1-2010

Building America research benchmark definition: Updated December 2009

R. Hendron

C. Engebrecht

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

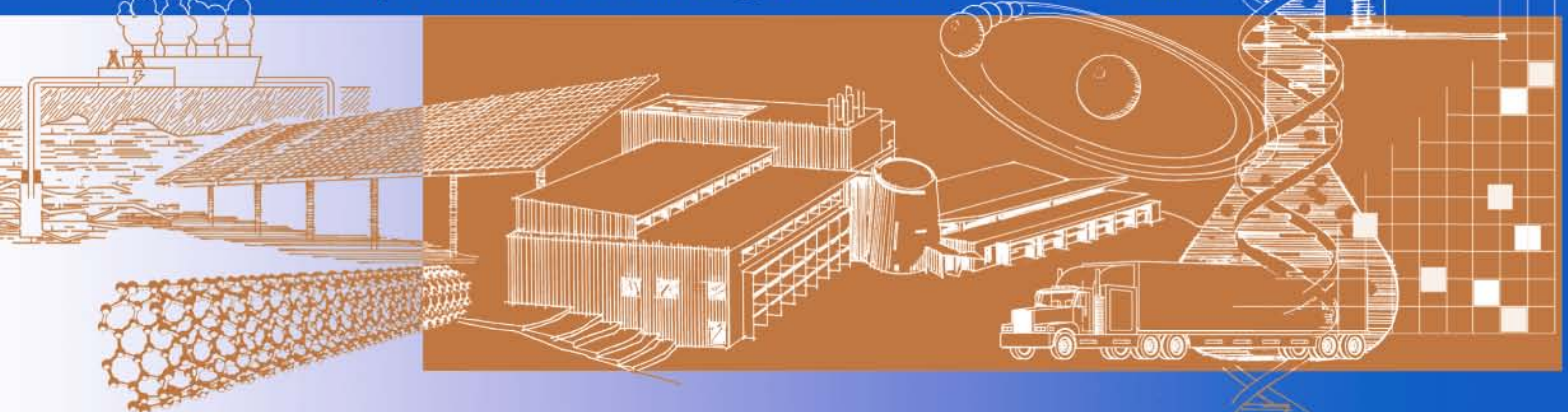
Building America Research Benchmark Definition

Updated December 2009

Robert Hendron and Cheryn Engebrecht

Technical Report
NREL/TP-550-47246
January 2010

NREL is operated for DOE by the Alliance for Sustainable Energy, LLC   Contract No. DE-AC36-08-GO28308



Building America Research Benchmark Definition

Updated December 2009

Robert Hendron and Cheryn Engebrecht

Technical Report
NREL/TP-550-47246
January 2010

Prepared under Task No. BE10.1001

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

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Contract No. DE-AC36-08-GO28308

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

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

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

Contents

Figures

Tables

Definitions

A/C	air conditioning
ACCA	Air Conditioning Contractors of America
AFUE	Annual Fuel Utilization Efficiency
ASHRAE	American Society of Heating, Refrigerating and 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
COU	coefficient of utilization
DEG	Davis Energy Group
DHW	domestic hot water
DOE	U.S. Department of Energy
DSE	distribution system efficiency
DUF	dryer usage factor
EER	energy efficiency ratio
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
IESNA	Illuminating Engineering Society of North America
LBNL	Lawrence Berkeley National Laboratory
MEL	miscellaneous electric load
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
SHGC	solar heat gain coefficient
SLA	specific leakage area
TMY3	Typical Meteorological Year, Version 2
TPU	Tacoma Public Utilities
TRNSYS	TRaNsient SYstem Simulation Program
UA	heat loss coefficient

Introduction

To track progress toward aggressive multi-year, whole-house energy savings goals of 40%–70% and on-site 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 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, 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 more and more 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, as well as multi-family housing.

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 multi-year 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 FY 2010 BA funding agreements. A comprehensive description of other important BA 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 BA 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 (FSEC) 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.

The Benchmark may be applied to either a single-family or multi-family home. A single-family home is contained within walls that go from the basement or the ground floor (if there is no basement) to the roof. A single-family attached home is defined as a single-family home with one or more stories that shares one or more walls with another unit. The single-family attached home definition includes, but is not limited to, duplexes, row houses, and townhomes.

A multi-family home (or multi-family building) is defined as a building with at least five housing units. Each multi-family housing unit must share at least a floor or a ceiling with another unit. Also, there may be no more than three stories for a given multi-family building, otherwise it is considered a commercial building, which is outside the scope of this document. These definitions are consistent with those provided by the RECS database (except the requirement on the number of units).

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 degrees from a horizontal plane
- Window area (A_F), including framing, determined by Equation 1 for detached homes, by Equation 2 for attached homes, and by Equation 3 for multi-family homes (regardless of whether the hallways are interior or exterior).

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

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

Equation 3:[2] $\mathbf{A_F = 0.37 \times A_{FL,Liv} \times F_{A,Liv} \times F}$

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),

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

[2] Equation 3 stems from an interpretation of NREL's Commercial Benchmark (2009) for mid-rise apartment buildings.

