Base | Base | Base | Base |
| Space Heating | 108 | 122 | 122 | 69 | **36%** | 44% | 44% | **16%** | 20% | 20% |
| Space Cooling | 14 | 21 | 21 | 11 | **23%** | 49% | 49% | **1%** | 4% | 4% |
| DHW | 25 | 26 | 26 | 24 | **5%** | 10% | 10% | **1%** | 1% | 1% |
| Lighting | 27 | 27 | 27 | 27 | **0%** | 0% | 0% | **0%** | 0% | 0% |
| Appliances + Plug | 65 | 65 | 65 | 64 | **1%** | 1% | 1% | **0%** | 0% | 0% |
| OA Ventilation | 2 | 2 | 2 | 9 | **-406%** | -406% | -406% | **-3%** | -3% | -3% |
| Total Usage | 240 | 263 | 263 | 204 | **15%** | 23% | 23% | **15%** | 23% | 23% |
| *Site Generation* | 0 | 0 | 0 | -44 | | | | 18% | 17% | 17% |
| *Net Energy Use* | 240 | 263 | 263 | 160 | 33% | 39% | 39% | 33% | 39% | 39% |

**Table C7. Annual Source Energy Savings for Ecovillage Unit 2**
**(Benchmark Version 2.1)**

| Unit 2<br>3 story, Bsmt | Annual Source Energy | | | | Source Energy Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Percent of End-Use | | | Percent of Total | | |
| | BA Bench | Region | Builder | Proto | BA | Reg | Bldr | BA | Reg | Bldr |
| End-Use | (MBtu/yr) | (MBtu/yr) | (MBtu/yr) | (MBtu/yr) | Base | Base | Base | Base | Base | Base |
| Space Heating | 71 | 70 | 70 | 33 | **53%** | 52% | 52% | **19%** | 18% | 18% |
| Space Cooling | 10 | 15 | 15 | 8 | **27%** | 49% | 49% | **1%** | 3% | 3% |
| DHW | 26 | 26 | 26 | 24 | **10%** | 10% | 10% | **1%** | 1% | 1% |
| Lighting | 28 | 28 | 28 | 28 | **0%** | 0% | 0% | **0%** | 0% | 0% |
| Appliances + Plug | 66 | 66 | 66 | 65 | **1%** | 1% | 1% | **0%** | 0% | 0% |
| OA Ventilation | 2 | 2 | 2 | 11 | **-511%** | -511% | -511% | **-5%** | -5% | -5% |
| Total Usage | 202 | 205 | 205 | 168 | **17%** | 18% | 18% | **17%** | 18% | 18% |
| *Site Generation* | 0 | 0 | 0 | -44 | | | | 22% | 21% | 21% |
| *Net Energy Use* | 202 | 205 | 205 | 125 | 38% | 39% | 39% | 38% | 39% | 39% |

**Table C8. Annual Source Energy Savings for Ecovillage Unit 3 (Benchmark Version 2.1)**

| Unit 3 3 story, Bsmt | Annual Source Energy | | | | Source Energy Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Percent of End-Use | | | Percent of Total | | |
| End-Use | BA Bench (MBtu/yr) | Region (MBtu/yr) | Builder (MBtu/yr) | Proto (MBtu/yr) | BA Base | Reg Base | Bldr Base | BA Base | Reg Base | Bldr Base |
| Space Heating | 72 | 71 | 71 | 34 | **53%** | 52% | 52% | **19%** | 18% | 18% |
| Space Cooling | 10 | 15 | 15 | 8 | **23%** | 49% | 49% | **1%** | 4% | 4% |
| DHW | 25 | 26 | 26 | 24 | **6%** | 10% | 10% | **1%** | 1% | 1% |
| Lighting | 27 | 27 | 27 | 27 | **0%** | 0% | 0% | **0%** | 0% | 0% |
| Appliances + Plug | 65 | 65 | 65 | 65 | **1%** | 1% | 1% | **0%** | 0% | 0% |
| OA Ventilation | 2 | 2 | 2 | 12 | **-525%** | -525% | -525% | **-5%** | -5% | -5% |
| Total Usage | 201 | 207 | 207 | 169 | **16%** | 18% | 18% | **16%** | 18% | 18% |
| *Site Generation* | 0 | 0 | 0 | -44 | | | | 22% | 21% | 21% |
| *Net Energy Use* | 201 | 207 | 207 | 125 | 38% | 40% | 40% | 38% | 40% | 40% |

**Table C9. Annual Source Energy Savings for Ecovillage Unit 4 (Benchmark Version 2.1)**

| Unit 4 2 story, slab | Annual Source Energy | | | | Source Energy Savings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Percent of End-Use | | | Percent of Total | | |
| End-Use | BA Bench (MBtu/yr) | Region (MBtu/yr) | Builder (MBtu/yr) | Proto (MBtu/yr) | BA Base | Reg Base | Bldr Base | BA Base | Reg Base | Bldr Base |
| Space Heating | 66 | 68 | 68 | 36 | **45%** | 46% | 46% | **18%** | 18% | 18% |
| Space Cooling | 6 | 10 | 10 | 5 | **18%** | 50% | 50% | **1%** | 3% | 3% |
| DHW | 22 | 22 | 22 | 21 | **6%** | 6% | 6% | **1%** | 1% | 1% |
| Lighting | 20 | 20 | 20 | 20 | **0%** | 0% | 0% | **0%** | 0% | 0% |
| Appliances + Plug | 49 | 49 | 49 | 48 | **1%** | 1% | 1% | **0%** | 0% | 0% |
| OA Ventilation | 1 | 1 | 1 | 9 | **-616%** | -616% | -616% | **-5%** | -4% | -4% |
| Total Usage | 165 | 171 | 171 | 140 | **15%** | 18% | 18% | **15%** | 18% | 18% |
| *Site Generation* | 0 | 0 | 0 | -27 | | | | 17% | 16% | 16% |
| *Net Energy Use* | 165 | 171 | 171 | 112 | 32% | 34% | 34% | 32% | 34% | 34% |

The energy savings contributions of individual efficiency measures in terms of source energy, site energy, and energy cost are summarized in Tables C10-C13. Cost information is presented using both a national average energy cost and a local energy cost based on utility information published by the Greater Cleveland Growth Association.[1] National average electricity cost is assumed to be \$0.10/kWh, and the national average gas cost is assumed to be \$0.50/therm. Gas prices are higher (\$0.65/therm), and electricity prices (\$0.07/kWh) are lower for the local utility when compared with national averages, resulting in larger cost savings for heating measures. "Source Energy Savings %" and "National

[1] See www.clevelandgrowth.com/pdf/FactSheets/Utilities.pdf.

Average Energy Cost Savings %" are calculated relative to the Building America Research Benchmark; "Energy Cost Savings %" and "Package Savings $/yr" are compared with the Builder Standard Practice house. Note again that the Building America Research Benchmark used for this analysis was Version 2.1, a hypothetical reference house that was significantly more energy efficient than either Regional or Builder Standard Practice. Section I of this report describes Version 3.1 of the Benchmark, which is consistent with the 1999 HERS/ENERGY STAR Reference Home and the 1993 Model Energy Code that has recently been developed by NREL.

The results suggest that the building envelope and windows are substantially better than those of the BA Benchmark, based on improvements to the envelope U-values, low window SHGC, reduced air infiltration, and the addition of slab insulation. Improvements to furnace, air conditioner, and hot water efficiency each contribute one or two percent of the total energy cost savings. Because the ducts are in conditioned space for the Benchmark according to the Version 2.1 guidelines, there is no energy savings credit for this measure. (This limitation was changed in Version 3.1) The ENERGY STAR dishwashers provide small but positive savings. Mechanical ventilation reduces energy savings by about 8%. The PV systems will reduce energy costs even more for all four units, and significantly, although actual savings depend on the price at which electricity is sold back to the grid.

## Table C10. Energy Savings from Specific Efficiency Measures for Ecovillage Unit 1 (Benchmark Version 2.1)

| Unit 1 - 3 story, Basement Unit | | | | | National Average | | Builder Standard (Local Costs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Site Energy | | Source Energy | | Energy Cost | | Energy Cost | | Measure | Package |
| Increment | (kWh) | (therms) | (MBtu) | Savings (%) | ($/yr) | Savings (%) | ($/yr) | Savings (%) | Value ($/yr) | Savings ($/yr) |
| Bldg America Benchmark | 9620 | 1206 | 240.5 | | $ 1,565 | | $ 1,457 | | | |
| Regional Std Practice | 10493 | 1326 | 263.5 | -10% | $ 1,712 | -9% | $ 1,596 | | | |
| Builder Std Practice | 10493 | 1326 | 263.5 | -10% | $ 1,712 | -9% | $ 1,596 | | | |
| Benchmark + Shell (wall/slab ins + inf) | 10071 | 916 | 211.0 | 12% | $ 1,465 | 6% | $ 1,300 | 19% | $ 296.0 | $ 296 |
| Benchmark ++ Windows | 9375 | 928 | 205.2 | 15% | $ 1,401 | 10% | $ 1,259 | 21% | $ 40.9 | $ 337 |
| Benchmark ++ Improved Ducts | 9375 | 928 | 205.2 | 15% | $ 1,401 | 10% | $ 1,259 | 21% | $ - | $ 337 |
| Benchmark ++ A/C SEER 12 and sizing | 9190 | 916 | 201.9 | 16% | $ 1,377 | 12% | $ 1,239 | 22% | $ 20.8 | $ 358 |
| Benchmark ++ High Efficiency Furnace | 9190 | 859 | 195.2 | 19% | $ 1,348 | 14% | $ 1,202 | 25% | $ 37.1 | $ 395 |
| Benchmark ++ DHW | 9190 | 838 | 192.8 | 20% | $ 1,338 | 15% | $ 1,188 | 26% | $ 13.7 | $ 408 |
| Benchmark ++ Ventilation | 9939 | 870 | 204.2 | 15% | $ 1,429 | 9% | $ 1,261 | 21% | $ (73.2) | $ 335 |
| Benchmark ++ Lighting, Appl. & Plug | 9887 | 872 | 203.9 | **15%** | $ 1,425 | **9%** | $ 1,259 | 21% | $ 2.3 | $ 338 |

