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Innovation for Our Energy Future

Building America Research Benchmark Definition

Updated December 19, 2008

R. Hendron

Technical Report
NREL/TP-550-44816
December 2008

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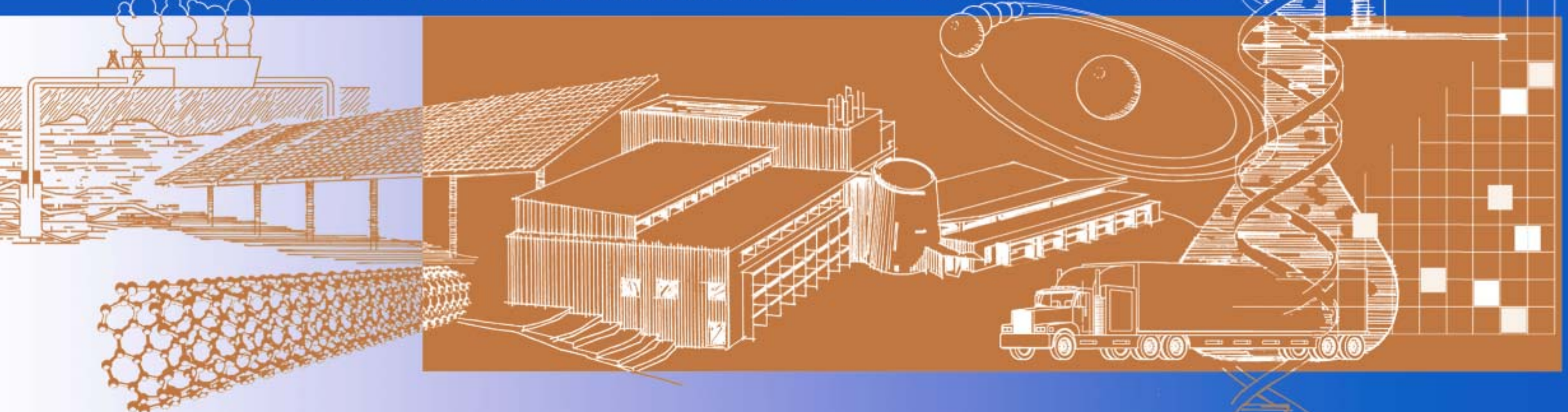

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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

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Definitions

A/C	air conditioning
ACCA	Air Conditioning Contractors of America
ACH	air changes per hour
AFUE	Annual Fuel Utilization Efficiency
ASHRAE	American Society of Heating, Refrigerating & Air Conditioning Engineers
ASTM	American Society for Testing and Materials
BA	Building America
CEC	California Energy Commission
CFA	Conditioned Floor Area
cfm	cubic feet per minute
DHW	domestic hot water
DOE	U.S. Department of Energy
DSE	distribution system efficiency
DUF	dryer usage factor
EER	energy efficiency ratio
EIA	Energy Information Administration
ELA	Effective Leakage Area
ELCAP	End-Use Load and Consumer Assessment Program
EPA	U.S. Environmental Protection Agency
FFA	finished floor area
FHA	Federal Housing Administration
FSEC	Florida Solar Energy Center
HERS	Home Energy Rating System
HP	heat pump
HUD	U.S. Department of Housing and Urban Development
ICC	International Code Council
IECC	International Energy Conservation Code
LBNL	Lawrence Berkeley National Laboratory
MAT	monthly average temperatures
MEC	Model Energy Code
MEL	miscellaneous electric loads
NAECA	National Appliance Energy Conservation Act

NASEO	National Association of State Energy Officials
NREL	National Renewable Energy Laboratory
RECS	Residential Energy Consumption Study
RESNET	Residential Energy Services Network
SCE	Southern California Edison Company
SDT	summer design temperatures
SEER	seasonal energy efficiency ratio
SLA	Specific Leakage Area
TMY3	Typical Meteorological Year, Version 2
TPU	Tacoma Public Utilities
TRNSYS	TRaNsient SYstem Simulation Program
UA	heat loss coefficient
WDT	winter design temperature

Introduction

To track progress toward aggressive multi-year, whole-house energy savings goals of 40%–70% and onsite power production of up to 30%, the U.S. Department of Energy (DOE) Residential Buildings Program and the National Renewable Energy Laboratory (NREL) developed the Building America (BA) Research Benchmark in consultation with the BA industry teams. The Benchmark is generally consistent with mid-1990s standard practice, as reflected in the Home Energy Rating System (HERS) Technical Guidelines (RESNET 2002), with additional definitions that allow the analyst to evaluate all residential end-uses, an extension of the traditional HERS rating approach that focuses on space conditioning and hot water. Unlike the reference homes used for HERS, ENERGY STAR®, and most energy codes, the Benchmark represents typical construction at a fixed point in time so it can be used as the basis for Building America's multi-year energy savings goals without the complication of chasing a "moving target." As time passes, we expect energy codes to become increasingly energy efficient compared to the Benchmark as better construction practices and more efficient equipment become commonplace in the market. A series of user profiles, intended to represent the behavior of a "standard" set of occupants, was created for use in conjunction with the Benchmark. The Benchmark is intended for use with detached and attached single-family housing only. It is not suitable for multi-family housing as written.

Energy analysis of a Prototype compared to the Benchmark can be performed with any software tool that complies with the BA Performance Analysis Procedures (Hendron et al. 2004). In addition, NREL will provide examples of technology packages that can be used to achieve different source energy savings based on BEopt analysis results (Anderson and Roberts, 2008). These technology packages, or alternative packages that provide equivalent source energy savings, may be used to demonstrate *minimum* whole house source energy savings for BA Gate reviews.[1]

[1] BEopt technology packages are provided as a reference point for BA program cost/performance analysis relative to BA multiyear performance goals. Any specific issues associated with BA performance analysis, use of hourly energy simulations, interpretation of source energy savings predictions, approaches for modeling advanced system options, or determination of average option costs should be referred to the BA analysis working group for resolution (http://tech.groups.yahoo.com/group/BAanalysis).

Benchmark House Specifications

The following sections summarize the definition of the Benchmark, updated for the fiscal year 2009 BA funding agreements. A comprehensive description of other important Building America reference houses (Builder Standard Practice and Regional Standard Practice), along with guidance for using hourly simulation tools to compare an energy-efficient Prototype house to the various base-case houses, can be found in the NREL technical report addressing systems-based performance analysis of residential buildings (Hendron et al. 2004). NREL and other Building America partners have also developed a series of tools, including spreadsheets with detailed hourly energy usage and load profiles, to help analysts apply the Benchmark quickly and in a consistent manner. These tools can be found on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html). In addition, the Florida Solar Energy Center has developed a version of EnergyGauge that automatically generates the Benchmark model when the specifications for a Prototype house are entered.

Any element of the Benchmark definition that is not specifically addressed in the following sections is assumed to be the same as the Prototype house. Because the definition is intended to be software-neutral, certain elements of the Benchmark cannot be modeled directly using every common simulation tool. If the energy use associated with such elements is significant, then they should be modeled or hand-calculated separately from the building model and reasonable adjustments should be made to the whole-house simulation results. If there is no significant energy effect associated with these elements, the Prototype and Benchmark should be modeled using similar approximations in an energy-neutral manner. The full Building America Performance Analysis Procedures (Hendron et al. 2004) include application notes addressing some practical implementation issues that may be encountered when simulating the Benchmark using DOE-2.2 or EnergyGauge.

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 the National Association of State Energy Officials (NASEO) and the Residential Energy Services Network (RESNET) in the "National Home Energy Rating Technical Guidelines," dated September 19, 1999 (RESNET 2002). These requirements are summarized below, along with a few minor clarifications and additional requirements. References to U-values in the 1993 Model Energy Code have been updated to the 2003 International Energy Conservation Code (IECC), because the corresponding U-values are identical and the IECC is more readily available (ICC 2003).

The Benchmark envelope specifications 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, which 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° from a horizontal plane
- Window area (A_F), including framing, determined by Equation 1 for detached homes and by Equation 2 for attached homes

Equation 1: $$A_F = 0.18 \times A_{FL,Liv} \times F_{A,Liv} + 0.18 \times A_{FL,Bsm} \times F_{A,Bsm}$$

Equation 2: $$A_F = (0.18 \times A_{FL,Liv} \times F_{A,Liv} + 0.18 \times A_{FL,Bsm} \times F_{A,Bsm}) \times F$$

where

A_F = total window area (ft^2)

$A_{FL,Liv}$ = total floor area of living space, excluding basement (ft^2)

$F_{A,Liv}$ = (perimeter of conditioned floor area of living space with exposed thermal boundary walls higher than 4 feet)/(total perimeter of conditioned floor areas of living space)

$A_{FL,Bsm}$ = floor area of basement (ft^2)

$F_{A,Bsm}$ = (exposed basement exterior wall area)/(total basement exterior 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, not including unvented crawl space walls

exposed thermal boundary wall is any thermal boundary wall not in contact with soil and not adjacent to a garage or other unconditioned space and

basement exterior wall is any basement wall adjacent to the ground or outside conditions

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.

- The window area calculated above is distributed with the same proportion on each wall and on each floor as the Prototype house. Thirty-three percent of the window area on each facade can be opened for the purpose of natural ventilation. The energy use is calculated with the Benchmark house in each of four orientations rotated in 90° increments relative to the Prototype orientation (+0°, +90°, +180°, +270°), and the average of these four cases is used to represent the energy use of the Benchmark.
- Thermal conductance of all thermal boundary elements equal to the requirements, expressed as U 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.
  - U-value (U_w) for the opaque fraction of exterior walls from Table 1 or 2, as appropriate.
  - The U-value and solar heat gain coefficient (SHGC) for vertical fenestration, including windows and sliding glass doors, shall be determined using Table 3. The values in Table 3 were calculated based on the HERS methodology for determining maximum window U-value, assuming a floor area to wall area ratio of 1.0. If the simulation tool uses a window library, a window that approximately matches the U_F and SHGC shall be selected, and the frame R-value shall be increased or decreased until the overall window U_F matches the value in Table 3.

Table 1. Opaque Wall U-Values (U_w) for Detached Homes (excerpted from ICC 2003)

Annual Heating Degree Days Base 65 (HDD65) from Nearest Location	U_w Air to Air, Includes Framing (Btu/hr-ft^2-°F)
> 13,000	0.038
9,000–12,999	0.046
6,500–8,999	0.052
4,500–6,499	0.058
3,500–4,499	0.064
2,600–3,499	0.076
<2,600	0.085

Table 2. Opaque Wall U-values (U_w) for Attached Homes (excerpted from ICC 2003)

Heating Degree Days Base 65 (HDD65) from Nearest Location	U_w Air to Air, Includes Framing (Btu/hr-ft^2-°F)
>9,000	0.064
7,100–8,999	0.076
3,000–7,099	0.085
2,800–2,999	0.100
2,600–2,799	0.120
<2,600	0.140

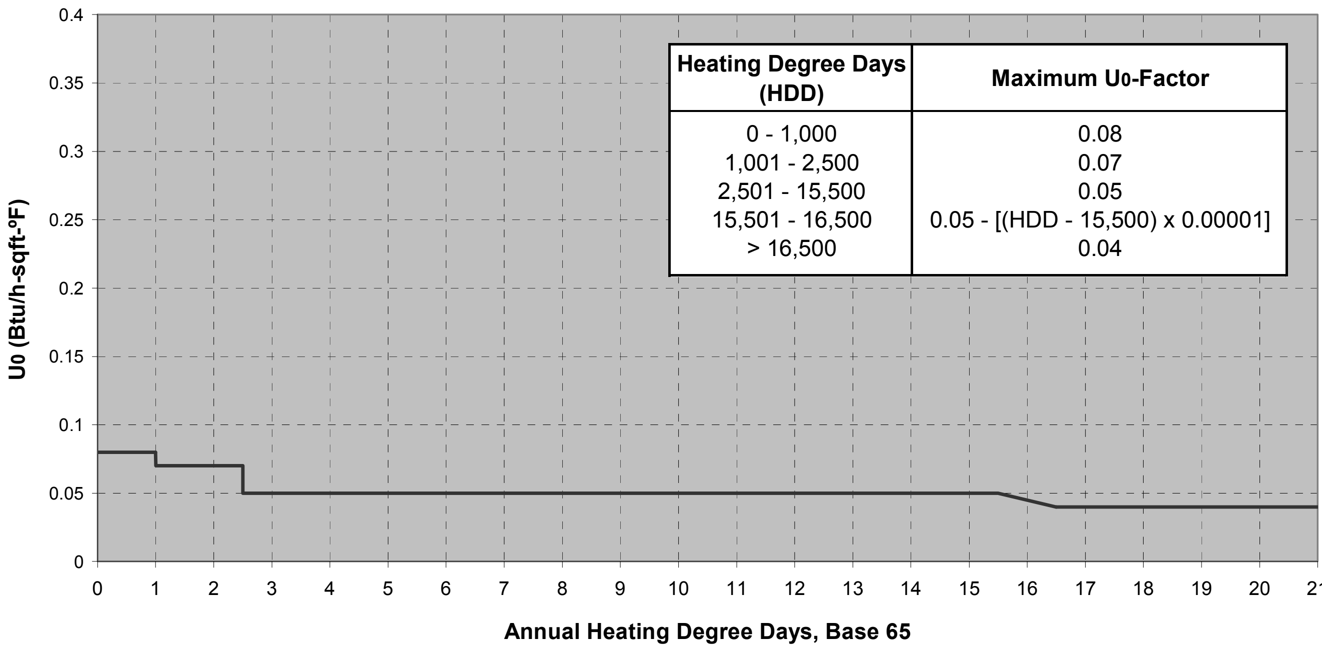
Table 3. Vertical Fenestration U-values (U_F) and SHGC

HDD65 from Nearest Location Based on TMY3 Data*	U_F Air to Air, Includes Framing and Sash (Btu/hr-ft^2-°F)	SHGC, Includes Framing and Sash
≥ 7,000	0.36	0.32
6,000–6,999	0.39	0.32
5,000–5,999	0.46	0.58
4,000–4,999	0.53	0.58
3,000–3,999	0.58	0.58
2,000–2,999	0.62	0.65
1,000–1,999	0.79	0.65
≤ 999	1.00	0.79

* Summary statistics for TMY3 sites can be found in the BA Analysis Spreadsheet (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html)