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.

- Thirty-three percent of the window area on each facade can be opened for the purpose of natural ventilation.
- Either of two approaches may be used to achieve solar neutrality for the Benchmark.
  - Option 1: The window area calculated above is distributed with the same proportion on each wall and on each floor as the Prototype house. 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.
  - Option 2: The window area is distributed equally on each of the four walls (including attached walls), and the orientation of the Benchmark is the same as the Prototype.
- 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 Table 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/h·ft²·°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 and Multi-Family Buildings (excerpted from ICC 2003)

Heating Degree Days Base 65 (HDD65) From Nearest Location	U_w Air to Air, Includes Framing (Btu/h·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/h·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 typical meteorological year (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). The ventilation rate shall be the same in the Benchmark as the Prototype, regardless of whether the ventilation is natural or fan induced.
- 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 2500 heating degree-days. If the Prototype includes an attic, the Benchmark shall have an unconditioned attic with insulation at the attic floor.

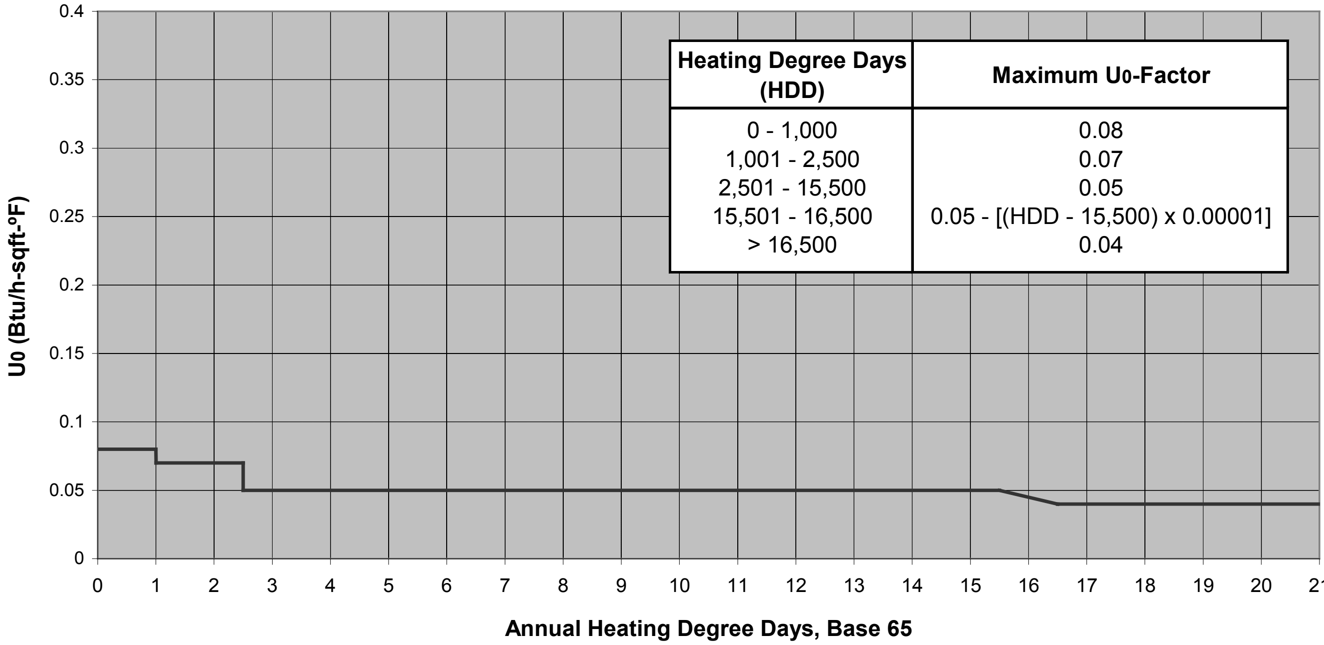


Figure 1. U-value of floor over unconditioned space (excerpted from ICC 2003)