**Table C11. Energy Savings from Specific Efficiency Measures for Ecovillage Unit 2**
(Benchmark Version 2.1)

| Unit 2 - 3 story, Basement | | | | | National Average | | Builder Standard (Local Costs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Site Energy | | Source Energy | | Energy Cost | | Energy Cost | | Measure | Package |
| Increment | (kWh) | (therms) | (MBtu) | Savings (%) | ($/yr) | Savings (%) | ($/yr) | Savings (%) | Value ($/yr) | Savings ($/yr) |
| Bldg America Benchmark | 9225 | 917 | 202.4 | | $ 1,381 | | $ 1,242 | | | |
| Regional Std Practice | 9687 | 903 | 205.5 | -2% | $ 1,420 | -3% | $ 1,265 | | | |
| Builder Std Practice | 9687 | 903 | 205.5 | -2% | $ 1,420 | -3% | $ 1,265 | | | |
| Benchmark + Shell (wall/slab ins + inf) | 9417 | 602 | 167.3 | 17% | $ 1,243 | 10% | $ 1,051 | 17% | $ 214.6 | $ 215 |
| Benchmark ++ Windows | 8900 | 613 | 163.3 | 19% | $ 1,197 | 13% | $ 1,021 | 19% | $ 29.0 | $ 244 |
| Benchmark ++ Improved Ducts | 8900 | 613 | 163.3 | 19% | $ 1,197 | 13% | $ 1,021 | 19% | $ - | $ 244 |
| Benchmark ++ A/C SEER 12 and sizing | 8778 | 605 | 161.1 | 20% | $ 1,180 | 15% | $ 1,008 | 20% | $ 13.7 | $ 257 |
| Benchmark ++ High Efficiency Furnace | 8778 | 578 | 157.9 | 22% | $ 1,167 | 16% | $ 990 | 22% | $ 17.6 | $ 275 |
| Benchmark ++ DHW | 8778 | 558 | 155.6 | 23% | $ 1,157 | 16% | $ 977 | 23% | $ 13.0 | $ 288 |
| Benchmark ++ Ventilation | 9731 | 588 | 168.9 | 17% | $ 1,267 | 8% | $ 1,063 | 16% | $ (86.2) | $ 202 |
| Benchmark ++ Lighting, Appl. & Plug | 9679 | 589 | 168.5 | **17%** | $ 1,262 | **9%** | $ 1,060 | 16% | $ 3.0 | $ 205 |

## Table C12. Energy Savings from Specific Efficiency Measures for Ecovillage Unit 3 (Benchmark Version 2.1)

| Unit 3 - 3 story, Basement | Site Energy | | Source Energy | | National Average Energy Cost | | Builder Standard (Local Costs) Energy Cost | | Measure | Package |
|---|---|---|---|---|---|---|---|---|---|---|
| Increment | (kWh) | (therms) | (MBtu) | Savings (%) | ($/yr) | Savings (%) | ($/yr) | Savings (%) | Value ($/yr) | savings $/yr |
| Bldg America Benchmark | 9098 | 915 | 200.9 | | $ 1,367 | | $ 1,232 | | | |
| Regional Std Practice | 9644 | 916 | 206.6 | -3% | $ 1,422 | -4% | $ 1,270 | | | |
| Builder Std Practice | 9644 | 916 | 206.6 | -3% | $ 1,422 | -4% | $ 1,270 | | | |
| Benchmark + Shell (wall/slab ins + inf) | 9351 | 607 | 167.2 | 17% | $ 1,239 | 9% | $ 1,049 | 17% | $ 221.4 | $ 221 |
| Benchmark ++ Windows | 8837 | 620 | 163.5 | 19% | $ 1,194 | 13% | $ 1,022 | 20% | $ 27.5 | $ 249 |
| Benchmark ++ Improved Ducts | 8837 | 620 | 163.5 | 19% | $ 1,194 | 13% | $ 1,022 | 20% | $ - | $ 249 |
| Benchmark ++ A/C SEER 12 and sizing | 8713 | 612 | 161.3 | 20% | $ 1,177 | 14% | $ 1,008 | 21% | $ 13.9 | $ 263 |
| Benchmark ++ High Efficiency Furnace | 8713 | 585 | 158.1 | 21% | $ 1,164 | 15% | $ 990 | 22% | $ 17.6 | $ 280 |
| Benchmark ++ DHW | 8713 | 564 | 155.6 | 23% | $ 1,153 | 16% | $ 977 | 23% | $ 13.7 | $ 294 |
| Benchmark ++ Ventilation | 9684 | 595 | 169.2 | 16% | $ 1,266 | 7% | $ 1,065 | 16% | $ (88.1) | $ 206 |
| Benchmark ++ Lighting, Appl. & Plug | 9634 | 596 | 168.8 | **16%** | $ 1,261 | **8%** | $ 1,062 | 16% | $ 2.8 | $ 209 |

## Table C13. Energy Savings from Specific Efficiency Measures for Ecovillage Unit 4 (Benchmark Version 2.1)

| Unit 4 - 2 story, slab | Site Energy | | Source Energy | | National Average Energy Cost | | Builder Standard (Local Costs) Energy Cost | | Measure | Package |
|---|---|---|---|---|---|---|---|---|---|---|
| Increment | (kWh) | (therms) | (MBtu) | Savings (%) | ($/yr) | Savings (%) | ($/yr) | Savings (%) | Value ($/yr) | Savings ($/yr) |
| Bldg America Benchmark | 6483 | 835 | 164.7 | | $ 1,066 | | $ 997 | | | |
| Regional Std Practice | 6928 | 846 | 170.5 | -4% | $ 1,116 | -5% | $ 1,035 | | | |
| Builder Std Practice | 6928 | 846 | 170.5 | -4% | $ 1,116 | -5% | $ 1,035 | | | |
| Benchmark + Shell (wall/slab ins + inf) | 6718 | 592 | 138.5 | 16% | $ 968 | 9% | $ 855 | 17% | $ 179.8 | $ 180 |
| Benchmark ++ Windows | 6335 | 613 | 137.0 | 17% | $ 940 | 12% | $ 842 | 19% | $ 13.2 | $ 193 |
| Benchmark ++ Improved Ducts | 6335 | 613 | 137.0 | 17% | $ 940 | 12% | $ 842 | 19% | $ - | $ 193 |
| Benchmark ++ A/C SEER 12 and sizing | 6259 | 604 | 135.2 | 18% | $ 928 | 13% | $ 831 | 20% | $ 11.2 | $ 204 |
| Benchmark ++ High Efficiency Furnace | 6259 | 573 | 131.5 | 20% | $ 912 | 14% | $ 811 | 22% | $ 20.2 | $ 224 |
| Benchmark ++ DHW | 6259 | 562 | 130.2 | 21% | $ 907 | 15% | $ 803 | 22% | $ 7.1 | $ 231 |
| Benchmark ++ Ventilation | 7000 | 581 | 140.1 | 15% | $ 991 | 7% | $ 868 | 16% | $ (64.2) | $ 167 |
| Benchmark ++ Lighting, Appl. & Plug | 6947 | 582 | 139.7 | **15%** | $ 986 | **8%** | $ 865 | 16% | $ 3.1 | $ 170 |

### *Solar Patriot Home, Purcellville, Virginia*

Imagine a home that produces as much energy as it consumes each year. That was the design goal of the "Solar Patriot" home constructed on the National Mall in Washington, D.C., as part of the American Solar Energy Society (ASES) annual conference in the spring of 2001 and later moved to its permanent location outside of Washington, DC in Purcellville, Virginia (see Figure 3C). The home was placed on an insulated full basement constructed from Superior Wall™ precast concrete panels. A 6-kW grid-connected, building-integrated photovoltaic system was added to a standing seam metal room on the home and a detached garage was built to the east of the home. Collectors for an active solar water heating system were placed on the roof of the garage along with a second photovoltaic array. The house is equipped with a ground-coupled heat pump system that supplies heating and cooling as well as backup water heating. A summary of the home specifications is given in Table C14.

Staff from NREL visited the home and installed a data collection system to measure the performance of the home. In addition to the measured performance, a detailed computer simulation of the house was created using DOE2.2 home energy simulation software. This simulation was also used in conjunction with a newly developed NREL research tool called Building Energy Optimization (BE OPT) that uses DOE2.2 and the TRaNsient SYstem Simulation (TRNSYS) Program to explore optimum combinations of energy efficiency measures to reach energy savings goals.

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**Figure C3. The Solar Patriot house at its permanent location in Purcellville, Virginia. (Photo by Ed Hancock)**

**Table C14. Summary of Specifications for the Hathaway House**

| | |
|---|---|
| Location | Purcellville, VA 22132 |
| Builder | Don Bradley, Solar Strategies Development Corporation |
| Conditioned floor area | 2880 square feet on two floors<br>Note that the basement and the third floor are both insulated and equipped with supply registers, but they were not being used as conditioned space during the time of this study. |
| Orientation | Front of home faces 10 degrees west of magnetic south (approximately true south) |
| Wall construction | 2x6 framing, 24” OC, R-19 fiberglass batt insulation with R-5 insulating sheathing. |
| Basement wall construction | Superior Wall™ precast concrete panels, 8’ ceiling<br>1 1/2” of concrete, 1” of rigid polystyrene foam (R- 5 ft hr ), R-19 fiberglass batts between 2.25” x 7” concrete ribs. |
| Window type | Seven-D Industries, Inc, Series 9000 Double glazed,<br>U = 0.35, SHGC = 0.37<br>(South windows have approximately 2’ overhangs.) |
| Space conditioning system | Direct Axxess® ground coupled heat pump with horizontal ground heat transfer piping buried 10’ under the front (south) yard of the home. Home is also equipped with a wood-burning fireplace. |
| Air distribution system | |
| Water heating system | Two Duke Solar CPC-2000 compound parabolic concentrator collectors (4.5 $m^2$ total collector area) connected to a single 80-gallon storage tank. Backup water heating is accomplished with the ground-coupled heat pump. |
| Appliances | Refrigerator, clothes washer, and dishwasher are Energy Star rated. Clothes dryer and oven are electric. Stove is propane. |
| Lighting | Compact florescent lighting is used throughout the home |
| Photovoltaic Systems | Grid connected with battery back-up (no maximum power point tracker)<br>Home array: Nominal 4 kW Unisolar amophorous<br>Garage array: Nominal 2 kW BP Solar monocrystalline<br>Inverters: Two Xantrex Model SW Series II inverters |

## Short-Term Tests

Throughout the study, both short-term and long-term tests were used to measure characteristics of the home that were not easy to determine from plans or specifications. Many of the results of these tests were later used to improve the accuracy of the computer simulations of the home and the confidence in the results from those simulations. Short-term tests also provide a quality check on some aspects of the home (such as air tightness and duct leakage) and assure that energy features (the PV system for example) are operating properly. The results of the short-term tests performed on the Hathaway house are summarized below. Further details about the field test procedures and results are available in the complete NREL test report (Norton et al. 2004).