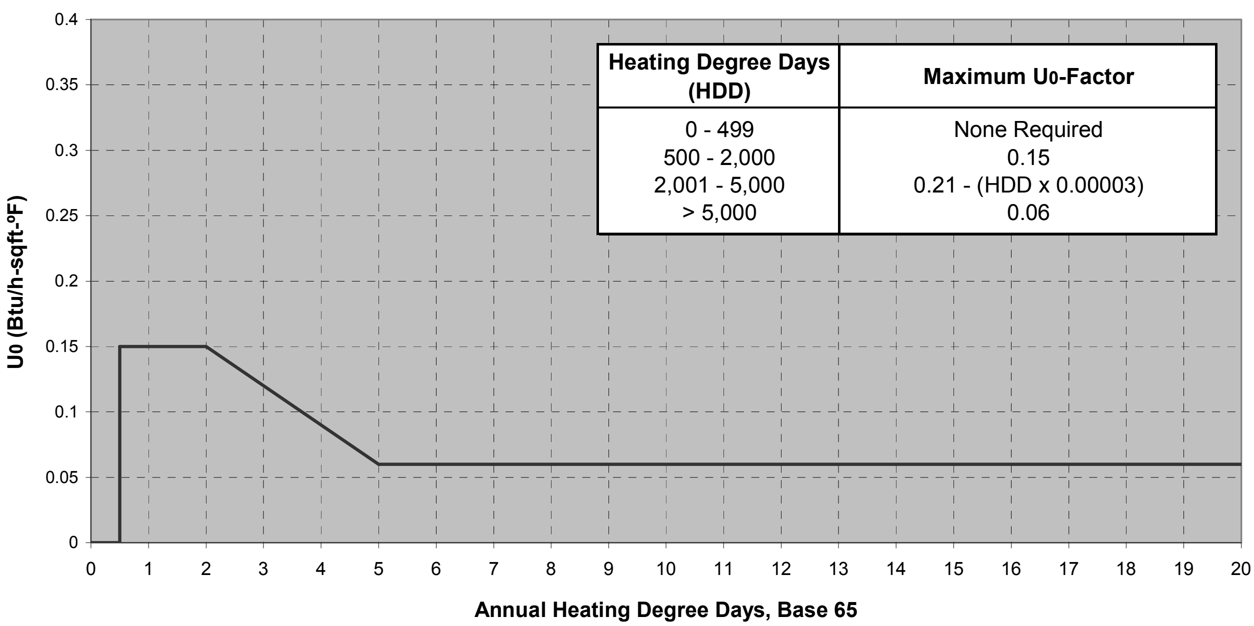
- U-value of an insulated floor above a vented crawl space or other unconditioned space shall be as specified in Figure 1 (excerpted from ICC 2003).
- U-value of insulated walls in an unvented crawl space shall be as specified in Figure 2 (excerpted from ICC 2003). This U-value represents the combined 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 3 (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 4 (excerpted from ICC 2003). This R-value is for rigid foam insulation and does not include the slab itself or ground effects.
- U-value of insulated roof/ceiling shall be as specified in Figure 5 (excerpted from ICC 2003), except for cathedral ceilings which shall have a U-value of 0.036 in all locations with more than 2,500 heating degree-days. 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 1. 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 2. Unvented crawl space wall U-value (excerpted from ICC 2003)

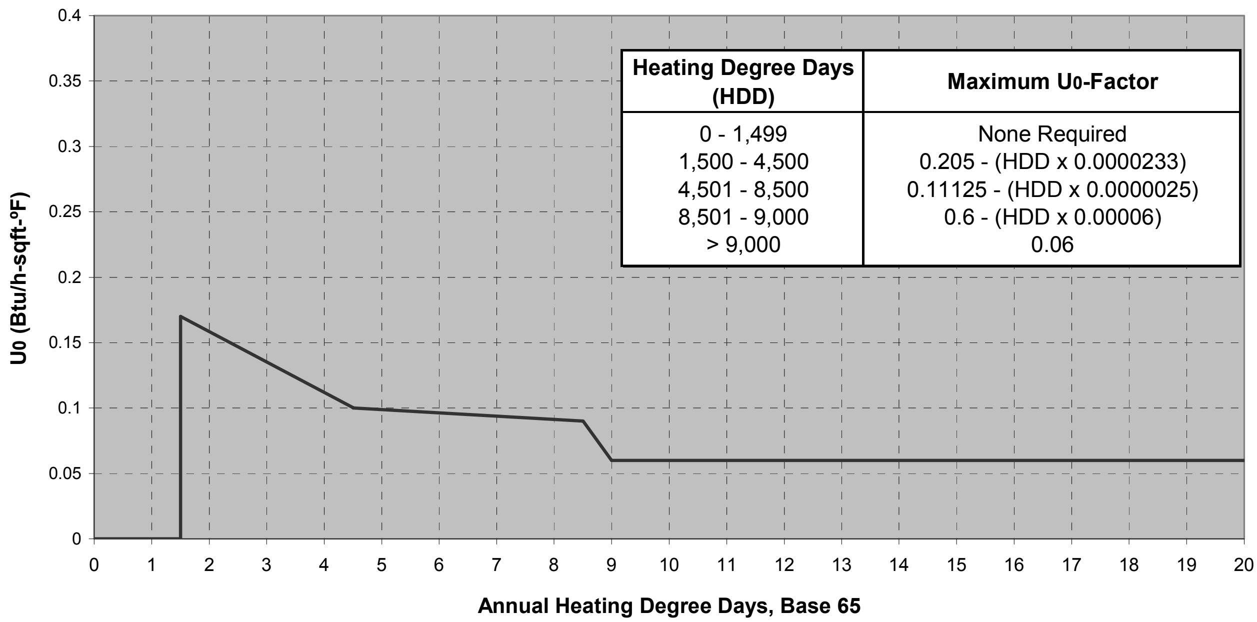


Figure 3. Basement wall U-value (excerpted from ICC 2003)

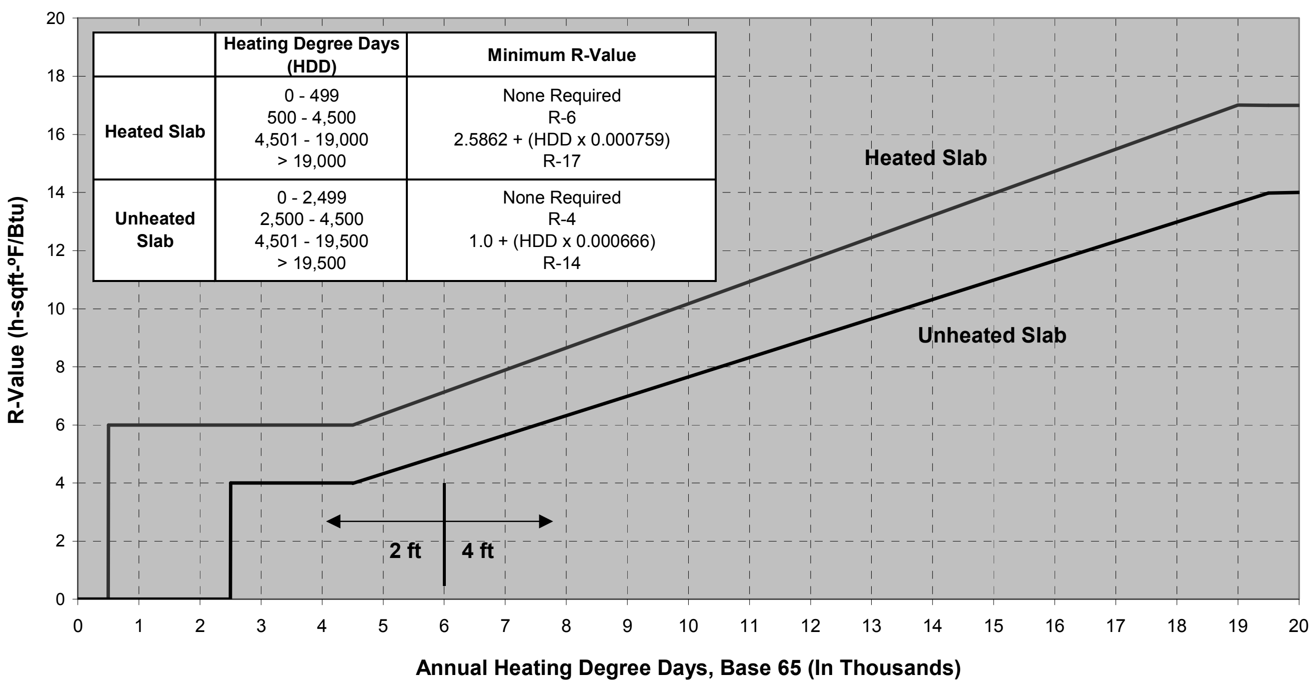


Figure 4. Slab insulation R-value and depth (excerpted from ICC 2003)

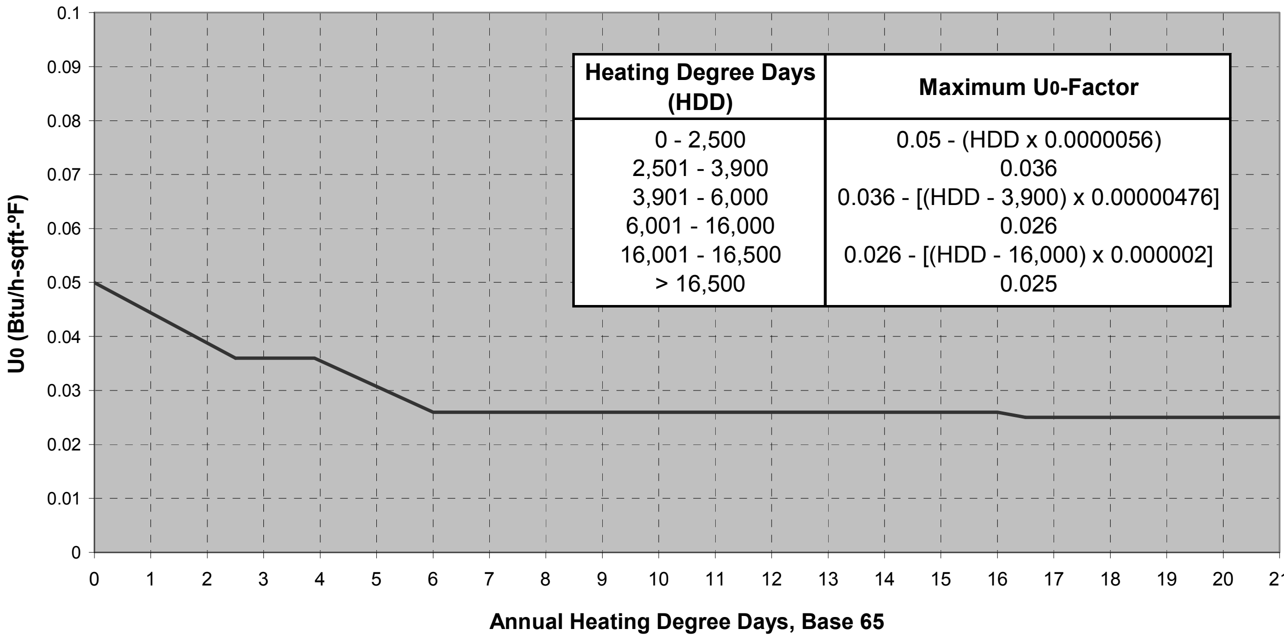


Figure 5. Roof/ceiling assembly U-value (excerpted from ICC 2003)

- 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 the model shall not include window shading effects from these features.
- No self-shading shall be modeled for the Benchmark.
- The area and location of opaque exterior doors shall be the same as the Prototype, with door U-value equal to 0.20 Btu/hr·ft^2·°F (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 2×4 or 2×6 wood construction with sufficient insulation to achieve the correct overall U-value. The framing factors in Table 3 are representative of typical construction practices and shall be used as inputs for the Benchmark model.

Table 4. Benchmark Framing Factors

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

- Interior partition walls shall be light-frame (2×4) wood construction.
- Masonry basement floor slabs and slab-on-grade foundations 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 equipment type and efficiency for the Benchmark shall be based on the type of heating and air-conditioning equipment found in the Prototype, as shown in Table 5.
- If the simulation tool requires the use of Energy Efficiency Ratio (EER) instead of Seasonal Energy Efficiency Ratio (SEER) for a heat pump or air conditioner, then the EER for the Benchmark shall be calculated using Equation 3. If the actual EER for the Prototype is not readily available, Equation 3 may also be used to make an approximate conversion from SEER to EER (Wassmer 2003):

Equation 3: $$EER = -0.02 \times SEER^2 + 1.12 \times SEER$$

- 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.
- If the Prototype actively controls relative humidity, then the Benchmark shall include a stand-alone dehumidifier with an energy factor of 1.1 liters/kWh (EPA 2006). Sensible heat generated by the dehumidifier shall be added to the cooling load.
- The Benchmark air handler shall have power consumption equal to 0.00055 kW/cfm.

Table 5. Benchmark Space Conditioning Equipment Efficiencies

Prototype Equipment	Function	Benchmark Space Conditioning Device
Gas or Oil Fired Furnace	Heating	78% AFUE Gas Furnace
Mobile Home Furnace	Heating	75% AFUE Gas Furnace
Gas or Oil Fired Boiler (Except Gas Steam)	Heating	80% AFUE Gas Boiler
Gas Steam Boiler	Heating	75% AFUE Gas Steam Boiler
Gas Space Heater	Heating	74% AFUE Gas Space Heater
Other Non-Electric Boiler	Heating	80% AFUE Gas Boiler
Gas Combi System	Heating	78% AFUE Gas Furnace
Other Non-Electric Heating	Heating	78% AFUE Gas Furnace
Ground Source Heat Pump	Heating/Cooling	6.8 HSPF/10 SEER Air Source Heat Pump
Air Source Heat Pump (Split)	Heating/Cooling	6.8 HSPF/10 SEER Air Source Heat Pump
Air Source Heat Pump (Package)	Heating/Cooling	6.6 HSPF/9.7 SEER Air Source Heat Pump
Other Electric* or No System	Heating	6.8 HSPF/10 SEER Air Source Heat Pump
Split System Air Conditioner	Cooling	10 SEER Air Conditioner
Single Package Air Conditioner	Cooling	9.7 SEER Air Conditioner
Room Air Conditioner	Cooling	9.0 EER Room Air Conditioner
Other Type or No Air Conditioner	Cooling	10 SEER Air Conditioner

* For Prototypes with electric resistance heating, the Benchmark shall have a 6.8 HSPF/10 SEER air source heat pump for both heating and cooling, regardless of the cooling system in the Prototype.

The Benchmark shall include an air distribution system with the properties listed in Table 6. The location of the ductwork in the Benchmark is based on the type of foundation used for the Prototype. If the simulation tool does not permit the input of duct specifications to the level of detail used in Table 6, 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) has been modified by NREL and integrated into the BA Analysis Spreadsheet (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html) to assist with this calculation.

Table 6. Duct Locations and Specifications for the Benchmark

	Prototype Foundation Type	Benchmark Duct Specification	
		One-Story	*Two-Story or Higher*
Supply Duct Surface Area (ft^2)	All	0.27 x FFA[a]	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 excluding Air Handler (Inside + Outside)	All	10% of Air Handler Flow (9% Supply, 1% Return) (Percentage lost to each space equal to percentage of duct area in that space, as specified below.	
Air Handler Leakage (Inside + Outside)	All	5% of Air Handler Flow (1% Supply, 4% Return)	
Percent of Duct / Air Handler Leakage Imbalance (Supply Minus Return, 5% of Air Handler Flow in All Cases) Made Up By Outside Air	Slab-on-grade or Raised floor	100% Outside air	37% Outside air
	Vented Crawl space	100% Outside air	37% Outside air
	Basement or Conditioned Crawlspace	100% Outside air[c]	60% Outside air[c]
Supply Duct Location	Slab-on-grade or Raised floor	100% Attic[b]	65% Attic[b], 35% Conditioned Space
	Crawl space	100% Crawl space	65% Crawl space, 35% Above-Grade Conditioned Space
	Basement	100% Basement	65% Basement, 35% Above-Grade Conditioned Space
Return Duct and Air Handler Location	Slab-on-grade or Raised floor	100% Attic[b]	100% Attic[b]
	Crawl space	100% Crawl space	100% Crawl space
	Basement	100% Basement	100% Basement
Total Leakage to the Outside and Fraction on the Return Side (Calculated Based on Values Specified Above)	Slab-on-grade or Raised floor	15% Total (33% Return Fraction)	11.8% Total (42.2% Return Fraction)
	Vented Crawl space	15% Total (33% Return Fraction)	11.8% Total (42.2% Return Fraction)
	Basement or Conditioned Crawlspace	5% Total (0% Return Fraction)	3% Total (0% Return Fraction)

[a] Finished floor area (ft^2)
[b] If the Prototype does not have an attic, then this percentage of duct leakage in the Benchmark is assumed to be in an attached garage. If the Prototype does not have an attached garage, then the leakage is assumed to be in conditioned space.
[c] It is assumed that supply leakage to the outside is 5% of total air handler flow when ducts are entirely within the thermal envelope in a 1-story house, and 3% of total air handler flow in a 2-story house.