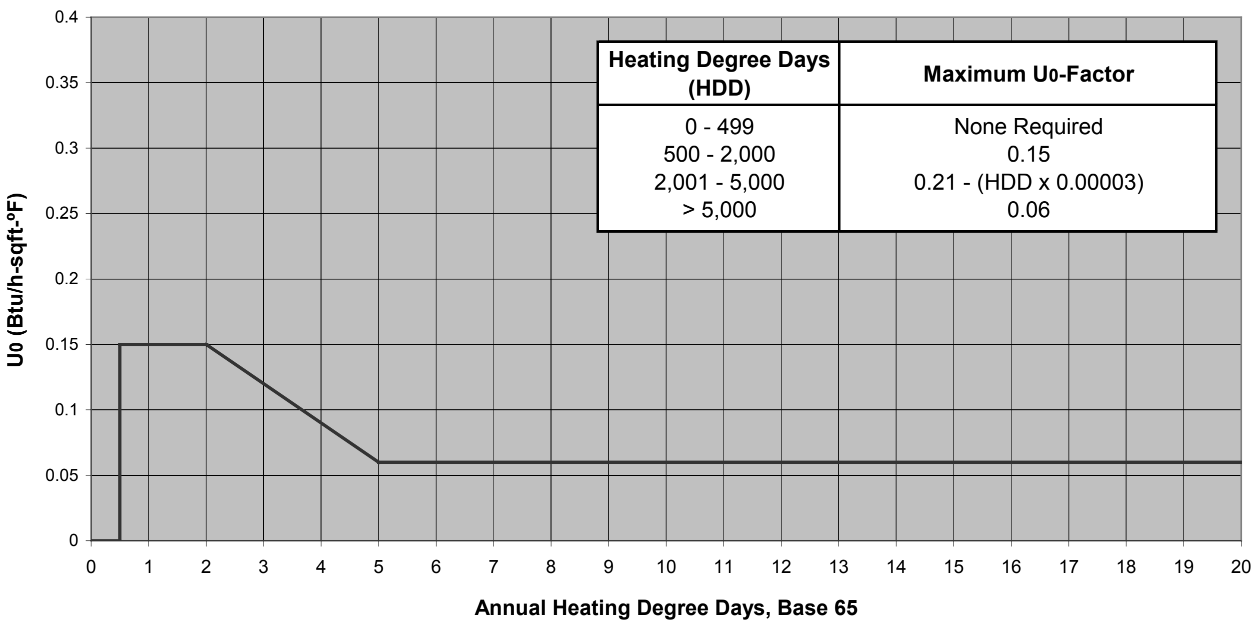
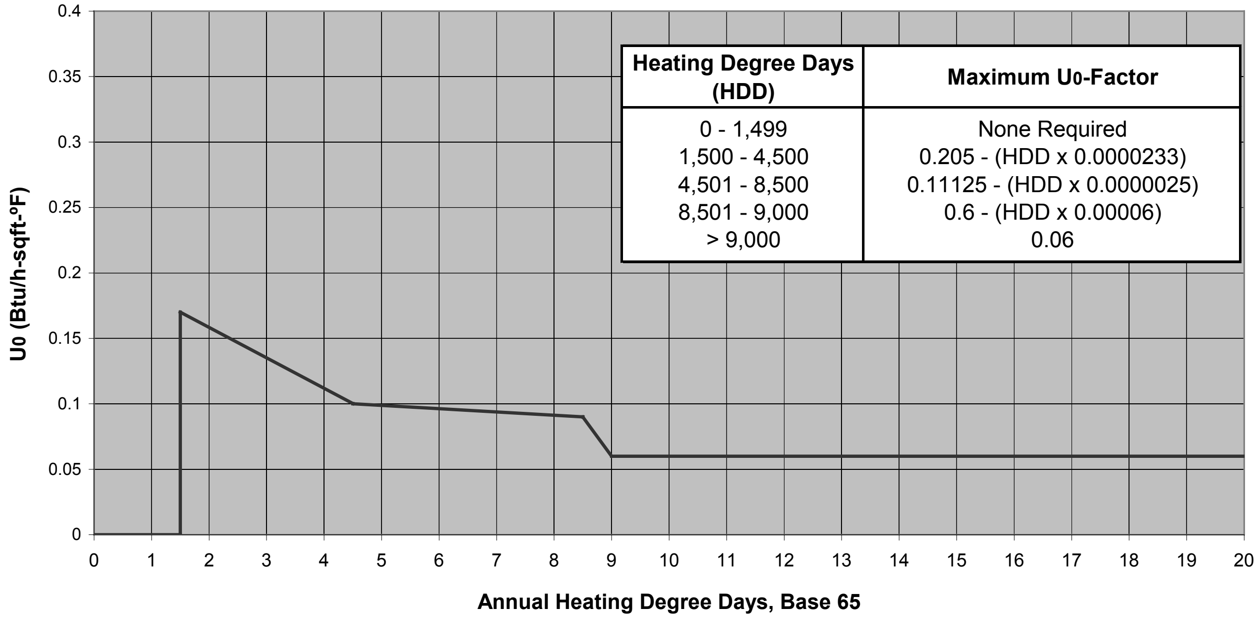
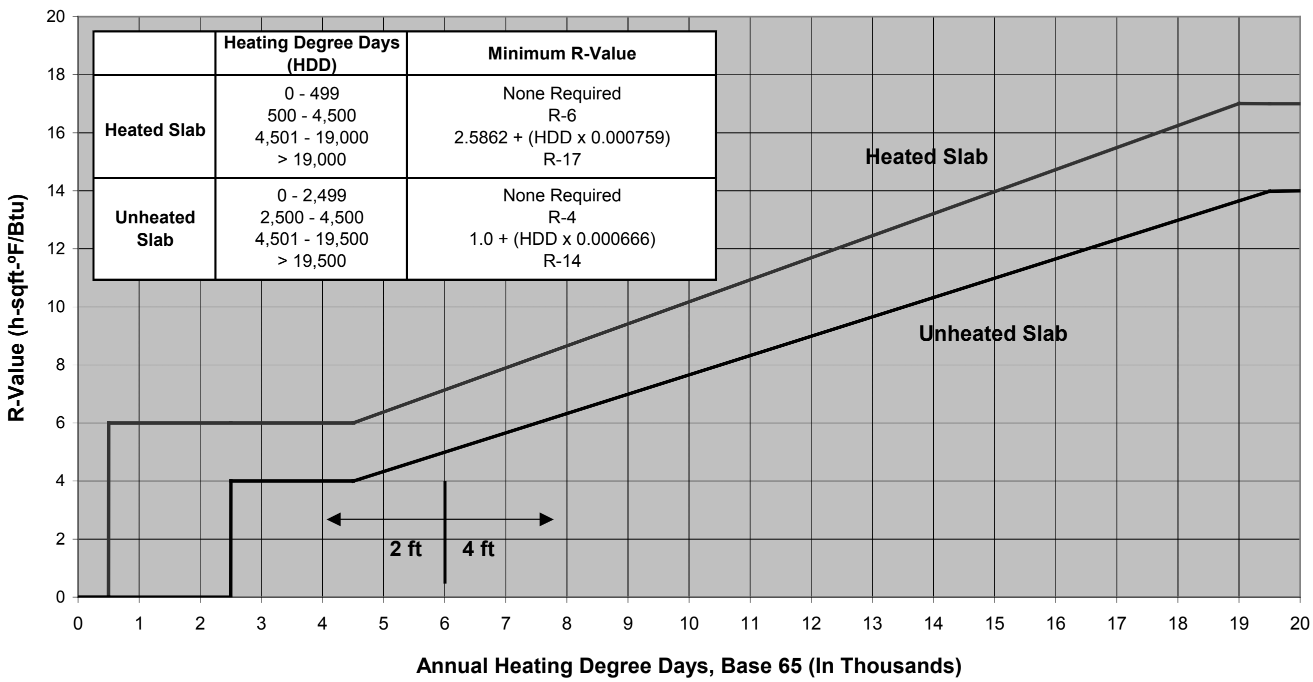