- Air exchange characteristics
  - Shell leakage measurement (Table C15)
  - Duct leakage measurement (Table C15 and Figure C4)
  - Register flow measurement (Table C16)
  - Air handler flow measurement (Table C17)
- Heat pump coefficient of performance for space conditioning, and water heating (Figures C5, C6, and C7)
- Solar water heating performance (Table C18)
- Other short-term measurements and observations
  - Tank UA
  - IR photography
  - Fireplace operation

**Table C15. Results of Blower Door and Duct Blaster Testing**

| | With duct registers taped CLOSED | With duct registers OPEN | Difference |
|---|---|---|---|
| **Blower Door Results** | | | |
| CFM at 50 Pa | 2241 | 2326 | 85 |
| ACH at 50 Pa | 3.73 | 3.88 | 0.15 |
| ELA ($in^2$ @ 4Pa) | 132.5 | 146.8 | 14.3 |
| Correlation Coefficient ($r^2$) | 0.99935 | 0.99639 | |
| Flow Coefficient (C) | 197.7 | 227.0 | |
| Exponent (n) | 0.621 | 0.595 | |
| **Average Annual Infiltration*** | | | |
| Average annual ACH | 0.17 to 0.19 | 0.18 to 0.20 | |
| Climate Factor (C) | 20 to 23 | 20 to 23 | |
| Height Factor (H) | 0.8 | 0.8 | |
| Wind Shielding Correction Factor (S) | 1.2 | 1.2 | |
| Leakiness Correction Factor (L) | 1.0 | 1.0 | |
| **Duct Blaster Results @ 25 Pa** | | | |
| Total (cfm) | 555 | | |
| Total to outside** (cfm) | 219 | | |

* Estimated using the LBL infiltration model and the assumed factors shown
** Measured with house pressurized to 25 Pa with the blower door

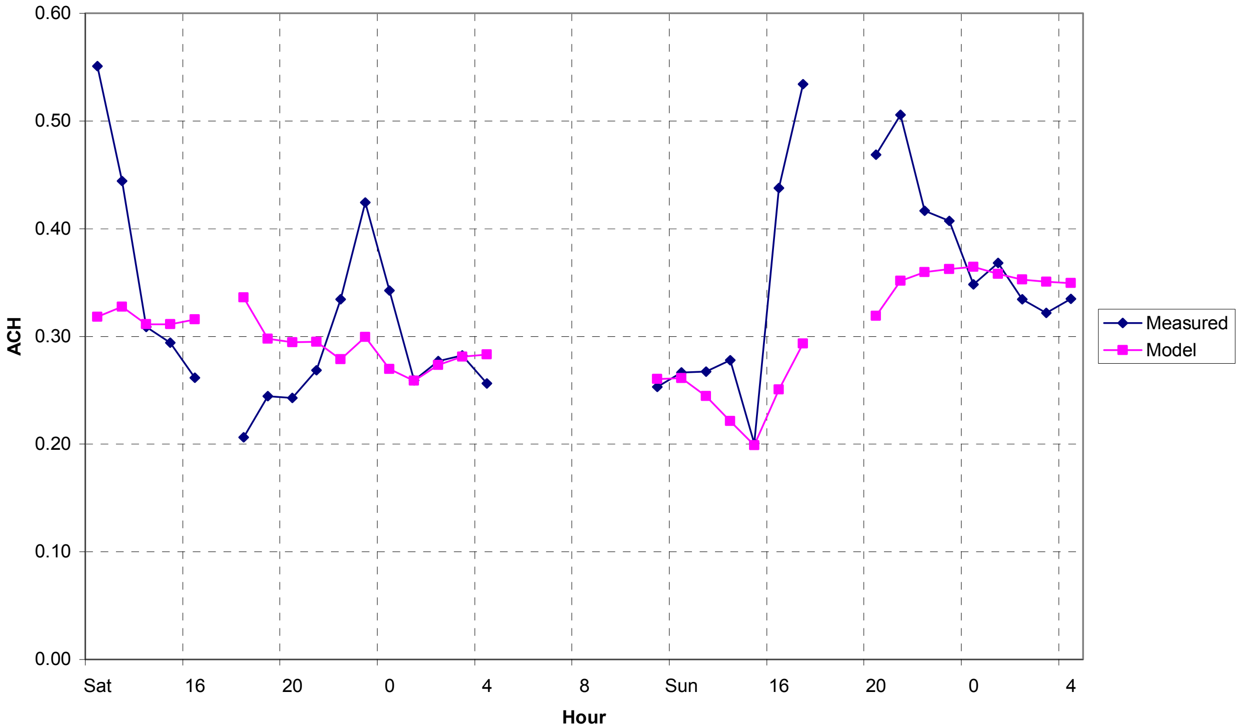


**Figure C4. Comparison of Tracer Gas ACH Measurements to ACH Modeled Using Blower Door Effective Leakage Area (ELA) Measurements.**

**Table C16. Register and Exhaust Fan Flow Results Measured with a Flow Hood**

| Room (Register) | Measured Air Flow Rates (cfm) | | |
|---|---|---|---|
| | Without filter | With dirty filter | With clean filter |
| **Supply Registers** | | | |
| Dining room (1) | 94 | 76 | 86 |
| Dining room (2) | 87 | 67 | 88 |
| Entry | 46 | 37 | 46 |
| Living room (1) | 89 | 66 | 83 |
| Living room (2) | 92 | 76 | 90 |
| Family room (1) | *80* | *60* | *70* |
| Family room (1) | 28 | 21 | 22 |
| Breakfast room ("Nook") | 58 | 48 | 54 |
| Kitchen (1) | *30* | *20* | *25* |
| Kitchen (2) | 70 | 51 | 63 |
| **First floor total** | **674** | **522** | **627** |
| Master Bedroom (1) | 71 | | |
| Master Bedroom (2) | 79 | | |
| Master closet | 38 | | |
| Master bathroom | 48 | | |
| Hall bathroom | 46 | | |
| NE bedroom | 76 | | |
| SE bedroom (1) | 73 | | |
| SE bedroom (2) | 73 | | |
| Office ("Sitting room") | 71 | | |
| **Second floor total** | **575** | | |
| Basement (1) | 80 | | |
| Basement (2) | 80 | | |
| Attic (1) - closed | 0 | | |
| Attic (2) - closed | 0 | | |
| **Total for all supply registers** | **1409** | | |
| **Return Registers** | | | |
| 1st floor entry | > 500 | | |
| 2nd floor entry | > 500 | | |
| Office ("Sitting room") | 238 | | |
| Master Bedroom | 65 | | |
| **Exhaust Fans** | | | |
| 1st floor bathroom | 13 | | |
| 2nd floor hall bathroom | 46 | | |
| Master bathroom | 33 | | |

**Table C17. Flow Plate Measurements of the Total Air Flow Rate at the Air Handler**

| Filter Condition | Return reference pressure (Pa) | Air flow rate (cfm) |
|---|---|---|
| Dirty filter | 34 | 1434 |
| No filter | 53 | 1795 |
| Best filter | 41 | 1580 |
| New filter | 47 | 1672 |