Domestic Hot Water

The specifications in Tables 7 and 8 shall be used 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 Administration (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 based on a typical three-bedroom, two-bathroom Prototype is shown in Table 9. The BA Analysis Spreadsheet developed by NREL automates many of the equations discussed in the following paragraphs and can be downloaded from the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html). The BA Analysis spreadsheet also calculates the correct DHW inputs for the TRNSYS computer program, including standby heat loss coefficient (UA). The spreadsheet has a comprehensive set of inputs and outputs that can be used to help calculate DHW properties for the Prototype house (Burch and Erickson 2004).

Table 7. Characteristics of Benchmark Domestic Hot-Water System

	Water Heater Fuel Type in Prototype	
	Electric	*Gas*
Storage Capacity (V) (Gallons)	See Table 8	See Table 8
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 Table 8	See Table 8
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 Benchmark space heating.*

Table 8. Benchmark Domestic Hot-Water Storage and Burner Capacity (ASHRAE 1999)

# Bedrooms	**1**	**2**			**3**			**4**			**5**	**6**
# Bathrooms	All	≤ 1.5	2-2.5	≥ 3	≤ 1.5	2-2.5	≥ 3	≤ 1.5	2-2.5	≥ 3	All	All
Gas												
Storage (gal)	20	30	30	40	30	40	40	40	40	50	50	50
Burner (kBtu/hr)	27	36	36	36	36	36	38	36	38	38	47	50
Electric												
Storage (gal)	20	30	40	50	40	50	50	50	50	66	66	80
Burner (kW)	2.5	3.5	4.5	5.5	4.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5

Table 9. Example Characteristics of Benchmark Domestic Hot-Water System Based on 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	

Five major end uses are identified for domestic hot water: showers, baths, sinks, dishwasher, and clothes washer. If a clothes washer is not provided by the builder, the Benchmark clothes washer shall be included in both the Benchmark and Prototype models. The average daily water consumption by end use is shown in Table 10. For showers, baths, and sinks, the specified volume is the combined hot and cold water. This allows hot-water use to fluctuate depending on the cold water (mains) temperature.[2] Hot-water usage values for the clothes washer and dishwasher were estimated based on several scientific references studied by NREL. For showers, baths, and sinks, the water usage is based on the average of three domestic hot-water studies (Christensen et al. 2000, Burch and Salasovich 2002, 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, which will be discussed later in this report. Latent and sensible heat gains were estimated based on guidance from the ASTM Manual on Moisture Control in Buildings (ASTM 1994).

Table 10. Domestic Hot-Water Consumption by End Use

End Use	End-Use Water Temperature	Water Usage	Sensible Heat Gain	Latent Heat Gain
Clothes Washer	N/A	7.5 + 2.5 x N_{br} gal/day (Hot Only)	0*	0*
Dishwasher	N/A	2.5 + 0.833 x N_{br} gal/day (Hot Only)	0*	0*
Shower	105°F	14.0 + 4.67 x N_{br} gal/day (Hot + Cold)	741 + 247 x N_{br} Btu/day	703 + 235 x N_{br} Btu/day (0.70 + 0.23 x N_{br} pints/day)
Bath	105°F	3.5 + 1.17 x N_{br} gal/day (Hot + Cold)	185 + 62 x N_{br} Btu/day	0**
Sinks	105°F	12.5 + 4.16 x N_{br} gal/day (Hot + Cold)	310 + 103 x N_{br} Btu/day	140 + 47 x N_{br} Btu/day (0.14 + 0.05 x N_{br} pints/day)

* Sensible and latent heat gains from appliances are included in the section entitled "Appliances and Miscellaneous Electric Loads."
** Negligible compared to showers and sinks.

Hourly hot-water use profiles for individual hot-water end uses are shown in Figures 6–10. For software tools that do not accept this level of detail, the combined hourly hot-water profile may be used, as shown

[2] 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.

in Figure 11. The numerical values for normalized hourly hot-water use can be found in the BA Analysis Spreadsheet.

The combined hourly profile is based on a 1990 study conducted by Becker and Stogsdill (1990), which included hot-water data from several earlier studies. The profiles for the clothes washer and dishwasher are based on the electrical end-use measurements in the ELCAP study conducted in the Pacific Northwest by the Bonneville Power Administration in the 1980s (Pratt et al. 1989). It is assumed that the normalized hourly profiles for electricity and hot water are the same for these two appliances. The shower, bath, and sink profiles were taken from the "Residential End-Uses of Water" study conducted by Aquacraft for the American Water Works Association (AWWA 1999).

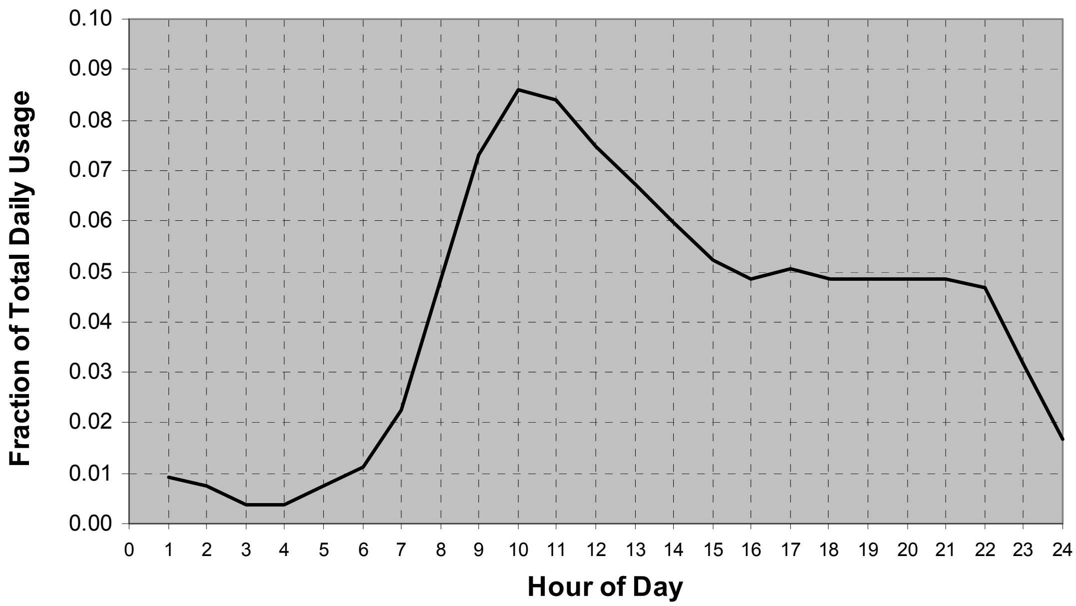


Figure 6. Clothes washer hot-water use profile

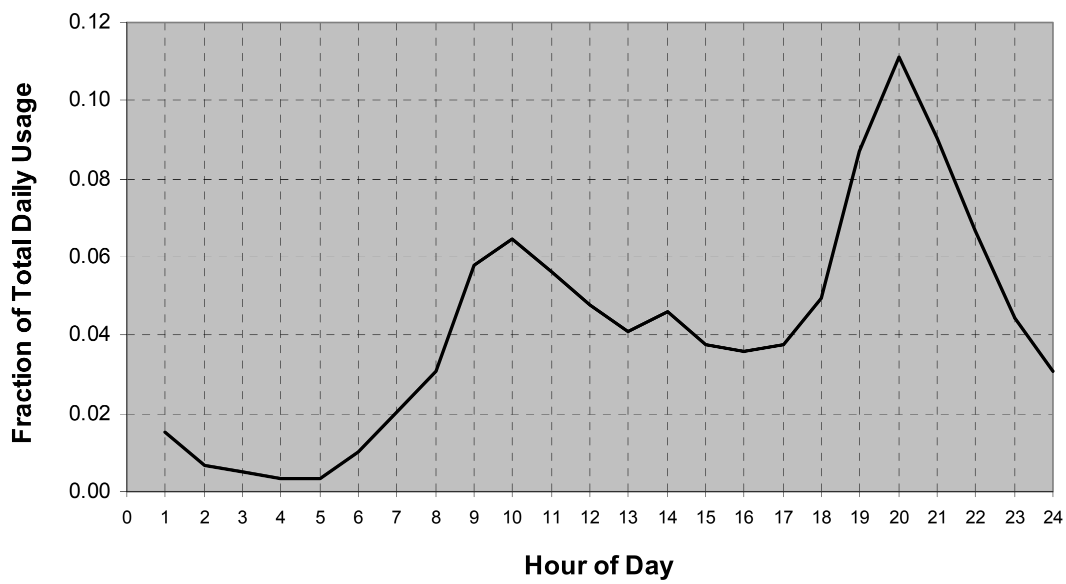


Figure 7. Dishwasher hot-water use profile

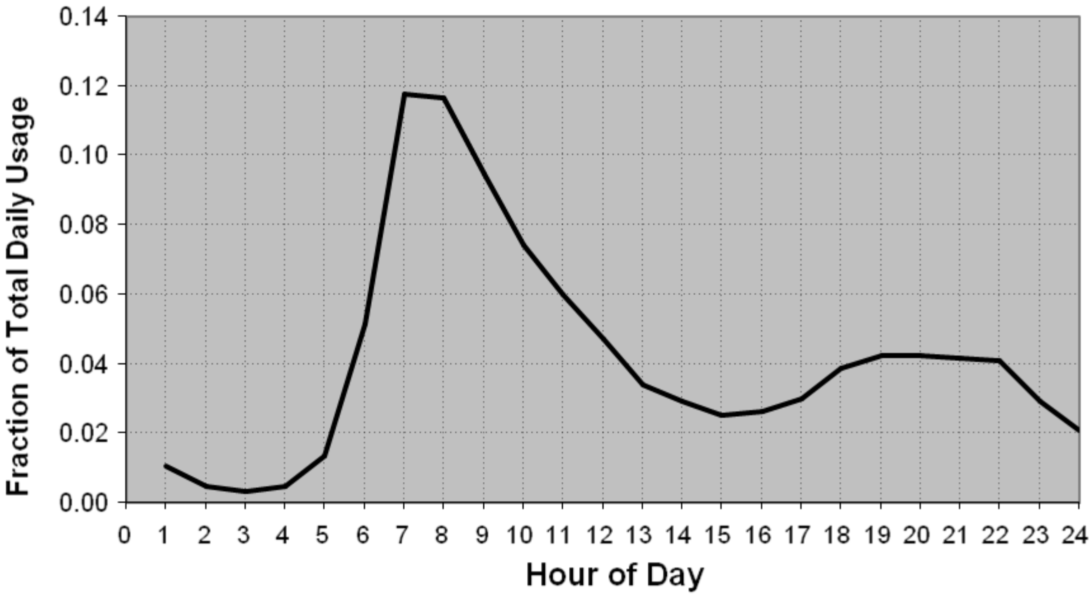


Figure 8. Shower hot-water use profile

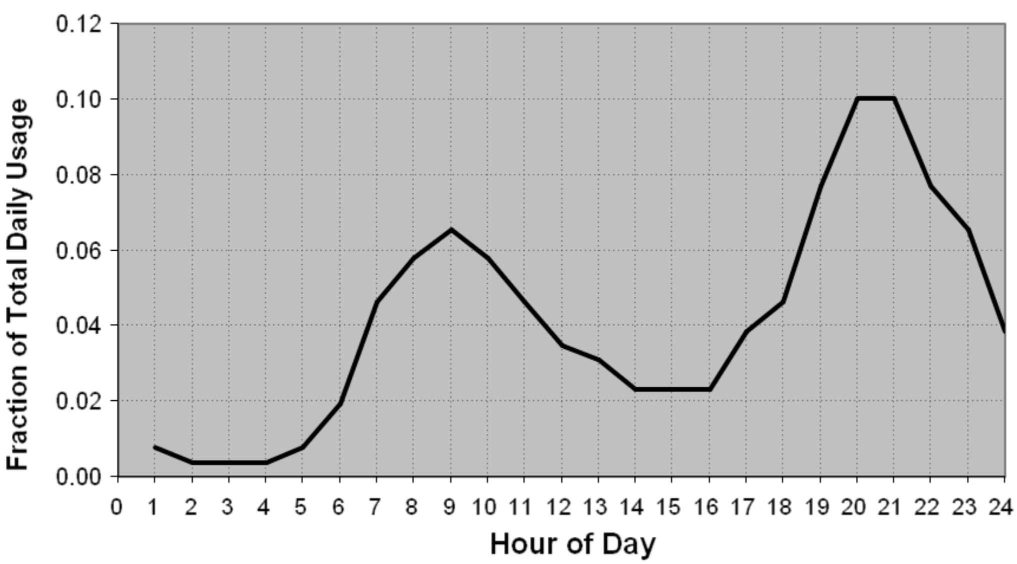


Figure 9. Bath hot-water use profile

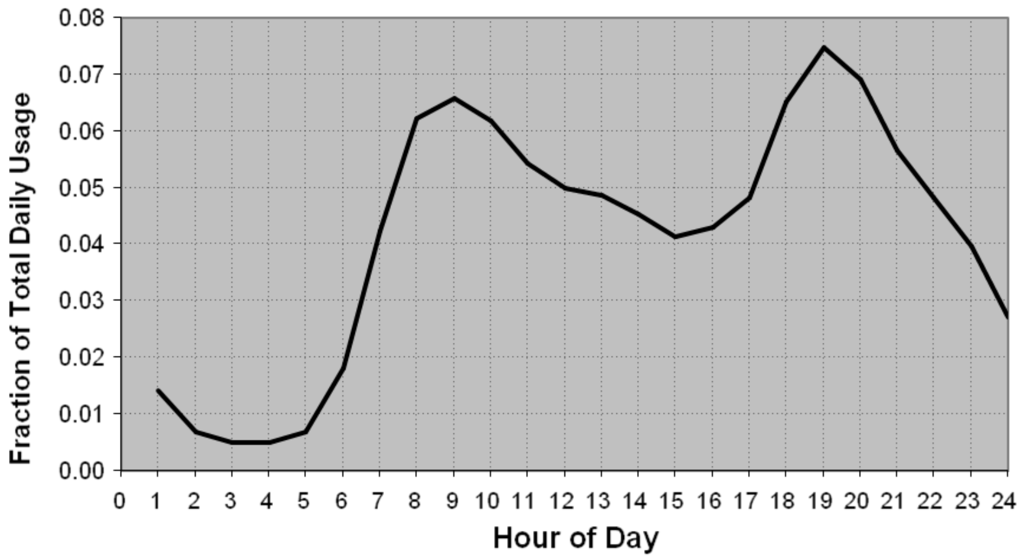


Figure 10. Sink hot-water use profile

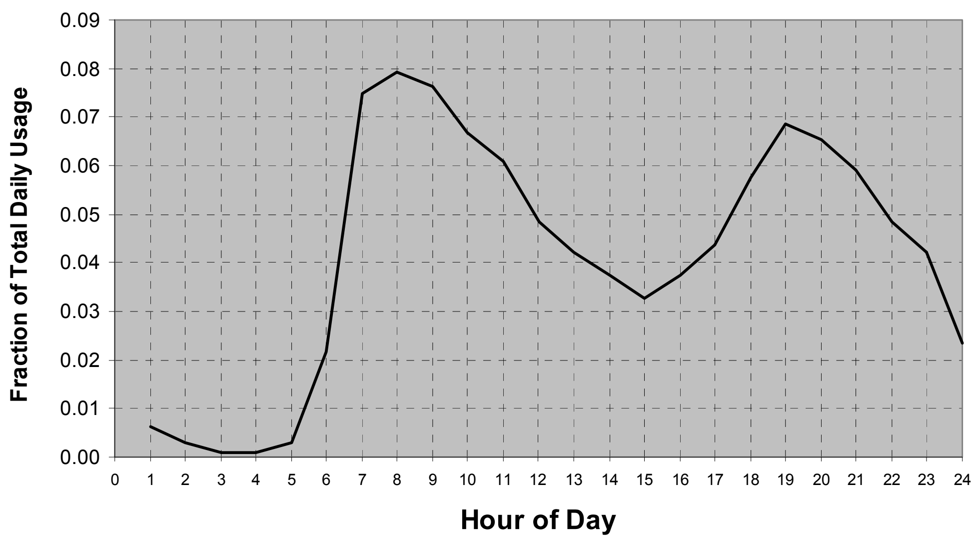


Figure 11. Combined domestic hot-water use profile

Monthly and weekend/weekday multipliers for daily hot-water use were derived from data collected in the 1,200-house Aquacraft study (AWWA 1999). In addition, three vacation periods with no hot water use were designated: May 26-28, August 12-18, and December 22-25. The multipliers that adjust for these effects are summarized in Table 11. This is an optional level of detail for DHW analysis, and is not required if the simulation tool being used by the analyst does not allow variable daily hot water use.