Figure 2. Crawl space wall U-value (excerpted from ICC 2003)



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

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



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

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

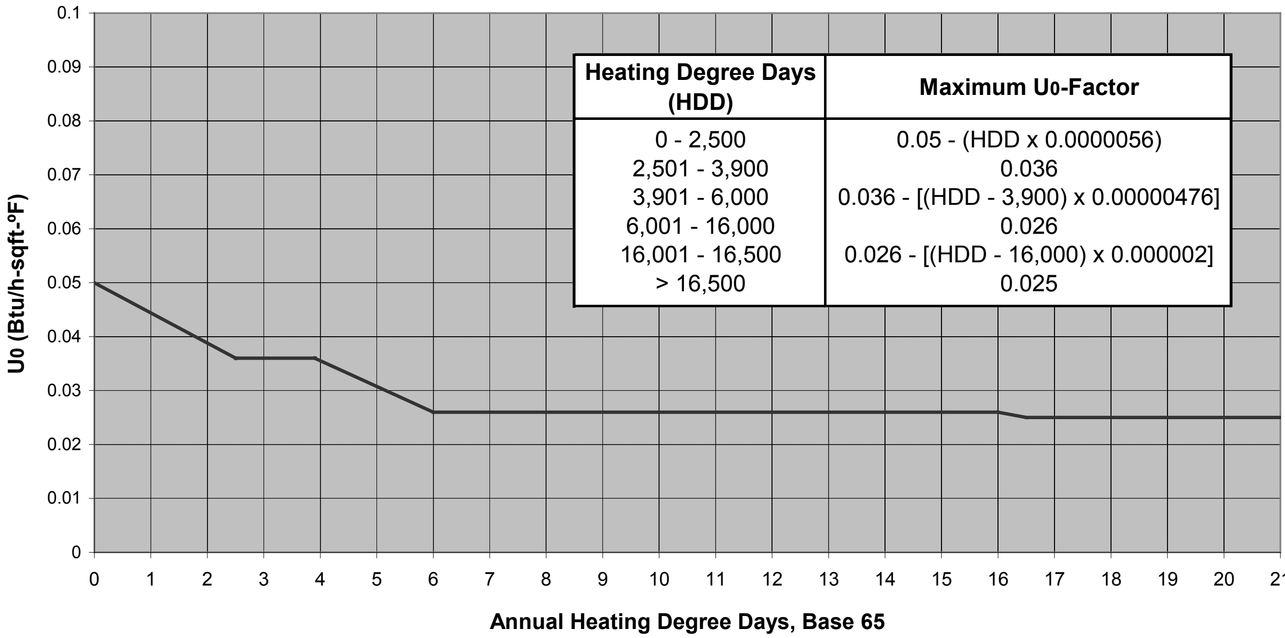


Figure 5. Roof/ceiling assembly U-value (excerpted from ICC 2003)

- 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/h·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 4 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** (in. 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. For multi-family buildings, the framing between floors will be 2 × 10 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:

- For detached or attached single-family homes, or multi-family homes with individual space conditioning systems, 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.