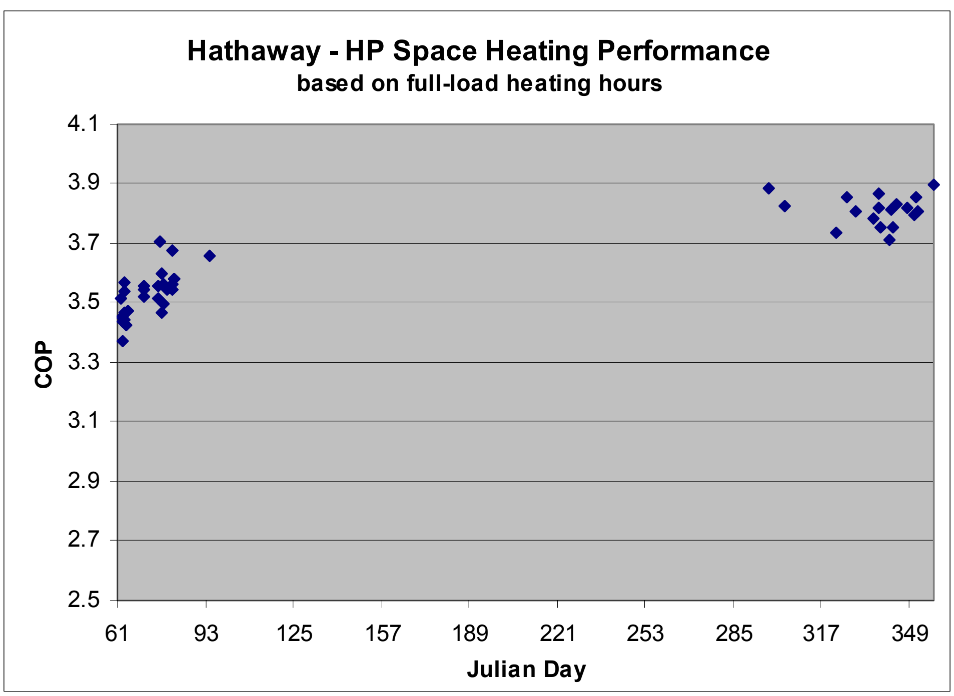


**Figure C5. Space Heating COP determined from monitored data (fan power not included)**

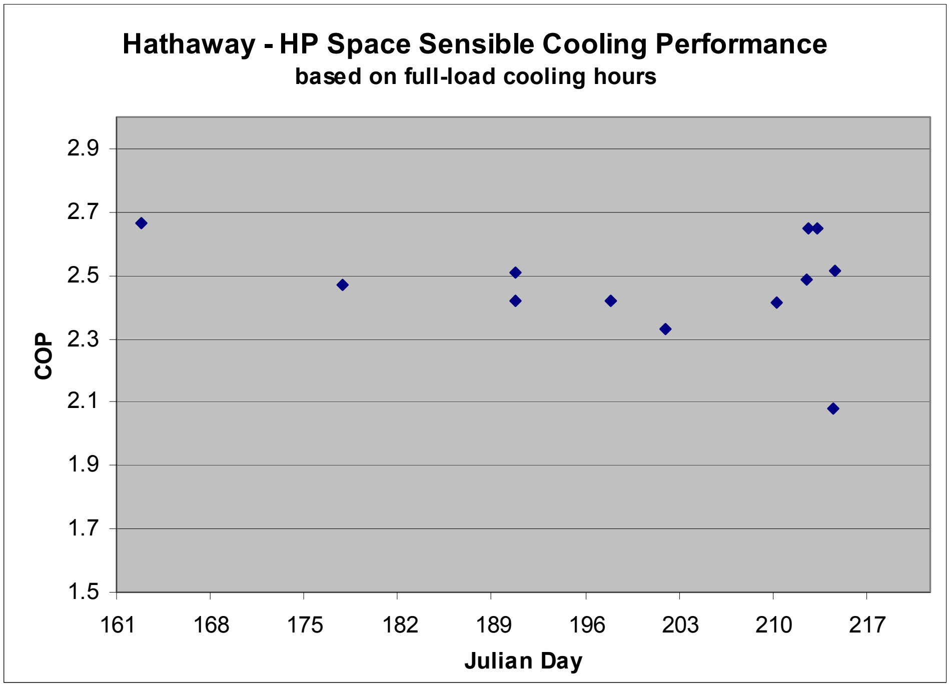


**Figure C6. Space cooling COP determined from monitored data (fan power not included)**

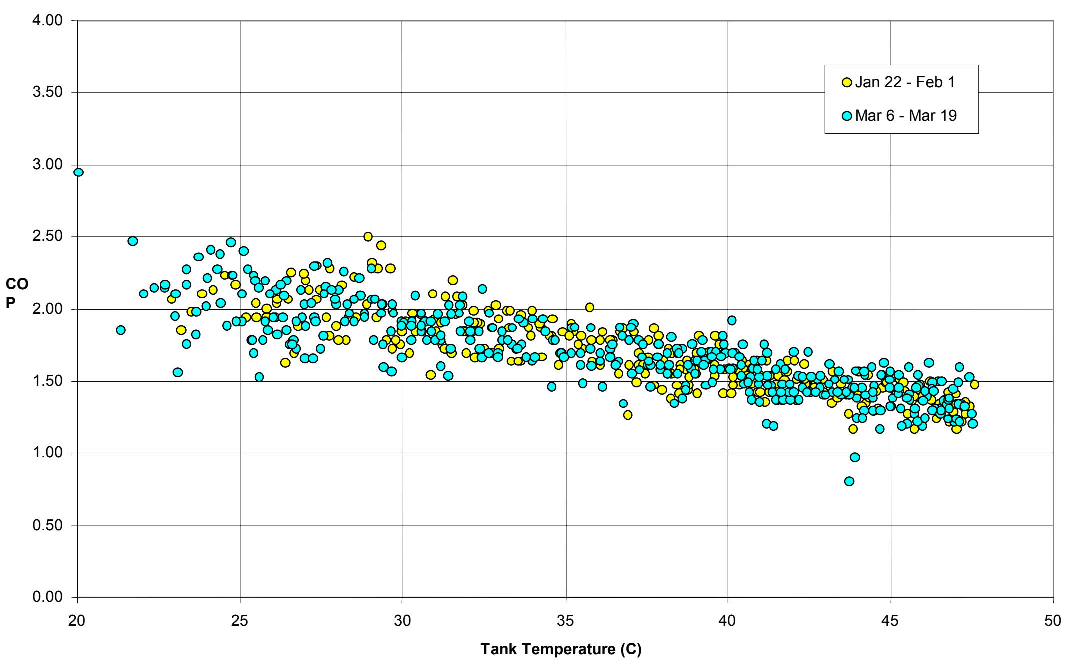


**Figure C7. COP of heat pump for water heating (total of 660 1-minute measurements)**

### Table C18. Energy Balance for DHW System

| Component | Value | | Source/Description |
|---|---|---|---|
| Hot Water Load: | | | |
| load of hot water used: | 8,797,329 | BTU | based on monitored flow and deltaT data |
| load due to heat loss from tank: | 1,153,305 | BTU | based on monitored temperature data |
| total heating load: | 9,950,634 | BTU | sum of above components |
| HP energy used to heat water: | 576 | kWh | based on monitored power data |
| HP energy delivered to water: | 3,051,232 | BTU | based on an average $HP_{dhw}$ COP of 1.55 |
| Solar energy delivered to water: | 6,899,402 | BTU | total load minus HP energy delivered |
| Solar Energy Fraction: | **69%** | | fraction of DHW heating load delivered by solar |
| Solar pump energy used: | 256 | kWh | from monitored data |
| | | | |
| *COP of delivered solar energy* | *7.9* | | (solar energy delivered)/(pump energy used) |
| *COP of total system* | ***3.5*** | | (DHW energy delivered)/(energy used) |

## Long-Term Monitoring

The short-term tests at the Hathaway house reveal much about the shell of the home and the operation of some of its subsystems. Measuring the long-term performance of the whole house and its subsystems requires the installation of a system that continuously monitors the changing conditions of the home such as energy use, PV energy production, temperatures, hot water use, etc. In September 2001 we installed sensors inside and outside the Hathaway house to monitor its performance.

The energy consumed in a home is greatly affected by climate, thermostat settings, number of occupants, energy use pattern of the occupants, the home design, and the equipment and appliance selection. The precise energy use of a home for a specific year and specific occupants cannot be predicted. Instead, predictions are based on typical weather data and typical occupant behavior. Monitored energy use data reflect the influence of all of the factors listed above. Depending on the level of detail of the monitoring, some of these influences can be disaggregated in order to make the date useful for refining the inputs to the building simulation model.

In designing the data collection system we focused on understanding the performance of the PV system, the solar water heating system, the heat pump, and the main home appliances. The home is equipped with sensors for the 39 measurements listed in Table C19.

## Table C19. Data Monitored at the Hathaway House

Solar radiation ($W/m^2$)
- In the plane of the collectors at the array on the house roof
- Vertical south facing

Energy (kWh)
- Energy entering the home from the grid
- Energy exiting the home to the grid
- Heat pump energy consumption
- Clothes dryer energy consumption
- Clothes washer energy consumption
- Air handler fan energy consumption
- Kitchen oven energy consumption (stove is propane)

Temperatures ($^oC$)
- Outside air temperature (from T and RH sensor)
- Outside air temperature (thermocouple)
- House PV array temperature
- Garage PV array temperature
- Attic air temperature
- 2$^{nd}$ floor air temperature
- 1$^{st}$ floor air temperature
- Basement air temperature
- Supply air temperature
- Cold water temperature
- Hot water temperature
- Temperature after the mixing valve
- Temperature of glycol fluid to the solar water collector
- Temperature of glycol fluid from the solar water collector
- Temperature of water from tank to heat pump
- Temperature of water from heat pump to tank

DC electrical measurements
- Voltage of west house PV array (V)
- DC current from west house PV array (A)
- DC power from west house PV array (W)
- DC current from east house PV array (A)
- DC power from east house PV array (W)
- DC current from garage PV array (A)
- DC power from garage PV array (W)
- Battery voltage (V)
- Current to or from battery bank (A)
- Current to well pump (A)

Other measurements
- 1$^{st}$ floor relative humidity
- Outside relative humidity
- Hot water consumption (liters)
- Solar water heater pump run time (minutes each hour)

The monthly energy consumption by end use is shown in Figure C8. The substantial "other" category is relatively constant from month to month. Notice that the water heating energy (HP, DHW) is several times larger in the first three months of data collecting than it was for the rest of the data collection period. During those first three months, the water heating mode of ground coupled heat pump was switched on and off manually. It was switched on early in the morning and left on until all morning showering was completed. By the time it was switched back off, it had already heated the water in the single 80-gallon storage tank. Because the storage tank water was warm at the beginning of the day, the solar collectors were effectively defeated. This problem was alleviated by using a timer to control the heat pump water heating mode. By adjusting the run time of the heat pump in water heating mode, the family was able to assure sufficient hot water supply for morning showering without leaving the storage tank full heated water at the beginning of the day. The change reduced water heating energy consumption dramatically.

Figure C9 shows the AC electrical energy produced by the PV system. The PV system is oriented due solar south and tilted at about 49 degrees – near optimum for year-round energy production. The system is not equipped with a maximum power point tracker. With the exception of May 2002 (when there was a short interruption in service from one of the inverters) the PV system appears to be operating as expected. Since there are fewer sunlight hours in the winter than the summer, the PV production is naturally lower in the winter. It is interesting to note how much the monthly PV power can vary from year to year due to variations in the weather. For example, the PV system output in October 2002 was little more than half of the output in October 2001. In October 2002 much lower solar radiation levels were recorded in the plane of the collectors than in October 2001. (It was a cloudy October.) Without solar radiation measurements, low PV output like that seen in October 2002 could be misinterpreted as a problem with the system.