Table 11. Hot-water use multipliers for specific day-types

	Clothes Washer	Dish-washer	Shower	Bath	Sinks
Weekend	1.15	1.05	1.05	1.26	1.04
Weekday	0.94	0.98	0.98	0.90	0.98
Vacation (May 26-28, August 12-18, Dec 22-25)	0	0	0	0	0
Not Vacation	1.04	1.04	1.04	1.04	1.04

Certain advanced hot water measures may require the use of detailed hot water events with realistic frequency, flow rates, durations, fixture assignment, and clustering. Such measures include solar hot water systems with demand-side heat exchangers, tankless water heaters, distribution system improvements, and recirculation loops. NREL has developed an interactive spreadsheet tool (DHW Event Generation Tool) that generates an annual set of event schedules automatically based on a series of user inputs, such as TMY3 location, number of bedrooms, and number of hot water fixtures. This tool is available for download from the BA performance analysis Web site, along with standard Benchmark event schedules for 2-, 3-, and 4-bedroom houses (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html). The events generated by the spreadsheet are consistent with the average daily volumes calculated based on Tables 10 and 11. Additional characteristics of the Benchmark hot water events for a 3-bedroom house are summarized in Table 12.

Table 12. Benchmark DHW event characteristics and constraints (3-bedroom house)

Characteristics	Sink	Shower	Bath	CW	DW
Avg Duration (min)	0.62	7.81	5.65	3.05	1.53
Std Dev Duration (min)	0.67	3.52	2.09	1.62	0.41
Probability Distribution for Duration	Expo-nential	Log-Normal	Normal	Discrete	Log-Normal
Avg Flow Rate (gpm)*	1.14	2.25	4.40	2.20	1.39
Std Dev Flow Rate (gpm)*	0.61	0.68	1.17	0.62	0.20
Probability Distribution for Flow Rate	Normal	Normal	Normal	Normal	Normal
Avg Event Volume (gal)*	0.76	16.73	23.45	6.95	2.13
Average Daily Volume (gal/day)*	25	28	7	15	5
Average Daily Events (events/day)	32.9	1.7	0.3	2.2	2.4
Annual Events (events/year)	12007	611	109	788	858
Max Time Between Events in Cluster (min)	15	60	60		60
Average Time Between Events in Cluster (min)	1.93	30.5			9.8
Average Events per Cluster	1.90	1.24	1.00	1.96	4.89
Number of Clusters per Year	6319	493	109	402	176
Max Time Between Events in Load (min)				30	
Max Time Between Loads in Cluster (min)				240	
Number of Loads per Cluster				1.40	
Average Number of Events per Load				1.40	
Average Time Between Events in Load (min)				5.0	
Average Time Between Loads in Cluster (min)				74.3	
Probability Distribution for Cluster Size	Discrete	Discrete	Discrete	Discrete	Discrete
Fraction of events at primary fixture (kitchen sink, master bath shower/tub)	0.70	0.75	0.75	1.00	1.00
Fraction of events at secondary fixture (master bath sink, second shower/tub)	0.10	0.25	0.25		
Fraction of events at 3rd fixture	0.10				
Fraction of events at 4th fixture	0.10				

* Hot + cold water combined for mixed temperature end-uses (sinks, showers, baths)

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

where

T_{mains}	= mains (supply) temperature to domestic hot-water tank (°F)
$T_{amb,avg}$	= annual average ambient air temperature (°F)
$\Delta T_{amb,max}$	= maximum difference between monthly average ambient temperatures (e.g., $T_{amb,avg,july} - T_{amb,avg,january}$) (°F)
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 Burch and Christensen of NREL using data for multiple locations (Burch and Christensen 2007), as compiled by Abrams and Shedd (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 $T_{amb,avg}$ = 44°F. 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 4 shall be calculated using Equation 5.

Equation 5: $day\# = 30 * month\# - 15$

where month# = month of the year (1–12).

An example using Equations 4 and 5 to determine the monthly mains temperature profile for Chicago, Illinois, is shown in Figure 12.

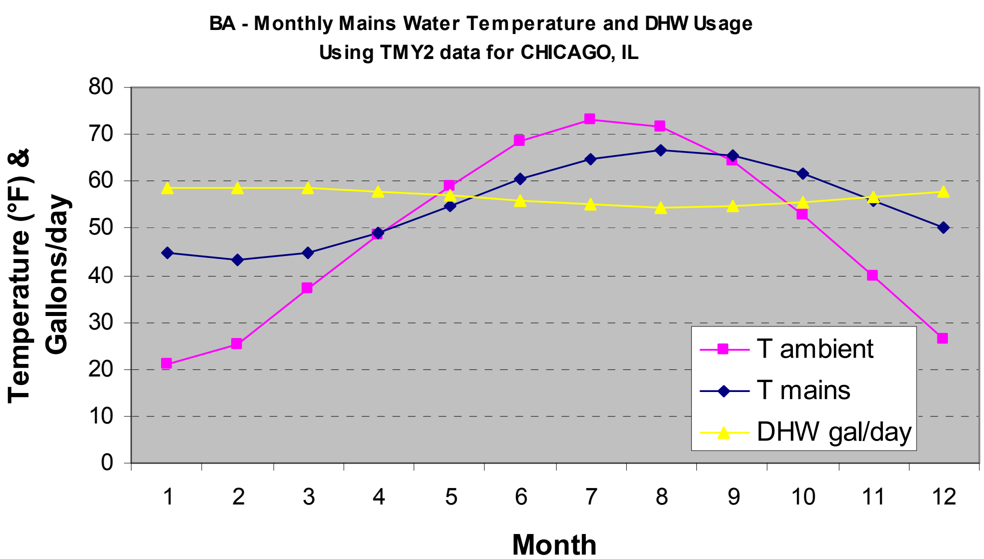


Figure 12. Mains temperature profile for Chicago

Hot water distribution system design can have a significant impact on wait times for hot water, interior heat gains from pipes, and total water heating energy. NREL and Davis Energy Group analyzed a wide range of distribution system types and developed a set of equations to assist with the calculation of whole-house energy savings for improved distribution systems. The basic characteristics of the Benchmark distribution system are summarized in Table 13. Treatment of other distribution system types is discussed in the "Modeling the Prototype" section of this report.

Table 13. Benchmark hot water distribution system characteristics

Branching configuration	Trunk and branch
Material	Copper
Pipe insulation	None
Pipe lengths and diameters	Based on 2010 ft^2 prototype house layout developed by DEG for CEC (DEG 2006)
Number of bathrooms	Nbr/2+½
Recirculation loop	None
Location	Inside conditioned space

The daily internal heat gain caused by the Benchmark distribution system shall be calculated using Equation 6. The heat gain shall be applied using the combined hourly DHW profile in Figure 11.

Equation 6: $$IHG\left(\frac{Btu}{day}\right) = \left\{IHG_{bench,avg} + 735 \times (N_{br} - 3)\right\} \times \left\{1 + \frac{1}{IHG_{bench,avg}} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$$

where

$$IHG_{bench,avg} = \text{average daily heat gain for Benchmark DHW system} = 4{,}257\ \text{Btu/day}$$
$$N_{br} = \text{Number of bedrooms}$$
$$\text{Month} = \text{Number of the month (January} = 1, \text{etc.)}$$

Air Infiltration and Ventilation

The hourly natural air change rate for the Benchmark shall be calculated based on the Specific Leakage Area (SLA) determined using Equation 7:

Equation 7: SLA = ELA/CFA = 0.00057

where ELA = effective leakage area (ft^2), defined as the amount of open area that would result in the same total air exchange as the actual leakage area of the house at a pressure of 4 Pa

CFA = conditioned floor area (ft^2)

When specifying natural infiltration for a Benchmark with either a directly or indirectly conditioned basement, the SLA shall be adjusted to account for the in-ground portions of the walls of the conditioned basement. Equation 8 shall be used to make this adjustment.

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

where

SLA = ELA (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

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 can also be done by applying $SLA_{overall}$ to the combined spaces if the Benchmark is modeled as a single zone.

Additional air exchange due to whole-house mechanical ventilation shall be calculated assuming a balanced ventilation system with the same ventilation rate used for the Prototype, up to a maximum value consistent with the rate recommended by ASHRAE Standard 62.2. Whole-house mechanical ventilation air shall be added to the natural infiltration rate assuming no interactive effects and no heat recovery. The whole-house ventilation fan energy use for the Benchmark shall be calculated using a fan efficiency of 0.5 W/cfm, where it is assumed only one fan is present.

In addition to whole-house ventilation, the Benchmark shall include a kitchen range hood and a spot ventilation fan in each bathroom. The flow rates of each fan shall be the same as the Prototype, and the efficiency for each fan shall be 0.50 W/cfm. The kitchen range hood is assumed to operate 30 minutes per day, and each bathroom fan is assumed to operate 60 minutes per day. Interactive effects between these spot exhaust ventilation fans and natural infiltration shall be included in the analysis.

Lighting Equipment and Usage

The total annual hard-wired lighting use for the Benchmark is determined using Equations 9–11. 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 Consulting 2002).

Equation 9: Interior hard-wired lighting = 0.8*(FFA * 0.8 + 455) kWh/yr
Equation 10: Garage lighting = 100 kWh/yr
Equation 11: Exterior lighting = 250 kWh/yr

Annual hard-wired indoor lighting, in kilowatt-hours, represents approximately 80% of all indoor lighting and is expressed as a linear function of finished house area relative to a constant base value. Garage and exterior lighting are treated as constants. When combined with plug-in lighting (discussed in the next section), the total interior lighting calculated using this equation is in the middle range of residential lighting energy use found in other lighting references, as shown in Figure 13, including Huang and Gu (2002), the 1993 RECS (DOE 1996), a Florida Solar Energy Center study (Parker et al. 2000), default lighting for Visual DOE software (Eley and Associates 2002), a lighting study conducted by Navigant for DOE (Navigant Consulting 2002), and two other studies in Grays Harbor, Washington (Manclark and Nelson 1992), and Southern California Edison (SCE 1993).

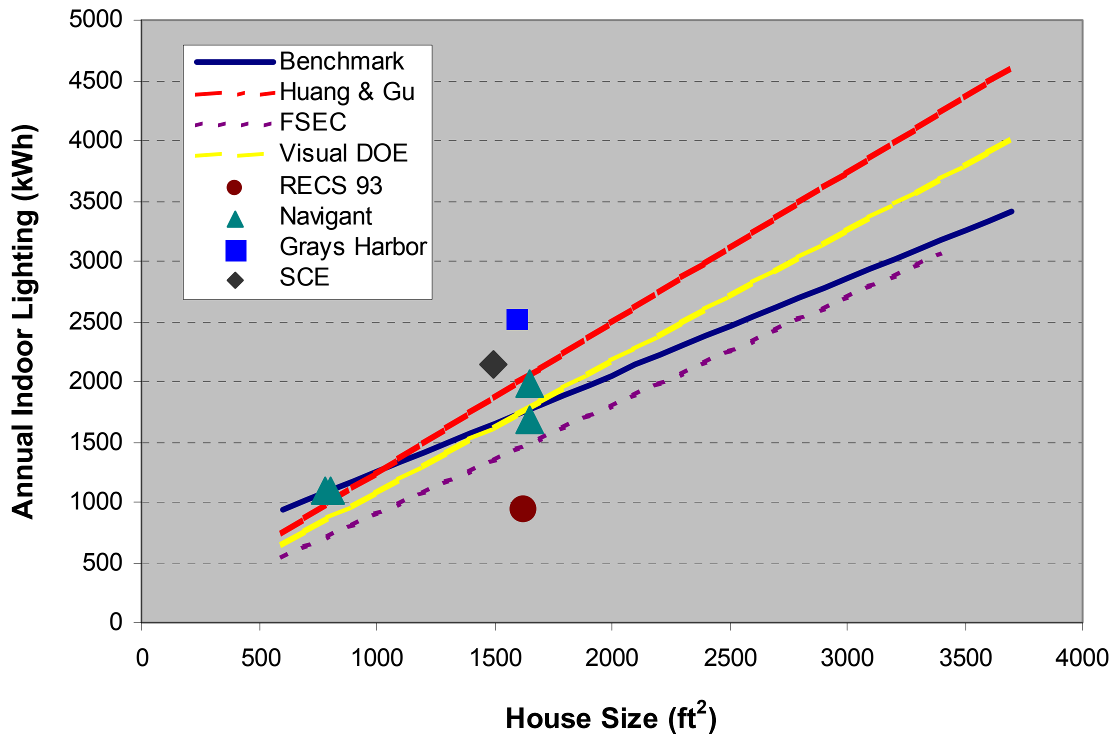


Figure 13. Comparison of Benchmark lighting equation to other references

The Benchmark lighting budget is based on an assumption that 86% of all lamps are incandescent, and the remaining 14% are fluorescent. 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, percentage 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.

If a comprehensive lighting plan has not been developed for the Prototype house, and only fluorescent and incandescent lamps are installed, then a simplified approach may be used to estimate energy savings compared to the Benchmark using Equation 12. This equation is based on an assumption that the efficacies of incandescent and fluorescent light fixtures are the same in the Prototype as they were in the TPU study, and that fluorescent lighting is distributed equally among all hard-wired fixtures, including garage and exterior lights.

Equation 12: Prototype hard-wired lighting (kWh/yr) = L_B*(1.12*F_I + 0.279*F_F)

$$\text{Prototype hard-wired lighting (kWh/yr)} = L_B * (1.12 * F_I + 0.279 * F_F)$$

where L_B = hard-wired interior, exterior, or garage lighting for the Benchmark from Equation 8, 9, or 10 (kWh/yr)
F_I = fraction of hard-wired lamps in the Prototype that are incandescent
F_F = fraction of hard-wired lamps in the Prototype that are fluorescent

The annual average normalized daily load shape for interior lighting use is shown in Figure 14, 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.

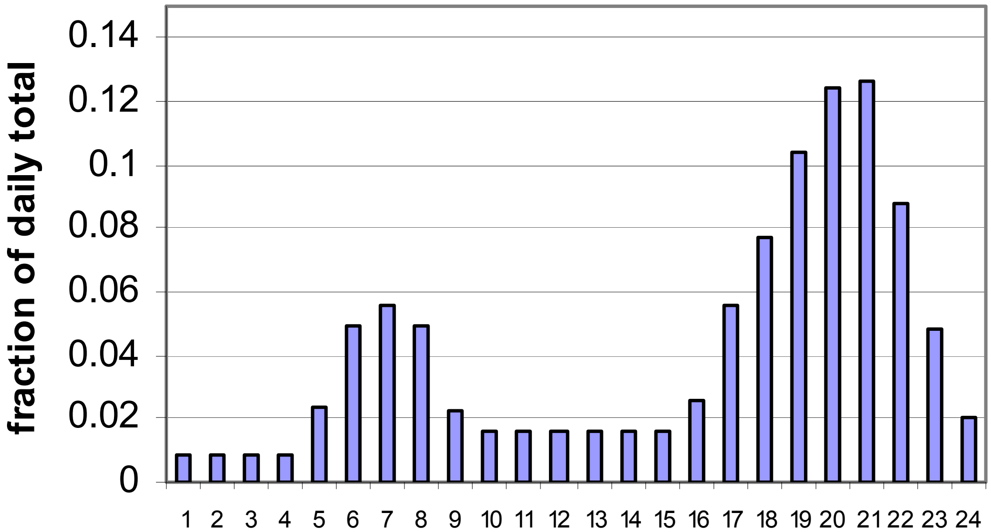


Figure 14. Interior lighting profile (built up from detailed profiles)

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 versus weekend), occupancy types (day-use versus non-day-use or "nuclear" versus "yuppie"), season (summer versus winter), and room types (living area versus bedroom area).