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 Combination 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

* Annual Fuel Utilization Efficiency
** 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.

- For centralized systems in multi-family homes, the Benchmark shall have individual systems with the characteristics shown in Table 5. The space heating distribution system shall be the same (e.g. baseboard heating, radiant floor), but the cooling distribution in the Benchmark shall always be forced-air.

- 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 4. If the actual EER for the Prototype is not readily available, Equation 4 may also be used to make an approximate conversion from SEER to EER (Wassmer 2003):

Equation 4: $$EER = -0.02 \times SEER^2 + 1.12 \times SEER$$

- Heating and cooling equipment (including the air handler) shall be sized using the procedures published by the Air Conditioning Contractors of America (ACCA). (See http://www.acca.org/store/category.php?cid=1.)
- 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 l/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.

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 American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 152P (ASHRAE 2001b). A spreadsheet developed by Lawrence Berkeley National Laboratory (LBNL) has been modified by NREL and integrated into the Building America 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*	Benchmark Duct Specification: *Two-Story or Higher*
Supply Duct Surface Area (ft^2)	All	0.27 × FFA[a]	0.20 × FFA
Return Duct Surface Area (ft^2)	All	0.05 x $N_{returns}$ × FFA (Maximum of 0.25 × FFA)	0.04 x $N_{returns}$ × FFA (Maximum of 0.19 × 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 crawl space	100% Outside air[c]	60% Outside air[c]
	Multi-family	100% Outside air[c]	100% 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
	Multi-family	100% Conditioned Space	100% 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
	Multi-family	100% Conditioned space	100% Conditioned space
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 crawl space or multi-family unit	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 Table 7 and Table 8 shall be used for the domestic hot water (DHW) system in the Benchmark. For multi-family housing units with a central hot water system, the Benchmark shall have individual systems using the same fuel type. 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 National Appliance Energy Conservation Act 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 × V)	0.62 – (0.0019 × 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*	
Tank Location	Same as Prototype	

* 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/h)	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/h
Supply Temperature	120°F	
Fuel Type	Same as Prototype	
Tank Location	Same as Prototype	

Five major end uses are identified for DHW: 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, except in the case of multi-family housing with a common laundry room. 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.[3] 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 DHW studies (Burch and Salasovich 2002, Christensen et al. 2000, 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 American Society for Testing and Materials (ASTM) Manual on Moisture Control in Buildings (ASTM 1994). The water usage equation for a common laundry room stems from the National Research Center's study of laundry use in multi-family housing (NRC 2002). The equation for the office/public sink is based on engineering judgment.

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	$7.5 + 2.5 \times N_{br}$ gal/day (Hot Only)	0*	0*
Common Laundry		2.47 gal/day/housing unit (Hot Only)	0*	0*
Dishwasher	N/A	$2.5 + 0.833 \times N_{br}$ gal/day (Hot Only)	0*	0*
Shower	105°F	$14.0 + 4.67 \times N_{br}$ gal/day (Hot + Cold)	$741 + 247 \times N_{br}$ Btu/day	$703 + 235 \times N_{br}$ Btu/day ($0.70 + 0.23 \times N_{br}$ pints/day)
Bath	105°F	$3.5 + 1.17 \times N_{br}$ gal/day (Hot + Cold)	$185 + 62 \times N_{br}$ Btu/day	0**
Sinks	105°F	$12.5 + 4.16 \times N_{br}$ gal/day (Hot + Cold)	$310 + 103 \times N_{br}$ Btu/day	$140 + 47 \times N_{br}$ Btu/day ($0.14 + 0.05 \times N_{br}$ pints/day)
Office/ Public Sink	105°F	$0.028 \times N_{units}$ gal/day (Hot + Cold)	$0.69 \times N_{units}$ Btu/day	$0.314 \times N_{units}$ Btu/day ($3.14 \times 10^{-4} \times N_{units}$ pints/day)

* Sensible and latent heat gains from appliances are included in the section titled, "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 Figure 6 to Figure 13. For software tools that do not accept this level of detail, the combined hourly hot water

[3] 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.

profile may be used, as shown in Figure 14. The numerical values for normalized hourly hot water use can be found in the Building America 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 End-Use Load and Consumer Assessment Program (ELCAP) study conducted in the Pacific Northwest by the Bonneville Power Administration in the 1980s (Pratt et al. 1989). The hourly profiles for the common laundry room hot water use are from the “Multi-Unit Residential Clothes Washer Replacement Pilot Project” produced by the City of Toronto (Lithgow et al. 1999). It is assumed that the normalized hourly profiles for electricity and hot water are the same for washing machines and dishwashers. The shower, bath, and sink profiles were taken from a study titled, “Residential End-Uses of Water” conducted by Aquacraft for the American Water Works Association (AWWA 1999). The central restroom profile stems from the office occupancy profile in the NREL Commercial Benchmark for a medium-rise apartment, in combination with engineering judgment (NREL 2009).