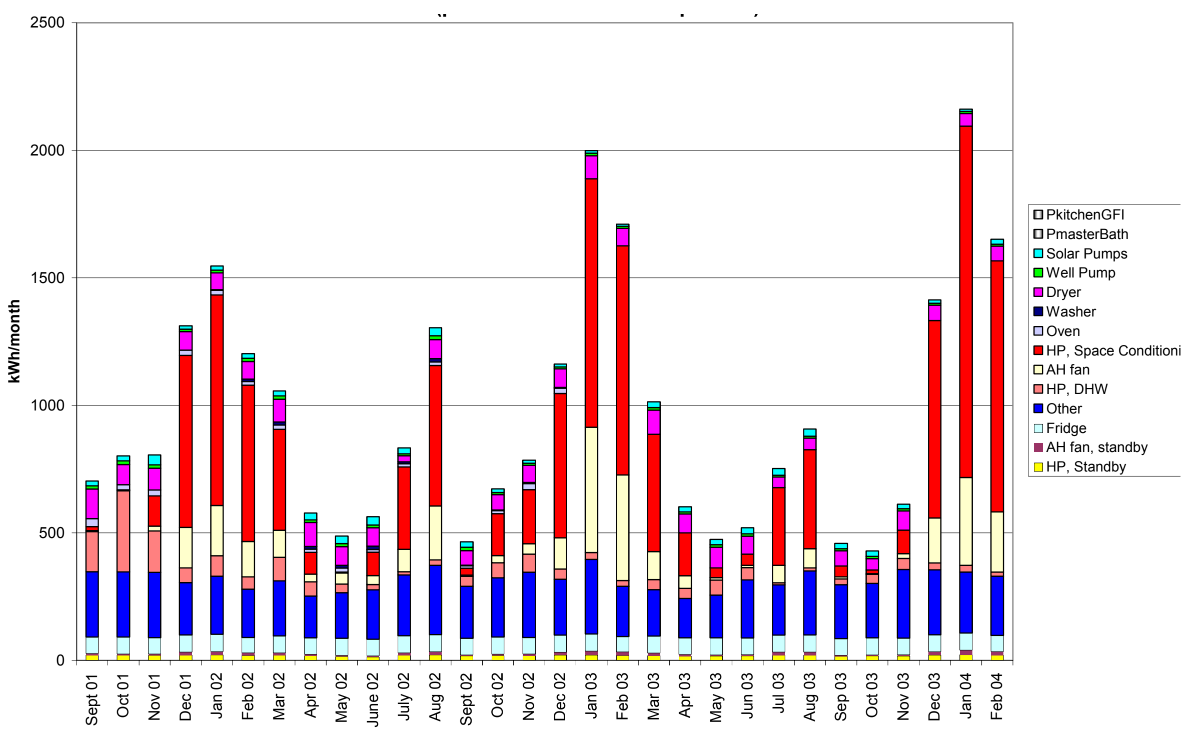


**Figure C8. Monthly energy consumption by end use**

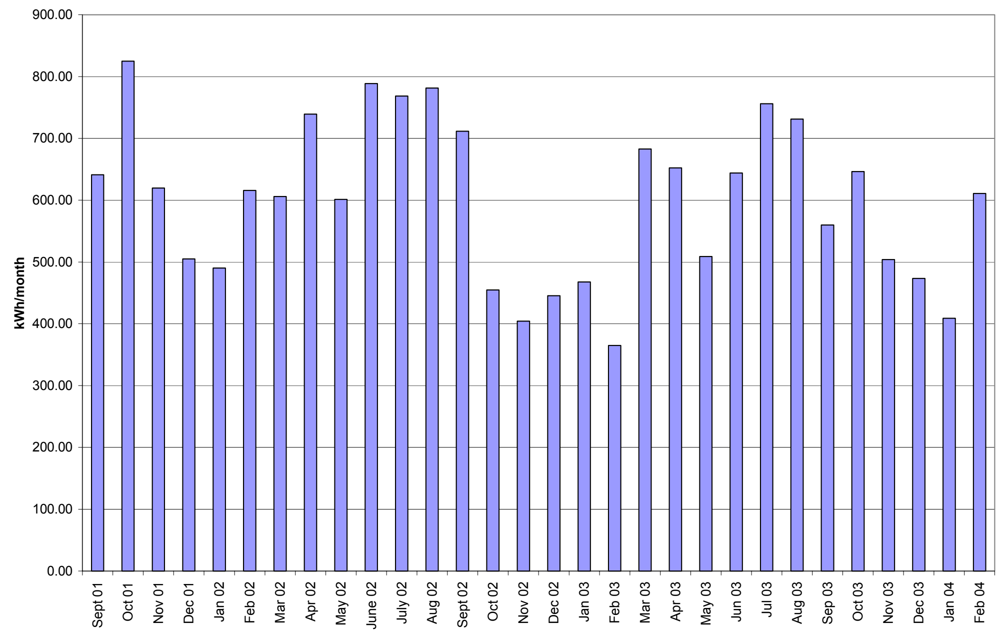


**Figure C9. Monthly electrical energy (AC) produced by the photovoltaic system**

A series of occupant behavior profiles are shown in Figures C10-13. These profiles can be used to compare simulated results to measured data using the same operating conditions.

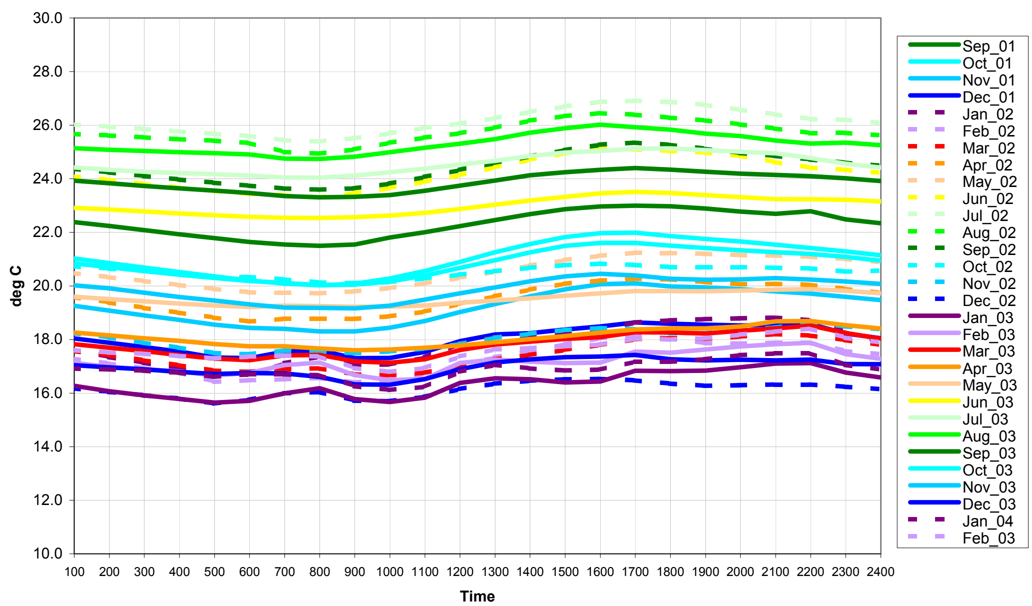


**Figure C10. First-floor indoor temperature average hourly profile**

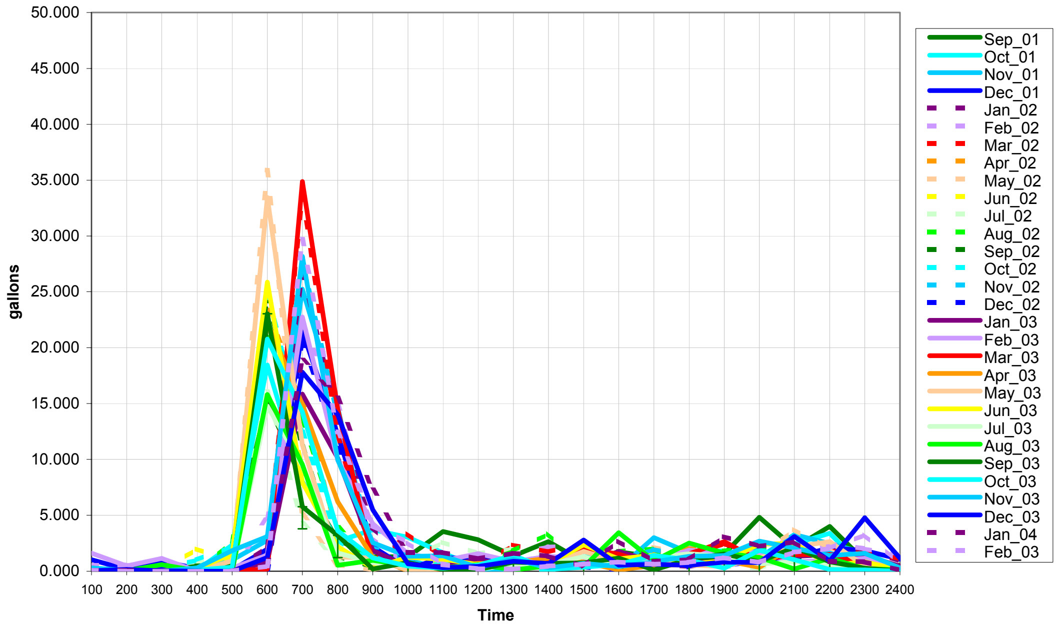


**Figure C11. Hot water draw average hourly profile**

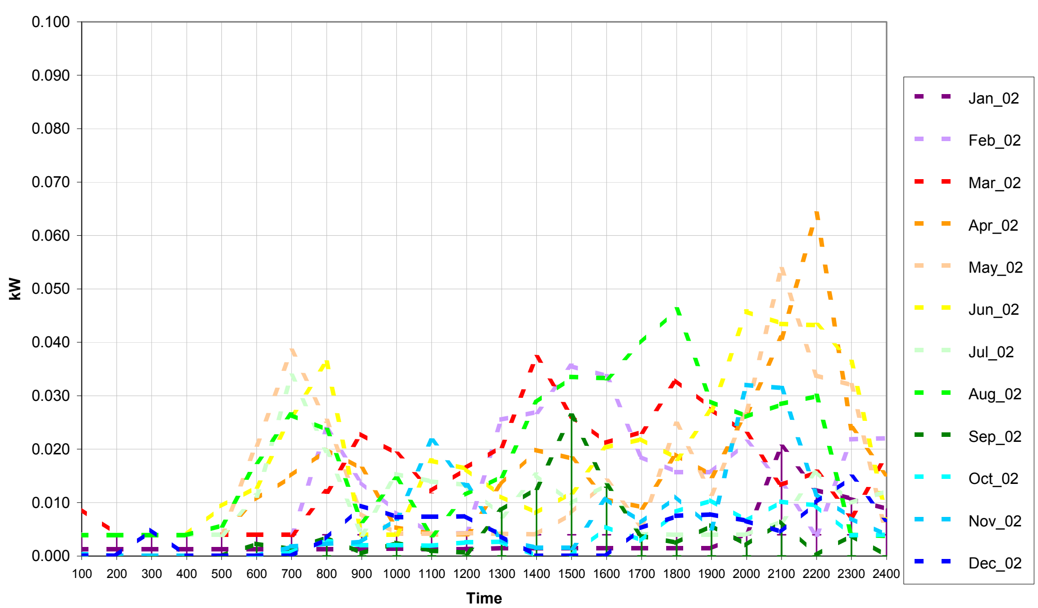


**Figure C12. Clothes washer power use average hourly profile**

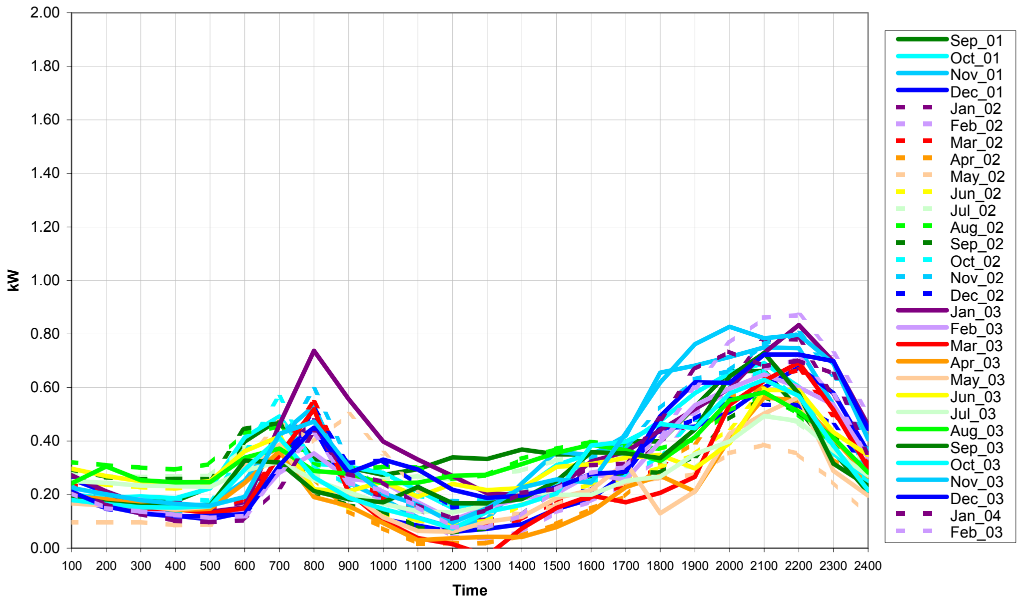


**Figure C13. "Other" power use average hourly profile**

## Simulations

We modeled the Hathaway house energy performance using DOE-2 simulation software. DOE-2 is a widely used and accepted building energy analysis program that was developed by the U.S. Department of Energy's Lawrence Berkeley National Laboratory. DOE-2 has been subjected to the BESTEST software validation procedure. Images of the DOE2 model produced using eQUEST are shown in Figure C14.