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 15. Other profiles are included in spreadsheets available on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html).

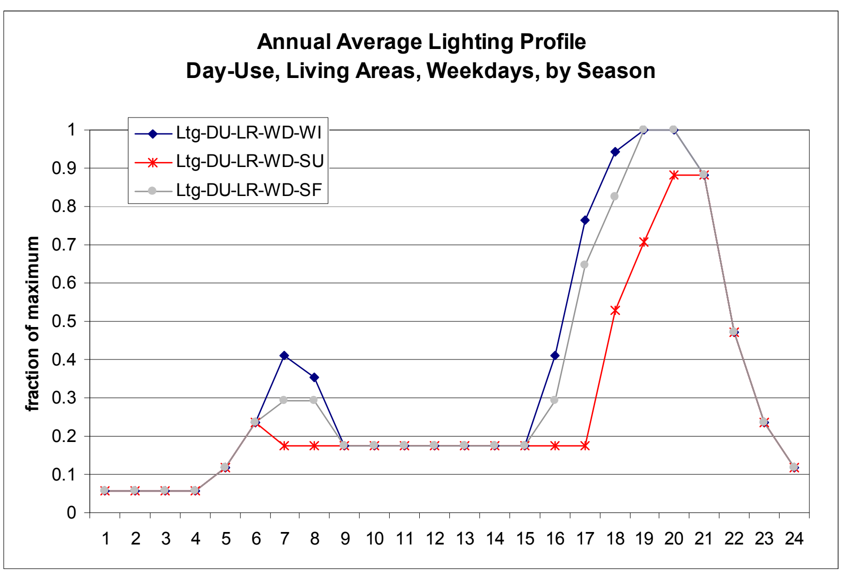


Figure 15. Example of a detailed lighting profile (expressed as fraction of peak daily lighting energy)

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 14), 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 14. Average Lighting Operating Hours for Common Room Types in a Sample of 161 Homes in the Pacific Northwest

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		

Source: Navigant Consulting 2002

Appliances and Miscellaneous Electric Loads

As with lighting, several characteristics must be defined for appliances and miscellaneous electric loads (MELs): 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 15. It is assumed for modeling purposes that all major appliances are present in both the Benchmark and the Prototype, even in cases where the builder does not provide all appliances. 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, a Navigant analysis of typical models available on the market that meet current NAECA appliance standards, and several other studies.

For a house of typical size (1,000–3,000 ft^2), the loads from the occupants and most appliances are assumed to be a function of the number of bedrooms and the finished floor area. The exceptions are the refrigerator and certain miscellaneous gas and electric loads, which are assumed to be constant regardless of the number of bedrooms. The general relationship between appliance loads, number of bedrooms, and house size was derived empirically from the 2001 RECS. The sensible and latent load fractions were developed based on engineering analysis and judgment.

The MEL end use is assumed to be primarily a function of finished floor area and number of bedrooms. A multiplier is applied if the prototype is located in one of the four most populated states as determined in the EIA Residential Energy Consumption Survey (RECS) (DOE 2001). Multipliers for these four states were estimated based on the final electric end-use regression equations developed for the 2001 RECS, substituting national average values for known housing characteristics and physical traits of the occupants (such as number of bedrooms, number of ceiling fans, and homeowner age) and removing end-uses that are disaggregated in the Benchmark (such as lighting and clothes dryer). The resulting multipliers are listed in Table 16. The multiplier is 1.0 for all states not listed because insufficient information is available about the magnitude of MELs in those states.

Miscellaneous loads are broken into variable electric loads and fixed gas and electric loads. By definition, energy savings are not calculated for improvements to fixed loads because an analysis methodology has not yet been established. However, NREL has developed a methodology for calculating energy savings associated with variable electric loads, which are generally the most common miscellaneous electric loads encountered in a typical house. Approximately 100 MELs in this category are listed in Table 17. If the analyst chooses to use anything other than the Benchmark MEL values for the Prototype, he or she must use the BA Analysis Spreadsheet for new construction posted on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html) to calculate energy savings, latent and sensible loads, and the split between standby and operating energy. This spreadsheet allows the analyst to change the quantity of each MEL in the Prototype, and the operating and standby power levels only. Operating hours cannot be changed, but a lower "effective" power draw may be used if occupancy sensors or other controls are used to turn off power to MELs that are not in use. In addition, only those MELs that are installed or provided by the builder may be included in the energy savings analysis. The remaining MELs in the Prototype revert to the default values used for the Benchmark. References for the typical MEL characteristics used in the calculations are documented in the "Detailed MEL Analysis" tab of the BA Analysis Spreadsheet.

Table 15. Annual Appliance and Miscellaneous Electric Loads for the Benchmark[3]

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)	$38 + 12.7 \times N_{br}$	$26.5 + 8.8 \times N_{br}$	1.00 (Electric) 0.10 (Gas)	0.00 (Electric) 0.05 (Gas)
Dishwasher (8 place settings)	$103 + 34.3 \times N_{br}$		0.60	0.15
Range (Electric)	$302 + 101 \times N_{br}$		0.40	0.30
Range (Gas)		$22.5 + 7.5 \times N_{br}$	0.30	0.20
Plug-In Lighting	0.2*(FFA * 0.8 + 455)]		1.00	0.00
Variable Miscellaneous Electric Loads (MELs)	$(1281 + 196 \times N_{br} + 0.345 \times FFA) \times F_s$		0.83	0.02
Fixed Miscellaneous Loads (Gas/Electric)	$(150 + 25 \times N_{br} + 0.039 \times FFA) \times F_s$	$(5.8 + 1.0 \times N_{br} + 0.0015 \times FFA) \times F_s$	0.12	0.23
Fixed Miscellaneous Loads (All-Electric)	$(319 + 53 \times N_{br} + 0.083 \times FFA) \times F_s$		0.12	0.23

Table 16. Plug Load Multipliers for Four Most Populated States (F_S)

State	Multiplier (F_S)
New York	0.82
California	0.77
Florida	0.94
Texas	1.11
All other states and territories	1.00

[3] 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 BA Analysis Spreadsheet on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html) can assist with the calculation of this split for an energy-efficient clothes washer or dishwasher based on the Energy Guide label.

Table 17. Benchmark Annual Energy Consumption for Miscellaneous Electric and Gas Loads (three-bedroom house, 1,920 ft^2)

Miscellaneous Electric Load	Avg Units/ Hshld	Energy/ Unit kWh/yr	Energy/ Hshld kWh/yr	Miscellaneous Electric Load	Avg Units/ Hshld	Energy/ Unit kWh/yr	Energy/ Hshld kWh/yr
Hard-Wired				***Home Office***			
Fan (Ceiling)	1.840	84.1	154.7	Laptop PC (Plugged In)	0.152	47.0	7.1
Air Handler Standby Losses	0.800	67.2	53.8	Desktop PC w/ Speakers	0.592	143.9	85.2
HVAC Controls	1.000	20.3	20.3	PC Monitor	0.592	119.8	70.9
Home Security System	0.187	195.1	36.5	Printer (Laser)	0.049	92.5	4.5
Ground Fault Circuit Interrupter	3.850	6.2	23.9	Printer (Inkjet)	0.118	39.0	4.6
Sump Pump	0.099	40.0	3.9	Dot Matrix Printer	0.030	115.0	3.5
Heat Lamp	0.010	13.0	0.1	DSL/Cable Modem	0.200	17.6	3.5
Garage Door Opener	0.266	35.0	9.3	Scanner	0.050	49.0	2.4
Carbon Monoxide Detector	0.260	17.5	4.6	Copy Machine	0.020	25.0	0.5
Smoke Detectors	0.840	3.5	2.9	Fax Machine	0.030	326.3	9.8
Garbage Disposal	0.404	10.0	4.0	***Bathroom***			
Doorbell	0.670	44.0	29.5	Hair Dryer	0.861	41.1	35.4
Home Entertainment				Curling Iron	0.532	1.0	0.5
First Color TV	0.986	215.5	212.5	Electric Shaver	0.470	12.8	6.0
Second Color TV	0.669	112.7	75.4	Electric Toothbrush Charger	0.118	19.3	2.3
Third Color TV	0.296	66.7	19.7	***Garage & Workshop***			
Fourth Color TV	0.104	52.1	5.4	Auto Block Heater	0.019	250.0	4.8
Fifth or More Color TV	0.028	45.8	1.3	Lawn Mower (Electric)	0.059	42.9	2.5
First VCR	0.876	71.3	62.5	Heat Tape	0.030	100.0	3.0
Second VCR	0.320	68.9	22.1	Kiln	0.020	50.0	1.0
Third or More VCR	0.072	68.6	4.9	Pipe and Gutter Heaters	0.010	53.0	0.5
DVD Player	0.472	50.1	23.7	Shop Tools	0.130	26.4	3.4
Video Gaming System	0.631	20.4	12.9	***Other***			
Clock Radio	1.260	14.9	18.8	Humidifier	0.150	100.0	15.0
Boombox / Portable Stereo	0.670	16.8	11.3	Water Bed	0.066	1068.0	70.5
Compact Stereo	0.460	112.3	51.6	Sm Freshwater Aquarium (5-20 gal)	0.024	105.0	2.5
Component / Rack Stereo	0.730	153.0	111.7	Md Freshwater Aquarium (20-40 gal)	0.024	180.0	4.3
Power Speakers	0.296	24.4	7.2	Lg Freshwater Aquarium (40-60 gal)	0.024	340.0	8.1
Subwoofer	0.099	68.3	6.7	Small Marine Aquarium (5-20 gal)	0.002	245.0	0.6
Radio	0.493	9.1	4.5	Medium Marine Aquarium (20-40 gal)	0.002	615.0	1.5
Equalizer	0.049	14.7	0.7	Large Marine Aquarium (40-60 gal)	0.002	740.0	1.8
Satellite Dish Box	0.202	131.7	26.6	Vacuum Cleaner (Upright)	0.983	42.2	41.5
Cable Box	0.637	152.7	97.3	Clock	0.956	26.0	24.8
Kitchen				Cordless Phone	0.601	23.2	13.9
Microwave	0.933	135.1	126.1	Cell Phone Charger	0.450	77.4	34.8
Freezer	0.323	935.0	302.0	Electric Blanket	0.286	120.0	34.3
Extra Refrigerator	0.179	1100.0	196.9	Answering Machine	0.650	33.5	21.8
Coffee Maker (Drip)	0.610	61.2	37.3	Battery Charger	0.437	14.8	6.5
Coffee Maker (Percolator)	0.210	65.0	13.7	Fan (Portable)	0.946	11.3	10.7
Toaster Oven	0.557	32.3	18.0	Air Cleaner	0.217	65.7	14.2
Toaster	0.904	45.9	41.5	Vacuum Cleaner (Cordless)	0.183	41.0	7.5
Waffle Iron	0.325	25.0	8.1	Heating Pads	0.670	3.0	2.0
Blender	0.788	7.0	5.5	Surge Protector / Power Strip	0.360	3.9	1.4
Can Opener	0.650	3.0	2.0	Timer (Lighting)	0.280	20.1	5.6
Electric Grill	0.010	180.0	1.8	Timer (Irrigation)	0.050	45.2	2.3
Hand Mixer	0.877	2.0	1.8	Iron	0.922	52.7	48.6
Electric Griddle	0.256	6.0	1.5	Baby Monitor	0.100	22.8	2.3
Popcorn Popper	0.305	5.0	1.5	***Fixed MELs***			
Espresso Machine	0.069	19.0	1.3	Pool Heater (Electric)	0.004	2300.0	9.2
Instant Hot-water Dispenser	0.006	160.0	1.0	Pool Pump (Electric)	0.066	2228.3	147.1
Hot Plate	0.236	30.0	7.1	Hot Tub / Spa Heater (Electric)	0.030	2040.7	61.2
Food Slicer	0.414	1.0	0.4	Hot Tub / Spa Pump (Electric)	0.038	460.0	17.5
Electric Knife	0.374	1.0	0.4	Well Pump (Electric)	0.129	400.0	51.6
Broiler	0.010	80.0	0.8	Coral Reef Aquarium (Electric)	0.001	4500.0	3.6
Deep Fryer	0.148	20.0	3.0	Gas Fireplace	0.035	1760.0	60.9
Bottled Water	0.010	300.0	3.0	Gas Grill	0.029	879.0	25.5
Trash Compactor	0.010	50.0	0.5	Gas Lighting	0.005	557.0	2.9
Slow Cooker / Crock Pot	0.581	16.0	9.3	Pool Heater (Gas)	0.024	6506.0	158.7
				Hot Tub / Spa Heater (Gas)	0.038	2374.0	90.2
				Other	1.000	9.4	9.4
				Total MEL Load			**3,170**

The hourly, normalized load shape for combined residential equipment use is shown in Figure 16, and is based on the ELCAP study of household electricity use in the Pacific Northwest (Pratt et al. 1989). In most situations, this profile is adequate for simulating all electric and gas end-uses except space conditioning and hot water. However, because some individual end-use profiles are nearly constant (such as refrigerator and transformer loads) and some are highly dependent on time of day (such as the range/oven and dishwasher), we have also developed a series of normalized hourly profiles for major appliances and plug loads, shown in Figures 17–22. Numerical values associated with these profiles can be found in the BA Analysis Spreadsheet posted on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html). The hourly profiles for machine energy usage in the clothes washer and dishwasher are identical to those provided earlier in the section on DHW (see Figures 6–7). The profile for plug-in lighting is the same as the profile for hard-wired lighting presented in Figure 14.

All hourly end-use profiles were taken from the ELCAP study, except the profile for "Miscellaneous Electric Loads," which was derived by subtracting the energy consumption profiles for the major appliances from the combined profile for all equipment, assuming an all-electric, 1,800-ft^2, three-bedroom house in Memphis, Tennessee. Internal sensible and latent loads from appliances and plug loads shall be modeled using the same profile used for end-use consumption. Appliance loads may be modeled in either the living spaces or bedroom spaces, depending on their location in the Prototype.