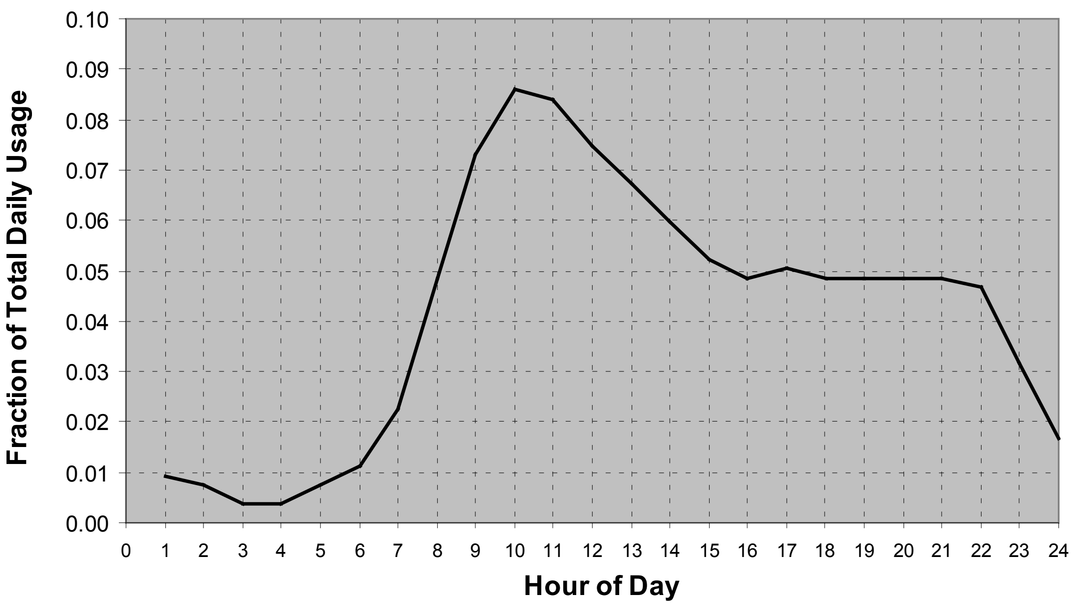


Figure 6. Clothes washer hot water use profile

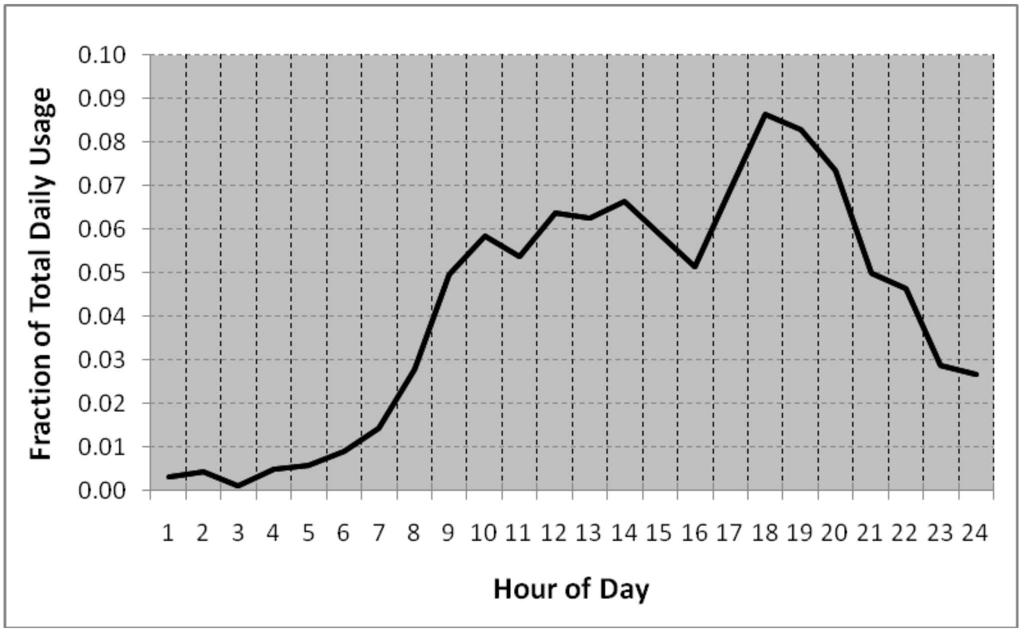


Figure 7. Multi-family common laundry hot water use profile: weekday