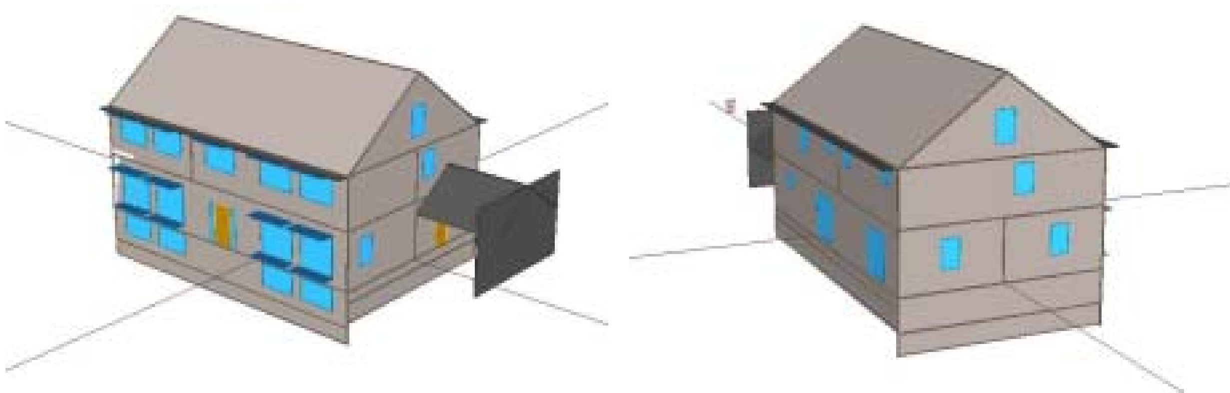

**Figure C14. DOE2 model of the Hathaway House. The dark area simulates the shading of the home by the garage and breezeway**

The residential system models available in DOE2 do not include a direct-expansion, ground-coupled heat pump, solar water heating system, or photovoltaic systems as is found in the Hathaway house. The long-term monitored data, therefore, was essential in characterizing the performance of these systems.

The COP of the heat pump in heating and cooling modes calculated based on field test measurements were used to characterize the performance of the heat pump in the DOE2 model. While this performance level of the heat pump is a function of the weather experienced during the monitored period, the overall calculated system performance was used in place of a component-based simulation.

For water heating, a simplified approach based on the overall COP of the solar/heat pump system was implemented in the DOE2 model. The actual measured energy contribution of the photovoltaic system for calendar year 2002 was incorporated into the whole house energy analysis independently of the DOE2 analysis. Note that the DOE2 analysis was driven using TMY2 weather data, but the photovoltaic performance is based on the actual 2002 weather.

The Building America prototype simulation model is based on the description of the house "as-built" along with standardized behavior and controls defined in this report. The model of the physical building attempts to be as true as possible to what was actually built and installed in the prototype house. The operation of the building, however, and the energy consumption associated with it, must rely on established assumptions regarding average occupant behavior and typical hourly weather data.

There is no reason to expect that the occupants of any particular house will behave according to the operating conditions established in this report. While the mean behavior of the occupants is expected to be close to the behavior assumed for the base cases, individual behavior may vary to a large degree. Comparing the monitored data (largely influenced by actual behavior) and simulation results (largely driven by assumed behavior) is therefore, mainly a comparison of how similar the actual occupants are to the "assumed" occupants.

Figure C15 below shows a monthly comparison of total electricity used at the Hathaway house in the year 2002 (not accounting for PV generation) and the total electric use of the Hathaway prototype simulation model. The model predicted that the house would use 62% more electricity than it actually used for the annual period. The model also predicted that the HVAC system would use approximately 23% more energy than was realized for the year, and predicted that non-HVAC electricity use (lights, appliances, plug loads) would be nearly 65% more than was observed. Overall, the simulation predicted 44% higher whole-house annual energy consumption than was measured in the home in 2002.

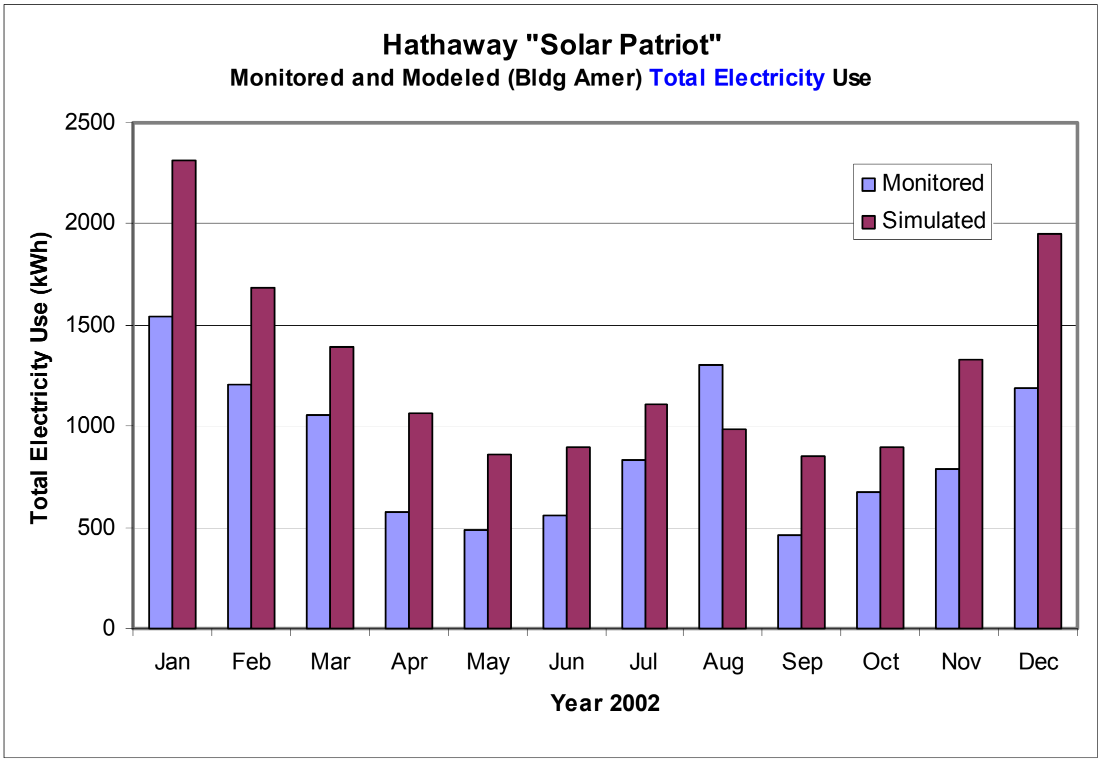


**Figure C15. Monitored data vs. simulation results for total electricity use using Building America operating conditions and TMY2 data**

Weather data used for the Hathaway site (TMY2 weather data for Sterling, Virginia) was significantly different than actual weather during February and October of the monitored period. Based on the monitored data, the "behavior" of the occupants and the operation of the house was adjusted in the simulation in the following ways:

- Internal Gains: plug loads were reduced by about 40% to match the monitored data.
- HVAC Control: thermostat schedules were adjusted monthly to match observed actual setpoints (which were significantly lower in the heating season than assumed). Also, the thermostat schedule accounts for two week-long vacation periods.
- DHW Load: a slight adjustment was made so that the simulated hot water volume used matched the observed volume.
- Infiltration: The average infiltration was adjusted based on measured data.

When the actual behavior of the Hathaway house occupants and the measured 2002 weather was used to drive the simulation model, the predicted and observed energy use was much closer. The annual total energy use was less than 5% different between the model results and the monitored data (See Figure C16).

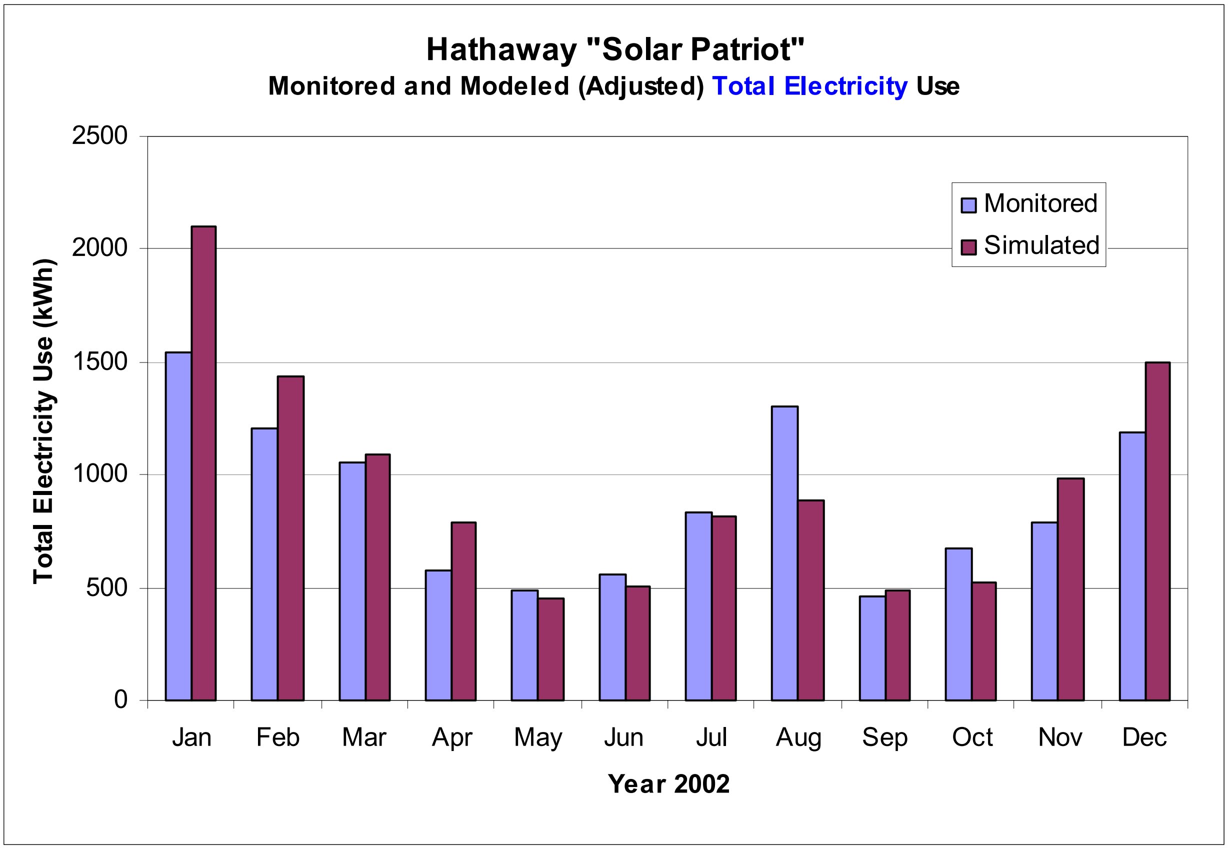


**Figure C16. Monitored data vs. the adjusted model results for whole-house electricity use**

The simulation continues to overpredict the energy consumption in some months – especially the winter months. Some of this difference in energy use is explained by the occupants' use of wood to heat the house in the winter months. But overall, it appears the simulation of the Hathaway prototype building is quite accurate.