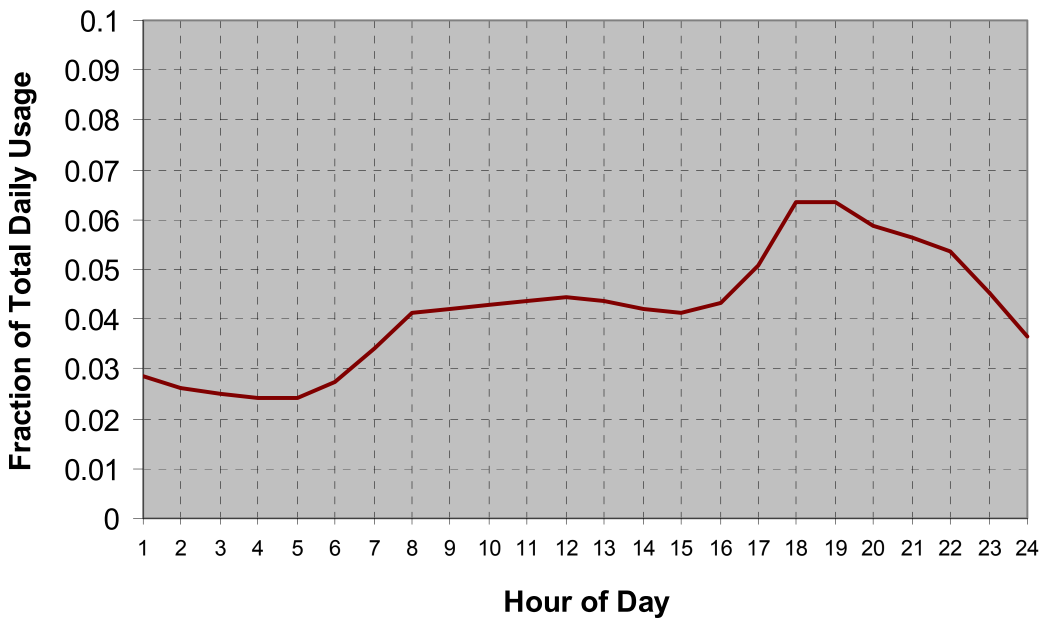


Figure 16. Total combined residential equipment profile (Pratt et al. 1989)

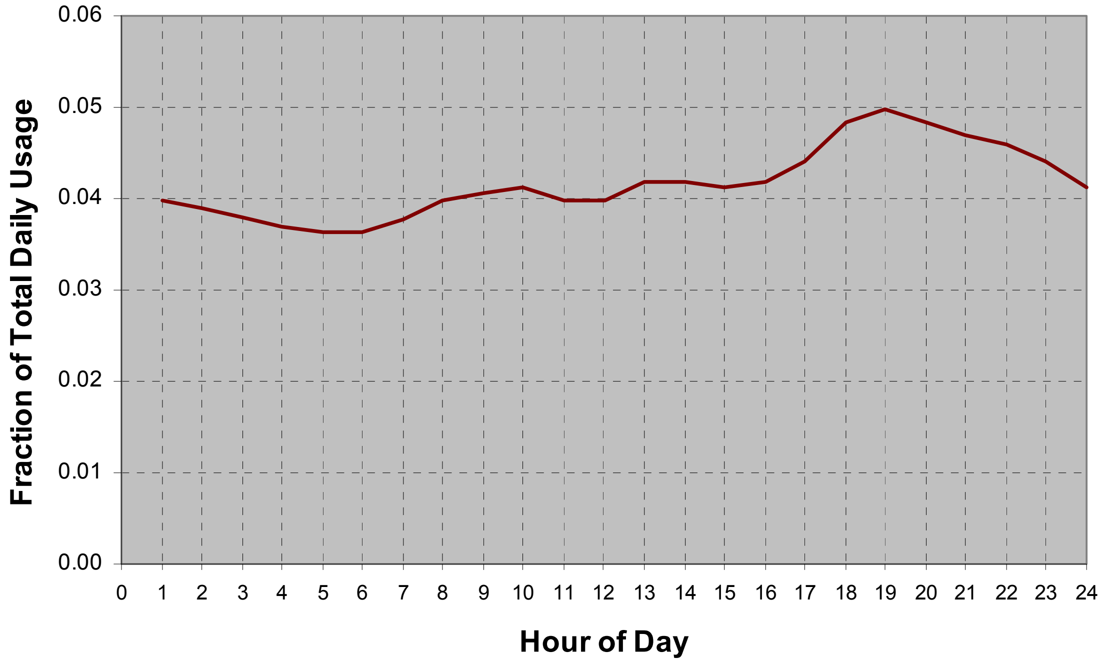


Figure 17. Refrigerator normalized energy use profile (Pratt et al. 1989)

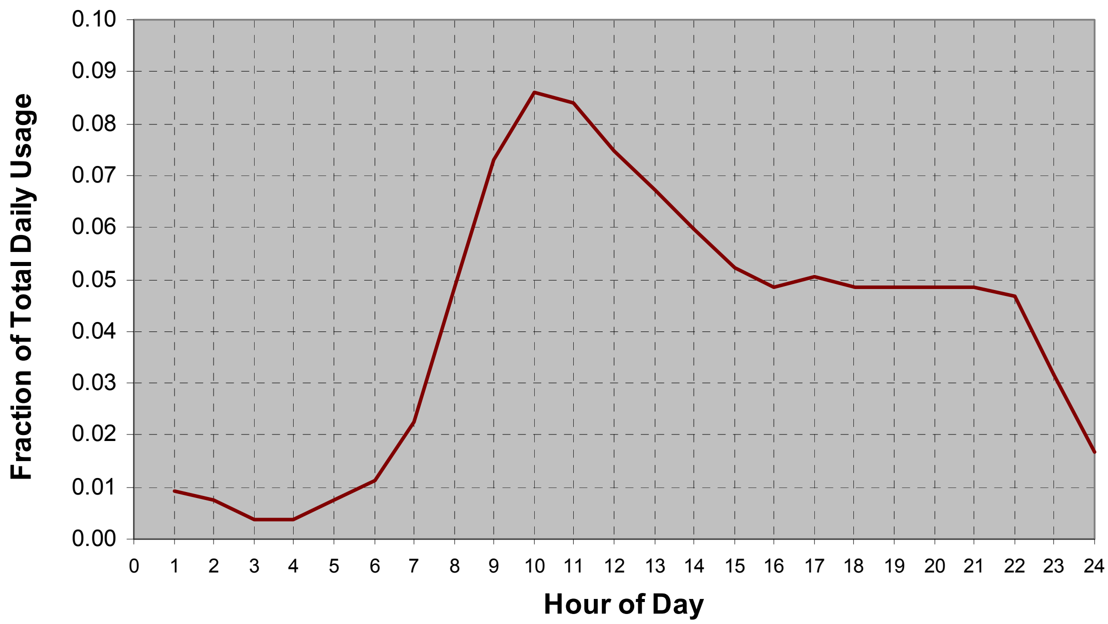


Figure 18. Clothes washer normalized machine energy use profile (Pratt et al. 1989)

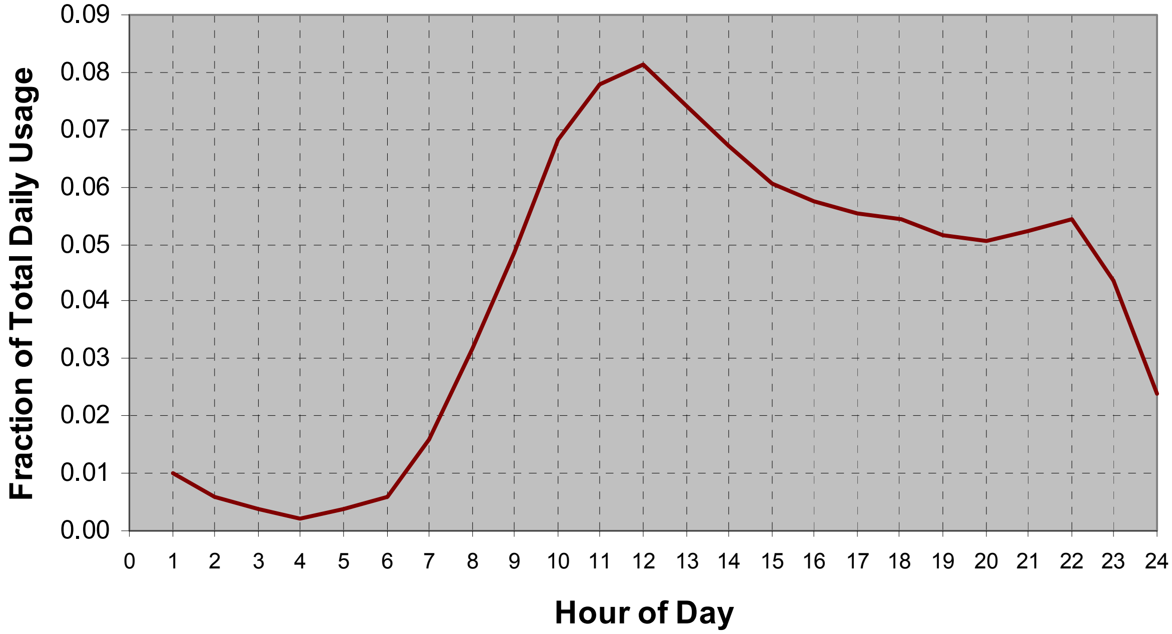


Figure 19. Clothes dryer normalized energy use profile (Pratt et al. 1989)

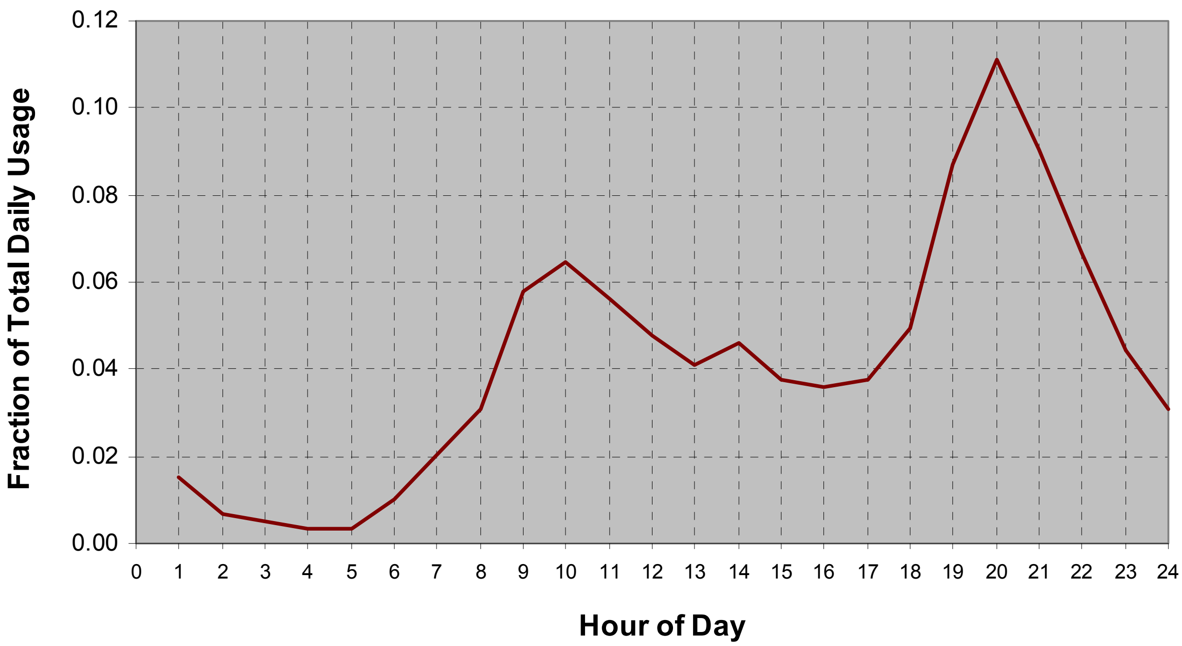


Figure 20. Dishwasher normalized energy use profile (Pratt et al. 1989)

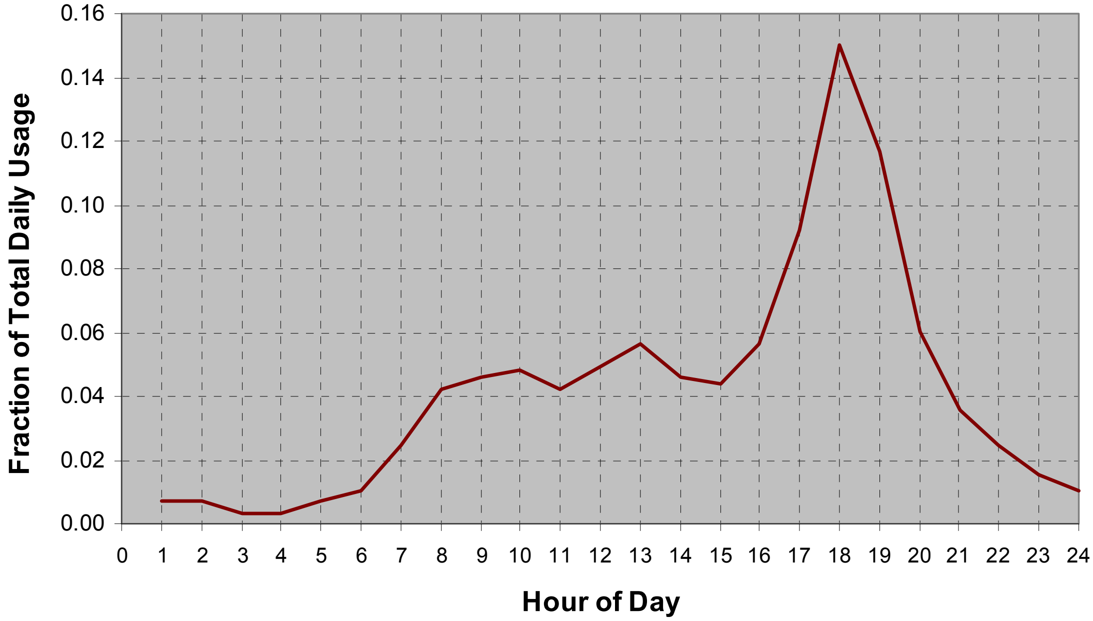


Figure 21. Range/oven normalized energy use profile (Pratt et al. 1989)

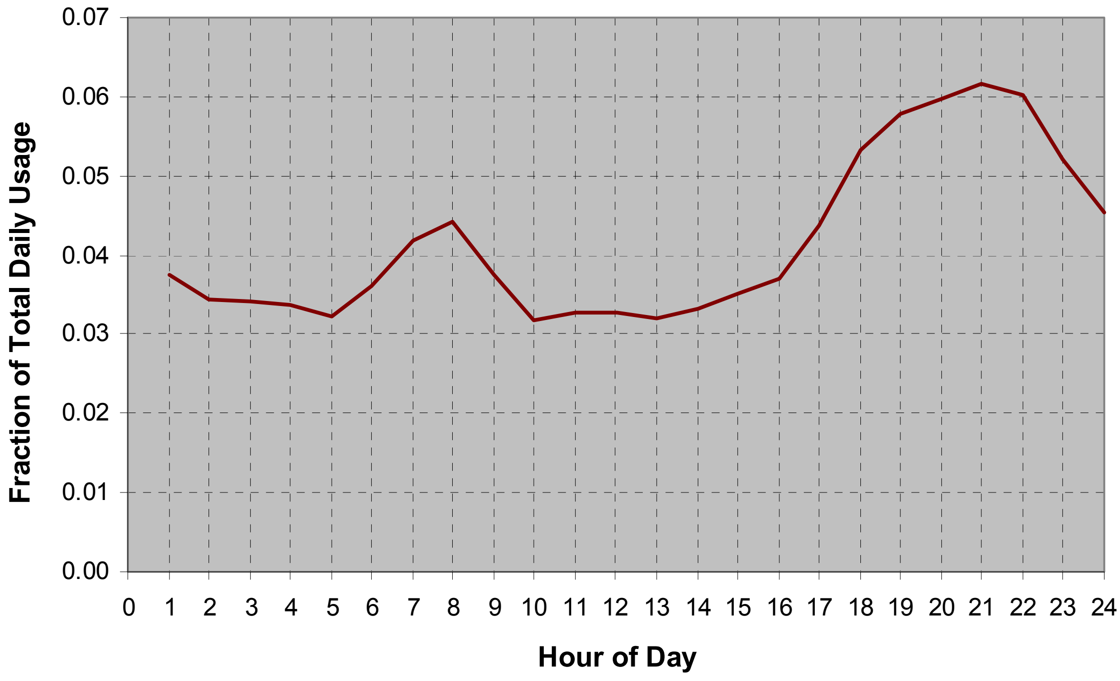


Figure 22. Miscellaneous electric loads normalized energy use profile

Site Generation

A review of data from the EIA (DOE 2001) 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, site electricity generation must be included in the whole-house energy performance analysis of the Prototype.