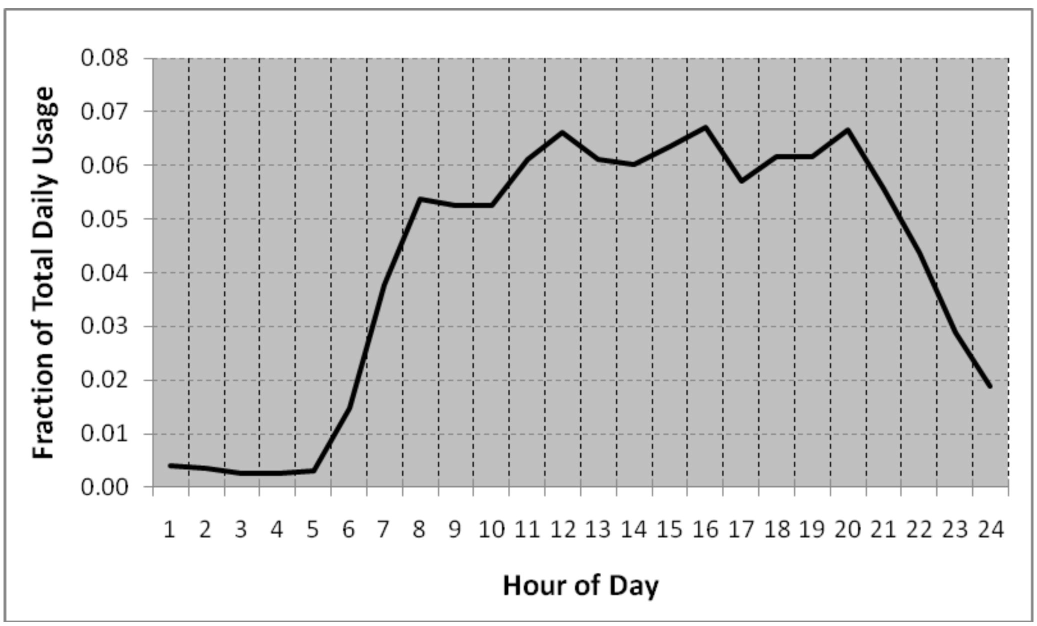


Figure 8. Multi-family common laundry hot water use profile: weekend

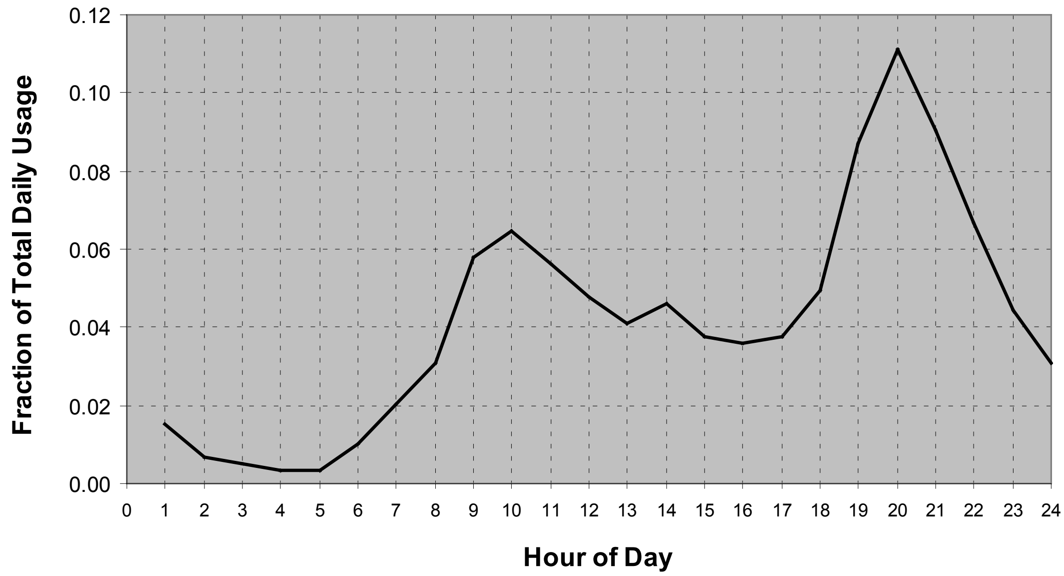


Figure 9. Dishwasher hot water use profile

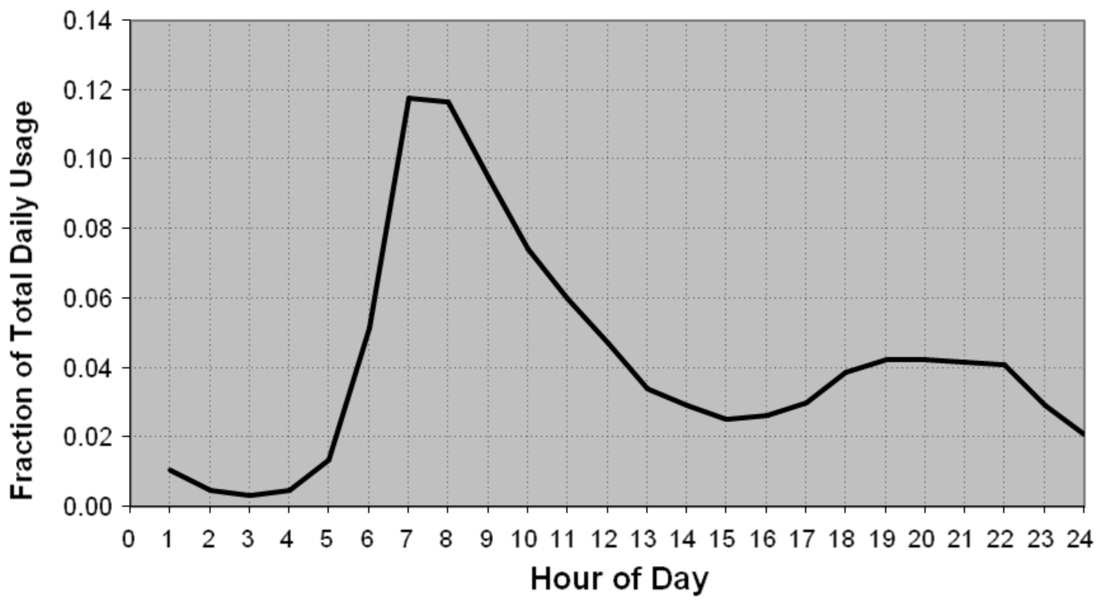