The modeled energy performance of the Hathaway house was compared to three base case houses with the same basic architectural features and floor plans. One base case for comparison is the Regional Standard Practice home, representing a standard new home in the same area as the Hathaway home according to guidelines in this report and the knowledge and judgment of the authors. Another is Builder Standard Practice, which in this case is very similar to Regional Standard Practice with a few minor differences. The other base case is the Building America Benchmark Version 3.1, as defined in this report. The basic characteristics of these base-case homes are described below:

**Regional Standard Practice:**
(assumes natural gas is not available on site)

| | |
|---|---|
| Building Shell: | 2 x 4 frame walls - R11 fiberglass insulation and wood sheathing<br>R30 ceiling insulation<br>R7 basement wall insulation<br>double-pane clear windows with aluminum frames<br>Standard air-infiltration (0.51 ACH average) |
| HVAC: | 10 SEER 5-ton air-conditioner<br>6.8 HSPF heat pump with electric backup |
| DHW: | Electric DHW, 40 gallons, EF=0.88 |

**Building America Benchmark 3.1:**
(assumes natural gas is not available on site)

| | |
|---|---|
| Building Shell: | 2 x 4 frame walls – overall R factor = 12.2<br>R33.3 ceiling insulation<br>R17 basement wall insulation<br>double-pane Low E windows with U = 0.40, SHGC = 0.40<br>Standard air-infiltration (0.51 ACH average) |
| HVAC: | 10 SEER 5-ton air-conditioner<br>6.8 HSPF heat pump with electric backup |
| DHW: | Electric DHW, 40 gallons, EF=0.88 |

The standard output tables for the Hathaway house are shown in Tables C20 through C22.

### Table C20. Summary of End-Use Site Energy

| | Annual Site Energy | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BA Base | | Region Standard | | Builder Standard | | BA Prototype | |
| End-Use | kWh | therms | kWh | therms | kWh | therms | kWh | therms |
| Space Heating | 6891 | 0 | 7753 | 0 | 11704 | 0 | 5030 | 0 |
| Space Cooling | 3560 | 0 | 2044 | 0 | 2273 | 0 | 1092 | 0 |
| DHW | 3523 | 0 | 3526 | 0 | 3537 | 0 | 987 | 0 |
| Lighting | 3110 | | 3110 | | 3110 | | 1204 | |
| Appliances + Plug | 7227 | 0 | 7227 | 0 | 7227 | 0 | 7017 | 0 |
| OA Ventilation | 0 | | 0 | | 0 | | 0 | |
| Total Usage | 24311 | 0 | 23660 | 0 | 27851 | 0 | 15330 | 0 |
| *Site Generation* | 0 | 0 | 0 | 0 | 0 | 0 | 7402 | 0 |
| *Net Energy Use* | 24311 | 0 | 23660 | 0 | 27851 | 0 | 7929 | 0 |

## Table C21. Summary of End-Use Source Energy and Savings

| | Annual Source Energy | | | | Source Energy Savings: Percent of End-Use | | | Source Energy Savings: Percent of Total | | |
|---|---|---|---|---|---|---|---|---|---|---|
| End-Use | Base MBTU/yr | Region MBTU/yr | Builder MBTU/yr | Proto MBTU/yr | BA Base | Reg Base | Bldr Base | BA Base | Reg Base | Bldr Base |
| Space Heating | 71 | 79 | 120 | 52 | **27%** | 35% | 57% | **8%** | 12% | 24% |
| Space Cooling | 36 | 21 | 23 | 11 | **69%** | 47% | 52% | **10%** | 4% | 4% |
| DHW | 36 | 36 | 36 | 10 | **72%** | 72% | 72% | **10%** | 11% | 9% |
| Lighting | 32 | 32 | 32 | 12 | **61%** | 61% | 61% | **8%** | 8% | 7% |
| Appliances + Plug | 74 | 74 | 74 | 72 | **3%** | 3% | 3% | **1%** | 1% | 1% |
| OA Ventilation | 0 | 0 | 0 | 0 | **0%** | 0% | 0% | **0%** | 0% | 0% |
| Total Usage | 249 | 242 | 285 | 157 | **37%** | 35% | 45% | **37%** | 35% | 45% |
| *Site Generation* | 0 | 0 | 0 | -76 | | | | 30% | 31% | 27% |
| *Net Energy Use* | 249 | 242 | 285 | 81 | 67% | 66% | 72% | 67% | 66% | 72% |

Notes:
The "Percent of End-Use" columns show how effective the prototype building is at reducing energy use in each end-use category.
The "Percent of Total" columns show how the energy reductions in each end-use category contribute to the overall savings.

## Table C22. Energy Savings of Energy Efficiency Measures

| | Site Energy | | Source Energy | | National Average Energy Cost | | Builder Standard (Local Costs) Energy Cost | | Measure | Package |
|---|---|---|---|---|---|---|---|---|---|---|
| Increment | kWh | therms | MBTU | Savings % | $/yr | Savings % | $/yr | Savings % | value ($/yr) | savings $/yr |
| Base (Bldg America) | 24311 | 0 | 249.1 | | $ 2,431 | | $ 2,395 | | | |
| Base (Regional Std Practice) | 23660 | 0 | 242.4 | 3% | $ 2,366 | 3% | $ 3,053 | | | |
| Base (Builder Std Practice) | 27851 | 0 | 285.4 | -15% | $ 2,785 | -15% | $ 2,743 | | | |
| Base + improved walls | 25642 | 0 | 262.7 | -5% | $ 2,564 | -5% | $ 2,526 | 8% | $ 217.6 | $ 218 |
| Base ++ Low-E Windows | 23140 | 0 | 237.1 | 5% | $ 2,314 | 5% | $ 2,279 | 17% | $ 246.4 | $ 464 |
| Base ++ Smaller A/C (5 -> 4 tons) | 22806 | 0 | 233.7 | 6% | $ 2,281 | 6% | $ 2,246 | 18% | $ 32.9 | $ 497 |
| Base ++ Inc. Bsmt Wall Insulation | 22499 | 0 | 230.5 | 7% | $ 2,250 | 7% | $ 2,216 | 19% | $ 30.2 | $ 527 |
| Base ++ Ground Source HP (+DHW) | 18380 | 0 | 188.3 | 24% | $ 1,838 | 24% | $ 1,810 | 34% | $ 405.7 | $ 933 |
| Base ++ Solar DHW | 17202 | 0 | 176.3 | 29% | $ 1,720 | 29% | $ 1,694 | 38% | $ 116.0 | $ 1,049 |
| Base ++ Lighting, Appl. & Plug | 15330 | 0 | 157.1 | **37%** | $ 1,533 | 37% | $ 1,510 | 45% | $ 184.4 | $ 1,233 |
| *Site Generation* | | | | | | | | | | |
| Base ++ PV | 7928 | 0 | 81.2 | 67% | $ 793 | | $ 781 | 72% | $ 729.0 | $ 1,962 |

Notes:
"Source Energy Savings %" and "National Average Energy Cost Savings %" compared to the Building America base case, whereas the "Energy Cost Savings %" and the "Package savings $/yr" are compared to the Builder Standard Practice case.

National Average Electric Cost: 0.10 $/kWh
National Average Gas Cost: 0.50 $/therm

The Hathaway house is expected to reduce total energy use by 67% compared to the Building America Benchmark. Lighting and DHW energy use is reduced by a large fraction, and is close to the limits of practical energy-saving technologies. The space conditioning energy use could be reduced further by eliminating some of the heating and cooling loads, as well as by applying even more efficient technologies. The appliance and plug load category is nearly untouched by the energy reduction measures, and accounts for nearly 46% of the total energy use of the prototype building. The application of building shell and other measures currently not cost effective, including super-insulated walls, electrochromic glazing and highly effective heat recovery ventilation, can eliminate much of the remaining space conditioning load. Figure C17 shows the change in energy use with each added technology. The column labeled “Ltg/Appliance” is the Hathaway prototype model. The last four columns apply additional technologies in an attempt to reduce the heating and cooling loads as much as practical (and beyond). In the end, the heating, cooling and DHW energy use is reduced to little more than 2000 kWh per year, nearly a 90% reduction. This analysis points out that even with highly effective energy savings technologies (pushed beyond levels currently practical), whole house energy use cannot be reduced much past 50% without reducing the energy use of appliances and plug loads.