Modeling the Prototype

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

- Any house characteristics that are unknown and are not part of the package of energy efficiency improvements shall be the same as the Benchmark.

- The effective leakage area for the Prototype shall be calculated based on blower door testing conducted in accordance with ASTM E779. Guarded blower door tests shall be conducted in attached housing to disaggregate leakage to the outside from leakage to adjacent units (see SWA 1995 for guidance on this technique). If the whole-house simulation tool cannot calculate hourly infiltration based on effective leakage area, an annual average natural infiltration rate may be used based on the guidelines in ASHRAE Standard 119 (ASHRAE 1988), Section 5, and ASHRAE Standard 136 (ASHRAE 1993), Section 4. It is recommended that blower door measurements be supplemented with tracer gas testing when possible.

- If the Prototype does not have a cooling system, but there is a non-zero cooling load, the Prototype shall be modeled assuming a standard 10 SEER air conditioner connected to the heating ducts. If the Prototype does not have a duct system for heating, the air conditioner shall be modeled as a ductless 10 SEER room air conditioner.

- Mechanical ventilation shall be combined with natural infiltration in accordance with Section 4.4 of ASHRAE Standard 136 to determine an approximate combined infiltration rate.

- If the actual EER for the Prototype is not readily available, Equation 13 may be used to make an approximate conversion from SEER to EER (Wassmer 2003):

Equation 13: $$\mathbf{EER = -0.02 \times SEER^2 + 1.12 \times SEER}$$

- If the Prototype has a hot water distribution system different from the Benchmark (see Table 13), the equations in Table 18 shall be used to determine the change in daily hot water volume, internal heat gain, change in recovery load on the water heater, and any special pump energy. For any distribution system type not listed in Table 18, the Benchmark distribution system shall be applied to both houses, unless the analyst has performed a detailed energy analysis of the distribution system using HWSIM or a similar tool. For all distribution systems, the heat gain, recovery load, and pump energy shall be applied using the combined hourly DHW profile in Figure 11. The change in hot water use shall be applied in accordance with the corresponding end-use DHW profile. The BA Analysis Spreadsheet automates these calculations based on the distribution system characteristics entered for the Prototype.

- If the Prototype does not have a clothes washer, the Prototype shall be modeled with the Benchmark clothes washer and dryer.

- The optional DHW event characteristics for the Benchmark (see Table 12) may be modified if the Prototype includes low-flow fixtures, an alternative distribution system, or energy efficient appliances. The DHW Event Generation Tool must be used to create the event schedules for the Prototype if the Standard DHW Event Schedules are not used.

- 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 profiles. 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), and the actual performance characteristics of the appliances. 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 using Equation 14:

  Equation 14: Clothes washer cycles per year = (392) × (½+N_{br}/6) × 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
  N_{br} = number of bedrooms

  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 × 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) × (½ + N_{br}/6)

  The BA Analysis Spreadsheet posted on the BA Web site automates these calculations, and is strongly recommended for the analysis of water-consuming appliances. The spreadsheet includes equations 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 hot water and cold water temperatures for the Prototype house that are different from the test values (140°F and 60°F/50°F), 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.

- Energy savings for a new range/oven may be credited only if an energy factor has been determined in accordance with the DOE test procedures for cooking appliances (DOE 1997). Annual energy consumption is then estimated as the product of the energy factor and the annual useful cooking energy output as defined in the same test procedure. This calculation is also automated in the BA Analysis Spreadsheet. If the energy factor is unknown for a new range/oven, then it shall be assumed that the Prototype energy use for cooking is the same as the Benchmark.

- Modifications to the Benchmark lighting profile and operating hours due to occupancy sensors or other controls may be considered for the Prototype, but negative and/or positive effects on space conditioning load must also be calculated, assuming 100% of interior lighting energy contributes to the internal sensible load.

- Internal heat gains associated with all end-uses shall be adjusted in proportion to the difference in energy use for the Prototype relative to the Benchmark, and the hourly profile for internal heat gains shall be the same as the corresponding Benchmark hourly profile for energy use.

- 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).

Table 18. Effects of Alternative DHW Distribution Systems on Daily Hot Water Volume, Internal Heat Gains, and Recovery Load

Prototype Dist. System Type	Attribute	Shower	Bath	Sink
Trunk and branch, copper, in basement or conditioned space, no recirculation	Daily increase in hot water volume (gal/day)	$\{-0.305 - 0.075 \times N_{br}\} \times \frac{R_{ins}}{2}$	$\{0.03 - 0.03 \times N_{br}\} \times \frac{R_{ins}}{2}$	$\{-0.755 - 0.245 \times N_{br}\} \times \frac{R_{ins}}{2}$
	Daily internal heat gain (Btu/day)	$\left\{4257 + 735 \times (N_{br} - 3) - \{948 + 158 \times (N_{br} - 3)\} \times \frac{R_{ins}}{2}\right\} \times \left\{1 + \frac{1}{4257} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	0		
	Pump energy (kWh/yr)	0		
Trunk and branch, PEX, in basement or conditioned space, no recirculation	Daily increase in hot water volume (gal/day)	$-0.85 - 0.44 \times \frac{R_{ins}}{2}$	$-0.12 - 0.06 \times \frac{R_{ins}}{2}$	$-1.69 - 1.74 \times \frac{R_{ins}}{2}$
	Daily internal heat gain (Btu/day)	$\left\{4257 - 1047 - 732 \times \frac{R_{ins}}{2}\right\} \times \left\{1 + \frac{1}{4257} \times 735 \times (N_{br} - 3) + \frac{1}{4257} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	0		
	Pump energy (kWh/yr)	0		
Trunk and branch, copper, in unconditioned attic and conditioned space, non-freezing climate	Daily increase in hot water volume (gal/day)	$\left(\{-1.14 - 0.36 \times N_{br}\} + (-0.34 - 0.08 \times N_{br}) \times \frac{R_{ins}}{2}\right) \times \left\{1 + 0.11 \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$	$\left(\{-0.28 - 0.11 \times N_{br}\} + (0.06 - 0.04 \times N_{br}) \times \frac{R_{ins}}{2}\right) \times \left\{1 + 0.13 \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$	$\left(\{-0.89 - 0.32 \times N_{br}\} + (-1.86 + 0.31 \times N_{br}) \times \frac{R_{ins}}{2}\right) \times \left\{1 + 0.16 \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$
	Daily internal heat gain (Btu/day)	$\left\{4257 + 735 \times (N_{br} - 3) - [3356 + 589 \times (N_{br} - 3)] - \left[\{90 + 11 \times (N_{br} - 3)\} \times \frac{R_{ins}}{2}\right]\right\} \times \left\{1 + \frac{1}{4257} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	0		
	Pump energy (kWh/yr)	0		
Trunk and branch, PEX, in unconditioned attic and conditioned	Daily increase in hot water volume (gal/day)*	$-0.85 + \frac{V_{b,sh} - 0.85}{V_{b,sh}} \times \{\{-1.14 - 0.36 \times N_{br}\} + (-0.34 - 0.08 \times N_{br}) \times \frac{R_{ins}}{2}\} \times$	$-0.12 + \frac{V_{b,ba} - 0.12}{V_{b,ba}} \times \{\{-0.28 - 0.11 \times N_{br}\} + (0.06 - 0.04 \times N_{br}) \times \frac{R_{ins}}{2}\} \times$	$-1.69 + \frac{V_{b,si} - 1.69}{V_{b,,sk}} \times \{\{-0.89 - 0.32 \times N_{br}\} + (-1.86 + 0.31 \times N_{br}) \times \frac{R_{ins}}{2}\} \times$

space, non-freezing climate		$\left\{1+0.11\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$	$\left\{1+0.13\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$	$\left\{1+0.16\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$
	Daily internal heat gain (Btu/day)	$\{4257-1047\}\times\left\{1+\frac{1}{4257}\times 735\times(N_{br}-3)-\frac{1}{4257}\times\left([3356+589\times(N_{br}-3)]+\left[\{90+11\times(N_{br}-3)\}\times\frac{R_{ins}}{2}\right]\right)\right\}\times\left\{1+\frac{1}{4257}\times[362+\{63\times(N_{br}-3)\}]\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	0		
	Pump energy (kWh/yr)	0		
Home Run plumbing, in basement or conditioned space, no recirculation	Daily increase in hot water volume (gal/day)	$\{-0.52-0.23\times N_{br}\}+(-0.35+0.02\times N_{br})\times\frac{R_{ins}}{2}$	$\{-0.06-0.05\times N_{br}\}+(-0.11+0.03\times N_{br})\times\frac{R_{ins}}{2}$	$\{+0.21-0.72\times N_{br}\}+(-0.75-0.15\times N_{br})\times\frac{R_{ins}}{2}$
	Daily internal heat gain (Btu/day)	$\left\{4257+735\times(N_{br}-3)-[1142+378\times(N_{br}-3)]-\left[\{649+73\times(N_{br}-3)\}\times\frac{R_{ins}}{2}\right]\right\}\times\left\{1+\frac{1}{4257}\times[362+\{63\times(N_{br}-3)\}]\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	0		
	Pump energy (kWh/yr)	0		
Home Run plumbing, in unconditioned attic and conditioned space, non-freezing climate, no recirculation	Daily increase in hot water volume (gal/day)	$-0.52-0.23\times N_{br}+\frac{V_{b,sh}-0.52-0.23\times N_{br}}{V_{b,sh}}\times\left\{\{-1.14-0.36\times N_{br}\}+(-0.34-0.08\times N_{br})\times\frac{R_{ins}}{2}\right\}\times\left\{1+0.11\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$	$-0.06-0.05\times N_{br}+\frac{V_{b,ba}-0.06-0.05\times N_{br}}{V_{b,bath}}\times\left\{\{-0.28-0.11\times N_{br}\}+(0.06-0.04\times N_{br})\times\frac{R_{ins}}{2}\right\}\times\left\{1+0.13\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$	$0.21-0.72\times N_{br}+\frac{V_{b,si}+0.21-0.72\times N_{br}}{V_{b,si}}\times\left\{\{-0.89-0.32\times N_{br}\}+(-1.86+0.31\times N_{br})\times\frac{R_{ins}}{2}\right\}\times\left\{1+0.16\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$
	Daily internal heat gain (Btu/day)	$\left[\{4257+735\times(N_{br}-3)-[1142+378\times(N_{br}-3)]\right]\times\left\{1-\frac{1}{4257}\times\left([3356+589\times(N_{br}-3)]+\left[\{90+11\times(N_{br}-3)\}\times\frac{R_{ins}}{2}\right]\right)\right\}\right]\times\left\{1+\frac{1}{4257}\times[362+\{63\times(N_{br}-3)\}]\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	0		
	Pump energy (kWh/yr)	0		
Trunk and branch, copper, in basement or conditioned space, timed recirculation	Daily increase in hot water volume (gal/day)	$\{-2.15+.25\times N_{br}\}+(-0.16-0.08\times N_{br})\times\frac{R_{ins}}{2}$	$\{-0.27+0.04\times N_{br}\}+(-0.01-0.03\times N_{br})\times\frac{R_{ins}}{2}$	$\{-2.01-0.95\times N_{br}\}+(-0.36-0.13\times N_{br})\times\frac{R_{ins}}{2}$
	Daily internal heat gain (Btu/day)	$\left\{4257+735\times(N_{br}-3)+[20{,}148+2140\times(N_{br}-3)]-\left[\{11{,}956+1355\times(N_{br}-3)\}\times\frac{R_{ins}}{2}\right]\right\}\times\left\{1+\frac{1}{4257}\times[362+\{63\times(N_{br}-3)\}]\times\sin\left(2\pi\times\left(\frac{Month}{12}+.3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	$\left\{18{,}135+2538\times N_{br}+(-12{,}265-1495\times N_{br})\times\frac{R_{ins}}{2}\right\}/\{8.33\times(120-T_{mains})\times 4184\times 0.00023886\}$		
	Pump energy (kWh/yr)	193		

Trunk and branch, copper, in basement or conditioned space, demand recirculation	Daily increase in hot water volume (gal/day)	$\{-2.61 + .35 \times N_{br}\} + (0.05 - 0.13 \times N_{br}) \times \frac{R_{ins}}{2}$	$\{-0.26 + 0.01 \times N_{br}\} + (-0.03 - 0.00 \times N_{br}) \times \frac{R_{ins}}{2}$	$\{-1.34 - 0.91 \times N_{br}\} + (-0.64 - 0.07 \times N_{br}) \times \frac{R_{ins}}{2}$
	Daily internal heat gain (Btu/day)	$\left\{4257 + 735 \times (N_{br} - 3) + [1458 + 1066 \times (N_{br} - 3)] - \left[\{1332 + 545 \times (N_{br} - 3)\} \times \frac{R_{ins}}{2}\right]\right\} \times \left\{1 + \frac{1}{4257} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	$\left\{-3648+2344 \times N_{br} + (-1328 - 761 \times N_{br}) \times \frac{R_{ins}}{2}\right\} / \{8.33 \times (120 - T_{mains}) \times 4184 \times 0.00023886\}$		
	Pump energy (kWh/yr)	$-0.13+0.72 \times N_{br} + (0.13 - 0.17 \times N_{br}) \times \frac{R_{ins}}{2}$		
Trunk and branch, PEX, in basement or conditioned space, timed recirculation	Daily increase in hot water volume (gal/day)	$-0.85 + \frac{V_{b,sh}-0.85}{V_{b,sh}} \times \left\{\{-2.15 + .25 \times N_{br}\} + (-0.16 - 0.08 \times N_{br}) \times \frac{R_{ins}}{2}\right\}$	$-0.12 + \frac{V_{b,ba}-0.12}{V_{b,ba}} \times \left\{\{-0.27 + 0.04 \times N_{br}\} + (-0.01 - 0.03 \times N_{br}) \times \frac{R_{ins}}{2}\right\}$	$-1.69 + \frac{V_{b,si}-1.69}{V_{b,si}} \times \left\{\{-2.01 - 0.95 \times N_{br}\} + (-0.36 - 0.13 \times N_{br}) \times \frac{R_{ins}}{2}\right\}$
	Daily internal heat gain (Btu/day)	$[4257 - 1047] \times \left\{1 + \frac{1}{4257} \times 735 \times (N_{br} - 3) + \frac{1}{4257} \times [20{,}148 + 2140 \times (N_{br} - 3)] - \frac{1}{4257} \times \left[\{11{,}956 + 1355 \times (N_{br} - 3)\} \times \frac{R_{ins}}{2}\right]\right\} \times \left\{1 + \frac{1}{4257} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left[2\pi \times \left(\frac{Month}{12} + .3\right)\right]\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	$\left\{18{,}135+2538 \times N_{br} + (-12{,}265 - 1495 \times N_{br}) \times \frac{R_{ins}}{2}\right\} / \{8.33 \times (120 - T_{mains}) \times 4184 \times 0.00023886\}$		
	Pump energy (kWh/yr)	193		
Trunk and branch, PEX, in basement or conditioned space, demand recirculation	Daily increase in hot water volume (gal/day)	$-0.85 + \frac{V_{b,sh}-0.85}{V_{b,sh}} \times \left\{\{-2.61 + .35 \times N_{br}\} + (0.05 - 0.13 \times N_{br}) \times \frac{R_{ins}}{2}\right\}$	$-0.12 + \frac{V_{b,ba}-0.12}{V_{b,ba}} \times \left\{\{-0.26 + 0.01 \times N_{br}\} + (-0.03 - 0.00 \times N_{br}) \times \frac{R_{ins}}{2}\right\}$	$-1.69 + \frac{V_{b,si}-1.69}{V_{b,si}} \times \left\{\{-1.34 - 0.91 \times N_{br}\} + (-0.64 - 0.07 \times N_{br}) \times \frac{R_{ins}}{2}\right\}$
	Daily internal heat gain (Btu/day)	$[4257 - 1047] \times \left\{1 + \frac{1}{4257} \times 735 \times (N_{br} - 3) + \frac{1}{4257} \times [1458 + 1066 \times (N_{br} - 3)] - \frac{1}{4257} \times \left[\{1332 + 545 \times (N_{br} - 3)\} \times \frac{R_{ins}}{2}\right]\right\} \times \left\{1 + \frac{1}{4257} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin\left[2\pi \times \left(\frac{Month}{12} + .3\right)\right]\right\}$		
	Recovery load as equivalent increase in hot water (gal/day)	$\left\{-3648+2344 \times N_{br} + (-1328 - 761 \times N_{br}) \times \frac{R_{ins}}{2}\right\} / \{8.33 \times (120 - T_{mains}) \times 4184 \times 0.00023886\}$		
	Pump energy (kWh/yr)	$-0.13+0.72 \times N_{br} + (0.13 - 0.17 \times N_{br}) \times \frac{R_{ins}}{2}$		

* Where $V_{b,x}$ is the average daily hot water use for showers (sh), baths (ba), or sinks (si) in the Benchmark.