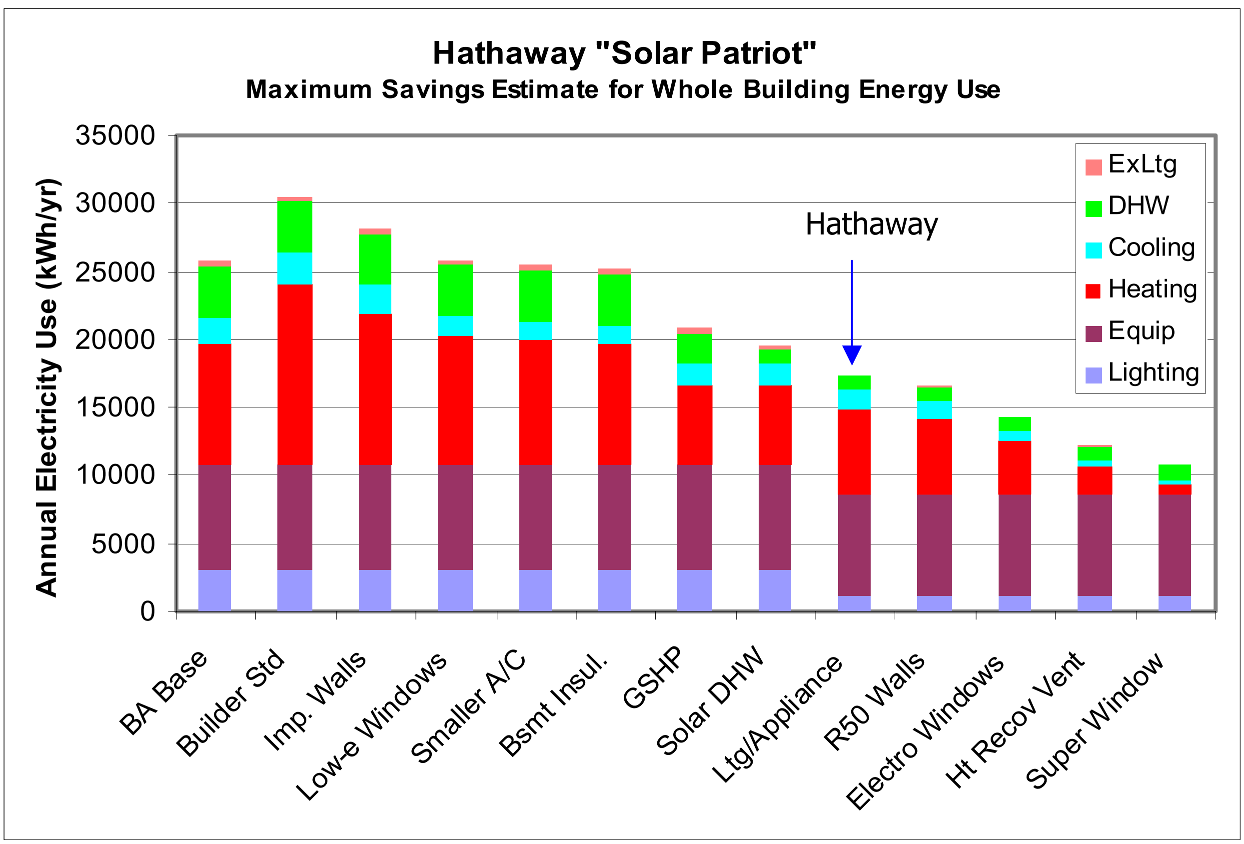


**Figure C17. Energy use by end-use category, beyond the Hathaway Prototype**

# Appendix D.  EnergyGauge Version 2.3 Application Notes

The following notes provide guidance for using the input screens in EnergyGauge USA Version 2.3 to simulate the Building America Research Benchmark using the operating conditions documented in Section I of this report.  EnergyGauge uses the DOE-2.1E engine, but it includes a user interface specifically designed for simulating residential buildings.  As with any model, there is a limitation to the amount of flexibility that EnergyGauge offers to users.  It is therefore necessary to approximate some of the features of the Benchmark using the inputs that are available.  It is expected that many of these approximations will not be necessary with future versions of EnergyGauge.  The purpose of these application notes is to provide some alternate definitions and approximations for the Benchmark to improve consistency among teams that use EnergyGauge to calculate energy savings for Building America prototype houses.  The Building America Web site features two example input files developed by the Building America teams using the EnergyGauge software, Version 2.3.

## General

- Use the “Detailed” entry mode and “New (From Plans)” building status.

## Building Envelope

- For a Benchmark with a directly conditioned basement, the conditioned basement box under the “Floors” tab should be checked.   For indirectly conditioned basements or unconditioned basements, the box should not be checked.  Do not include basement area in the conditioned area specified under the “Project” tab.
- Iterate the R-values for walls, floors, and ceiling until the desired U-value is achieved.  For walls, use “Frame-Wood” and either R-13 or R-19 cavity insulation, and adjust the insulating sheathing R-value until the Benchmark U-value is met.
- Use single glazing if the Benchmark window U-value is greater than 0.8.
- Assign all window areas to the above-grade floors.  Basement windows cannot be modeled in EnergyGauge 2.3.
- Select the “Drapes/Blinds” option under the “Interior Shading” menu.  The EnergyGauge interior shading coefficients of 0.9 and 0.7 for drapes and blinds are acceptably close to the Benchmark coefficients of 0.85 and 0.7.
- Specify floor slabs with 80% carpet fraction and 20% tile fraction.
- The following elements of the Benchmark envelope cannot be entered using Version 2.3; EnergyGauge default values must be used:
  - Basement wall construction type
  - Vertical, exterior slab edge insulation depth
  - Emittance of exterior walls and roof
  - Vertical distribution of window area among floors

## Space Conditioning/Air Distribution Equipment

- Use the EnergyGauge system sizing procedures for the heating and cooling equipment.  These procedures are based on the ACCA Manual J 7th Edition.
- Use the “Proposed Air Leakage” option and enter duct attributes directly into EnergyGauge.  Do not use the ASHRAE 152P guidelines to calculate duct system efficiency.
- EnergyGauge 2.3 does not allow supply or return ducts to be split between two locations, but the Benchmark is often defined that way.  If necessary as an approximation, use the “AHU Leakage Fraction” to fine-tune the distribution of leakage so that the correct percentage of total duct leakage goes to each space.  For example, if the Benchmark is a one-story house with a crawl

space, 95% of both the supply and return duct leakage should be to the crawl space, with the remaining 5% of each going to the exterior (See Table D1). There is no air handler leakage specified for the Benchmark. To achieve the correct leakage in each space, the values shown in Table D2 should be entered into EnergyGauge.

- Enter the supply duct R-value, which EnergyGauge will apply to both supply and return ducts.
- The user cannot enter the following features of the Benchmark space conditioning equipment. The EnergyGauge default values must be used.
  - Air handler power consumption
  - Duct material
  -

**Domestic Hot Water**

- Enter a constant gallons per day based on the annual average mains temperature calculated using the "Appliance and DHW" spreadsheet posted on the Building America Web site (http://www.eere.energy.gov/buildings/building_america/benchmark_def.html).
- Do not enter any water pipe or tank wrap insulation for the Benchmark.
- The following elements of the Benchmark operating conditions cannot be entered; the EnergyGauge default values must be used:
  - Recovery efficiency (1.0 for electric, 0.78 for natural gas)
  - Burner capacity (4500 W for electric)
  - Water usage schedule
  - Mains water temperature (same as Benchmark)

**Table D1. Breakdown of Benchmark Duct Leakage as % of Total Duct Leakage (1-story, air handler in crawl space)**

| | Duct Leakage to Crawl Space | Duct Leakage to Exterior | Total Duct Leakage |
|---|---|---|---|
| Supply | 62% | 3% | 65% |
| Return | 33% | 2% | 35% |
| Air Handler | 0% | 0% | 0% |
| ***Total*** | ***95%*** | ***5%*** | ***100%*** |

**Table D2. EnergyGauge Approximation of Benchmark Duct Leakage as % of Total Duct Leakage (1-story, air handler in crawl space)**

| | Duct Leakage to Crawlspace | Duct Leakage to Exterior | Total Duct Leakage |
|---|---|---|---|
| Supply | 62% | 0% | 62% |
| Return | 33% | 0% | 33% |
| Air Handler | 0% | 5% | 5% |
| ***Total*** | ***95%*** | ***5%*** | ***100%*** |

## Air Infiltration and Ventilation

- Use the "Proposed ACH" option for entering air infiltration rate. EnergyGauge calculates the corresponding effective leakage area that results in the correct annual average ACH.
- FSEC and NREL have developed a spreadsheet to help analysts calculate the correct EnergyGauge input for specific leakage area (SLA) for the Benchmark when a directly or indirectly conditioned basement is present in the Prototype; the spreadsheet is on the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html) and is based on the SLA approach to natural infiltration defined in Equation 7. The spreadsheet adjusts the above-grade leakage area so that the desired overall leakage area is obtained (thereby compensating for the basement SLA, which is fixed at 50% of the above grade SLA for conditioned basements and 25% of the above grade SLA for unconditioned basements.) There are separate tabs in the spreadsheet for directly and indirectly conditioned basements.
- For a Benchmark with a conditioned crawl space (or unvented with insulated walls), use the ACH calculated using Equation 6 for the main floors and the EnergyGauge default for an unvented crawl space.
- In order to report ventilation fan energy separately from other end uses, it must be tracked outside EnergyGauge. The "Forced Ventilation" box should not be checked, or else the fan energy will be included in heating and cooling. Assume the ventilation fan energy does not contribute to the internal heat load for the Benchmark (i.e., an exhaust ventilation fan).
- Check the "Cross-Ventilation" cooling attributes box under the "Cooling" tab.
- The user cannot enter the following aspects of the Benchmark infiltration and ventilation; the EnergyGauge default values must be used:
  - Conditioned crawl-space infiltration

## Lighting Equipment and Usage

- Create a new appliance and lighting schedule representing Version 3.1 of the Benchmark.
- Calculate "% Heat Released" based on an assumption that all of the interior lighting, and none of the garage or exterior lighting, is converted to heat and becomes part of the internal heat load.
- The "Peak Demand" should be 12.7% of the daily watt-hours for lighting (annual kWh including garage and exterior lighting divided by 0.365) divided by the number of thousand $ft^2$ of floor area.
- The hourly fraction of peak demand can be obtained in the "Ltg L0" tab of the Lighting End-Use Profile spreadsheet posted on the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html).
- Do not use the "% Fluorescent" field. Energy savings resulting from the use of fluorescent lamps should be calculated by changing the "Peak Demand" field.

## Appliances and Other Plug Loads

- Create a new appliance and lighting schedule representing Version 3.1 of the Benchmark.
- The appliance type labeled "Other" should include the following end uses:
  - Clothes washer (machine energy only)
  - Dishwasher (machine energy only)
  - The electric component of energy for a gas dryer
  - Other appliance and plug loads
- "Peak Demand" and "% Heat Released" for the "Other" appliance category must be calculated separately based on the guidelines in Table 9, and they should reflect the contribution of each of the four end uses listed above. (For the Prototype, sensible heat fraction may need to be reduced if the clothes washer includes a heater for automatic temperature control.)
- "Peak Demand" and "% Heat Released" for the dryer and range end uses should be entered directly based on the guidelines in Table 9.

- The “Peak Demand” for all other appliance types should be set to zero.
- The hourly fraction of peak demand for all appliances can be obtained in the “Appliance & Plug Schedule” tab of the Appliance and DHW End-Use Profile spreadsheet on the Building America Web site (www.eere.energy.gov/buildings/building_america/benchmark_def.html).
- The user cannot enter the following features of the Benchmark appliances and other loads; the EnergyGauge default values must be used:
    - Split between sensible and latent loads from appliances.

## Operating Conditions

- Create a new set of thermostat schedules representing Version 3.1 of the Benchmark.
- Use the default seasonal schedules, which are consistent with the guidelines in this report.
- The following elements of the Benchmark operating conditions cannot be entered; the EnergyGauge default values must be used:
    - Occupant sensible and latent loads (400 Btu/hr/person)
    - Internal mass of furniture and contents (8 lb/ft$^2$)
    - Distribution of internal mass (uniform)
    - Window operation (enthalpy-based natural ventilation based on Sherman-Grimsrud model, 25% of the window area open, a discharge coefficient of 0.85, a screening fraction [effective aperture] of 0.60 for normal ventilation and 0.8 for cross ventilation with ventilation control based on the last four days running as to whether heating or cooling is required).

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To measure progress toward multi-year Building America research 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 report summarizes the guidelines for reporting such analytical results using the Building America Research Benchmark (Version 3.1) in studies that also include consideration of current Regional and Builder Standard Practice. Version 3.1 of the Benchmark is generally consistent with the 1999 Home Energy Rating System (HERS) Reference Home, with additions that allow evaluation of all home energy uses.

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