Operating Conditions

The following operating conditions and other assumptions shall apply to both the Prototype house and the Benchmark. The operating conditions are based on the cumulative experience of the authors through their work on BA, HERS, Codes and Standards, and other residential energy efficiency programs.

- Thermostat set points based on the optimum seasonal temperature for human comfort as defined in ASHRAE Standard 55-1992 (ASHRAE 1992):

Set point for cooling:	76°F with no setup period
Set point for heating:	71°F with no setback period
Set point for dehumidification (if controlled):	60% relative humidity

- The natural ventilation schedule shall be set to reflect windows being opened occasionally. In situations where it is a Monday, Wednesday, or Friday and there is a cooling load, windows will be opened if the cooling capacity of outdoor air flow can maintain the cooling set point and the outdoor enthalpy is below the indoor enthalpy (in humid climates). The natural ventilation rate shall be calculated using the Sherman-Grimsrud model. Fifty percent of the maximum open area for windows on each facade and on each floor shall be open. Windows are assumed to be closed once the indoor temperature drops below 73°F or if the air change rate exceeds 20 ACH. If there are local circumstances that would tend to discourage window operation (pollution, high humidity, security, community standards, etc.), then it is acceptable to use a more appropriate schedule, as long as the same natural ventilation schedule is applied to both the Benchmark and Prototype. Mechanical ventilation fans shall be turned off when natural ventilation is being used.

- Interior shading multiplier = 0.7 when the cooling system is operating, and 0.85 at all other times.

- Internal heat gains from lighting, hot water fixtures and distribution systems, appliances, and MELs were discussed in previous sections. These loads are not necessarily the same for the Prototype and the Benchmark; therefore, they are not considered operating conditions for the purposes of Building America performance analysis.

- Annual cycles for clothes washers, dryers, and dishwashers calculated using the BA Analysis Spreadsheet are posted on the BA Web site.

- The occupancy schedule is defined with the same level of detail as other internal load profiles. For typical BA houses, the number of occupants shall be estimated based on the number of bedrooms using Equation 17.

  Equation 17: Number of occupants = 0.5 × N_{br} + 1.5

  where N_{br} = Number of bedrooms

  Sensible and latent gains shall be accounted for separately, and different loads shall be applied in different space types when possible, as described in Table 19. The occupant heat gains are based on ASHRAE recommendations (ASHRAE 2001). The average hourly occupancy profile is shown in Figure 23, and an example set of detailed hourly occupancy curves is shown in Figure 24. Example occupancy profiles for different day and room types are available in spreadsheet format on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html). These profiles, which were developed by NREL, are based on the basic ASHRAE occupancy schedule combined with engineering judgment.

Table 19. Peak Sensible and Latent Heat Gain from Occupants (ASHRAE 2001)

Multiple Zones	Internal Load (Btu/person/hr)
Living Area Sensible Load	230
Living Area Latent Load	190
Bedroom Area Sensible Load	210
Bedroom Area Latent Load	140
Single Zone	**Internal Load (Btu/person/hr)**
Sensible Load	220
Latent Load	164

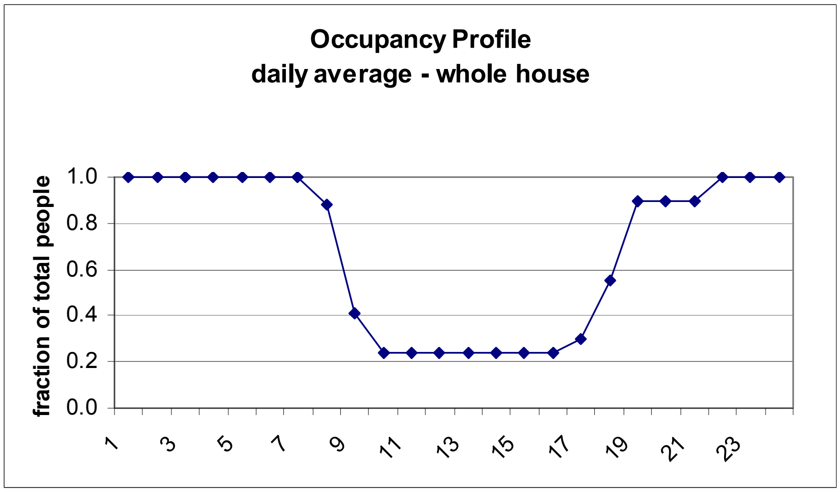


Figure 23. Average hourly load profile from occupants for all day-types and family types (16.5 hours/day/person total)

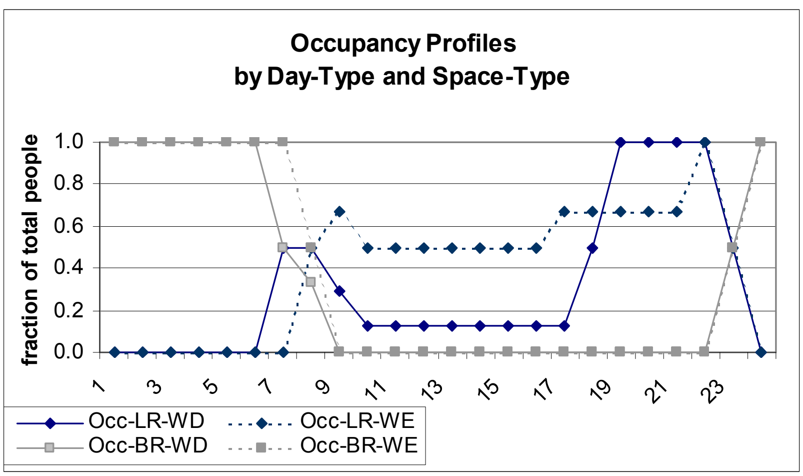


Figure 24. Detailed hourly load profiles resulting from occupants being in different parts of the house on weekdays (WD) and weekends (WE)

- 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 (TMY3) data from 1991–2005[4] or equivalent data for the nearest weather station.

- Heating and cooling shall be available during all months of the year to control indoor air temperature.

[4] Analytic Studies Division, NREL (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3).

Reporting Energy Use, Energy Savings, and Cost Neutrality

Reporting energy use and energy savings in a consistent format is an important component of BA analysis. The following tables shall be supplied with the analysis report for every BA Prototype.

Table 20 shows an example of a site energy consumption report for a hypothetical Prototype, along with all relevant base cases. Similar information based on source energy is presented in Table 21, along with percent energy savings for each end use. End uses are described in more detail in Table 22.

The "Percent of End Use" columns in Table 21 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 shall be determined using Equation 18, using the site-to-source multipliers in Table 23.

Equation 18: $$\textbf{Source MBtu} = \textbf{kWh} * 3.412 * M_e / 1000 + \textbf{therms} * M_g / 10 + \textbf{MBtu} * M_o$$

where M_e = 3.365 = site to source multiplier for electricity
M_g = 1.092 = site to source multiplier for natural gas
M_o = site to source multiplier for all other fuels (See Table 24)

Table 20. Example Summary of Site Energy Consumption by End Use Using BA Research Benchmark

	Annual Site Energy							
	BA Benchmark		Region Standard		Builder Standard		BA Prototype	
End Use	(kWh)	(therms)	(kWh)	(therms)	(kWh)	(therms)	(kWh)	(therms)
Space Heating	11,225	0	11,286	0	11,286	0	4,397	0
Space Cooling	2,732	0	2,432	0	2,432	0	902	0
DHW	4,837	0	4,838	0	4,838	0	1,351	0
Lighting	3,110		3,110		3,110		1,204	
Appliances & MELs	7,646	0	7,646	0	7,646	0	7,436	0
OA Ventilation	400		400		400		400	
Total Usage	29,950	0	29,712	0	29,712	0	15,690	0
Site Generation	0	0	0	0	0	0	7,402	0
Net Energy Use	29,950	0	29,712	0	29,712	0	8,289	0

Table 21. Example Summary of Source Energy Consumption by End Use Using Building America Research Benchmark

End Use	Estimated Annual Source Energy Benchmark (MBtu/yr)	Region (MBtu/yr)	Builder (MBtu/yr)	Proto (MBtu/yr)	Source Energy Savings: Percent of End-Use BA Base	Reg Base	Bldr Base	Percent of Total 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 & MELs	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 22. 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 backup HP supplemental heat, gas ignition standby
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 water heater, HP water heater, hot-water circulation pumps	Gas hot-water heater
Lighting	Indoor lighting, outdoor lighting	None
Appliances & MELs	Refrigerator, electric clothes dryer, gas clothes dryer (motor), cooking, miscellaneous electric loads	Cooking, gas clothes dryer, gas fireplace
OA Ventilation	Ventilation fans, air handler during ventilation mode	None
Site Generation	Photovoltaic electric generation	None

Table 23. Source Energy Factors for Energy Delivered to Buildings (Deru and Torcellini 2007)

Energy Source	Source Energy Factor
Electricity	3.365
Natural Gas	1.092
Fuel Oil/Kerosene	1.158
Gasoline	1.187
LPG	1.151

Table 24 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 to the Builder Standard Practice (representing a real design or set of practices that is currently being used by the builder) rather than to 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.

Reporting of peak hourly energy consumption is also encouraged 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.

Every Prototype house performance analysis shall include documentation of whether the house meets the cost neutrality definition established as a "Should Meet" criterion for Gate 2 and a "Must Meet" criterion for Gate 3 of the Building America Stage-Gate Process. The "Summary of Technical Reporting Requirements" (Anderson 2008) defines neutral cost as the following:

> "The final incremental annual cost of energy improvements, when financed as part of a 30-year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the BA benchmark house."

The "annual reduction in utility bill costs relative to the BA benchmark house" is simply the difference between the two yellow cells in Table 24. This represents the estimated energy cost savings of the Prototype house compared to the Benchmark house based on current local utility costs.

The "final incremental annual cost of energy improvements" shall be the analyst's best estimate of the increased cost of the technology package relative to minimum code, when financed as part of a 30-year mortgage at a 7% interest rate. The incremental cost shall include a reasonable markup, no less than 10%, to cover builder operating costs and profit. Cost relative to minimum code can be estimated in either two steps or one:

1. Incremental cost of builder standard practice (see Hendron et al. 2004) relative to minimum code, plus,
2. Incremental cost of the Prototype relative to builder standard practice;

   Or,

1. Incremental cost of the Prototype relative to minimum code.

The cost of the Prototype, builder standard practice, and minimum code house shall be calculated using the following approach:

- First cost only (do not include replacement or maintenance costs).
- Financed as part of a 30-year mortgage at an interest rate of 7%.
- First cost shall be the estimated mature cost of new technologies at 5% market penetration in new homes.
- Cost incentives such as subsidies and tax credits shall be noted, but not included in the incremental cost for the Prototype. Such incentives must be documented in the analysis, including the nature of the incentive, the amount, who receives it, and the expected duration of the incentive.

- The minimum code house shall be the least energy efficient house allowed by the relevant local or state energy codes. If no energy code exists for the locality, then the Benchmark shall be used as the cost reference, but with federal minimum standard equipment for space conditioning, water heating, lighting, and appliances.
- The cost of HERS ratings or other energy-related 3rd party certifications shall be included in the Prototype cost.

Neutral cost calculations shall be performed using the "Cost Neutrality" tab of the BA Performance Analysis Spreadsheet (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html).

Table 24. Example Measure Savings Report[5] Using Building America Research Benchmark

					National Average		Builder Standard (Local Costs)			
	Site Energy		Est. Source Energy		Energy Cost		Energy Cost		Measure	Package
Increment	(kWh)	(therms)	(MBtu)	Savings (%)	($/yr)	Savings (%)	($/yr)	Savings (%)	Value ($/yr)	Savings ($/yr)
Bldg America Benchmark	29,950	0	306.9		$ 2,995		$ 2,950			
Regional Std Practice	29,712	0	304.4	1%	$ 2,971	1%	$ 2,927			
Builder Std Practice (BSP)	29,712	0	304.4	1%	$ 2,971	1%	$ 2,927			
BSP + improved walls	27,779	0	284.6	7%	$ 2,778	7%	$ 2,736	7%	$ 190.4	$ 190
BSP ++ Low-E Windows	25,810	0	264.5	14%	$ 2,581	14%	$ 2,542	13%	$ 193.9	$ 384
BSP ++ Smaller A/C (5 -> 4 tons)	25,420	0	260.5	15%	$ 2,542	15%	$ 2,504	14%	$ 38.4	$ 423
BSP ++ Inc. Bsmt Wall Insulation	25,170	0	257.9	16%	$ 2,517	16%	$ 2,479	15%	$ 24.6	$ 447
BSP ++ Ground Source HP (+DHW)	19,331	0	198.1	35%	$ 1,933	35%	$ 1,904	35%	$ 575.1	$ 1,023
BSP ++ Solar DHW	17,718	0	181.5	41%	$ 1,772	41%	$ 1,745	40%	$ 158.9	$ 1,181
BSP ++ Lighting, Appl. & Plug	15,690	0	160.8	48%	$ 1,569	48%	$ 1,545	47%	$ 199.8	$ 1,381
Site Generation										
BSP ++ PV	8,288	0	84.9	72%	$ 829		$ 816	72%	$ 729.0	$ 2,110

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

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
December 2008

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Building America Research Benchmark Definition: Updated December 29, 2008

5a. CONTRACT NUMBER
DE-AC36-08-GO28308

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
R. Hendron

5d. PROJECT NUMBER
NREL/TP-550-44816

5e. TASK NUMBER
BET8.8004

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-550-44816

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
To track progress toward aggressive multi-year whole-house energy savings goals of 40-70% and onsite power production of up to 30%, DOE's Residential Buildings Program and NREL developed the Building America Research Benchmark in consultation with the Building America industry teams. The Benchmark is generally consistent with mid-1990s standard practice, as reflected in the Home Energy Rating System (HERS) Technical Guidelines (RESNET 2002), with additional definitions that allow the analyst to evaluate all residential end-uses, an extension of the traditional HERS rating approach that focuses on space conditioning and hot water. Unlike the reference homes used for HERS, EnergyStar, and most energy codes, the Benchmark represents typical construction at a fixed point in time so it can be used as the basis for Building America's multi-year energy savings goals without the complication of chasing a 'moving target'.

15. SUBJECT TERMS
benchmark; building america; home energy rating system; hers

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER (*Include area code*)

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

F1147-E(10/2008)