Figure 10. Shower hot water use profile

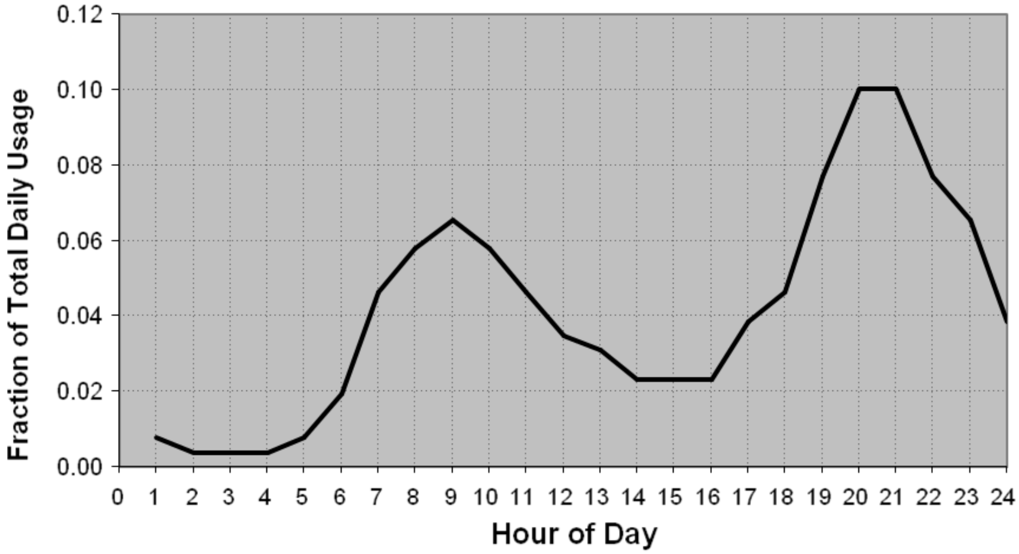


Figure 11. Bath hot water use profile

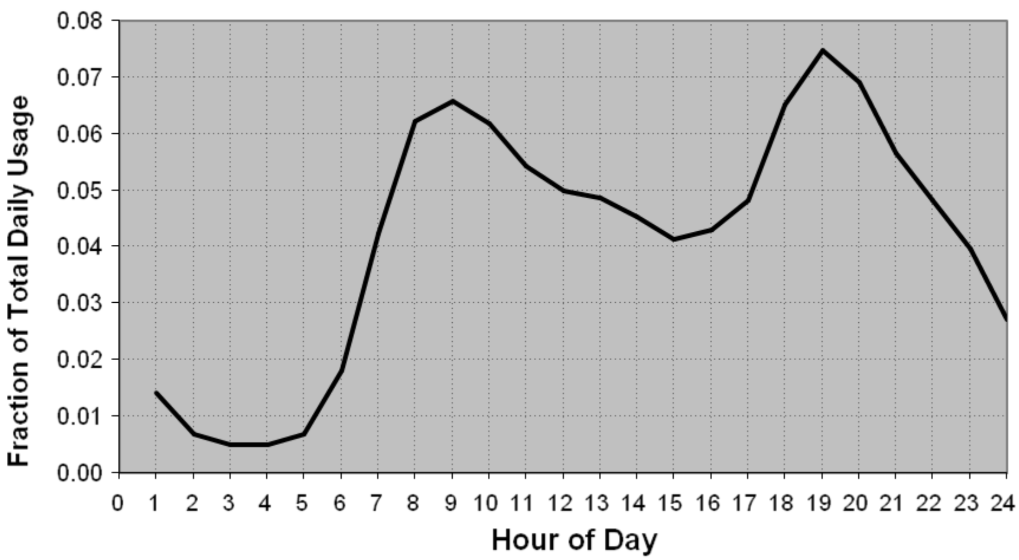


Figure 12. Sink hot water use profile

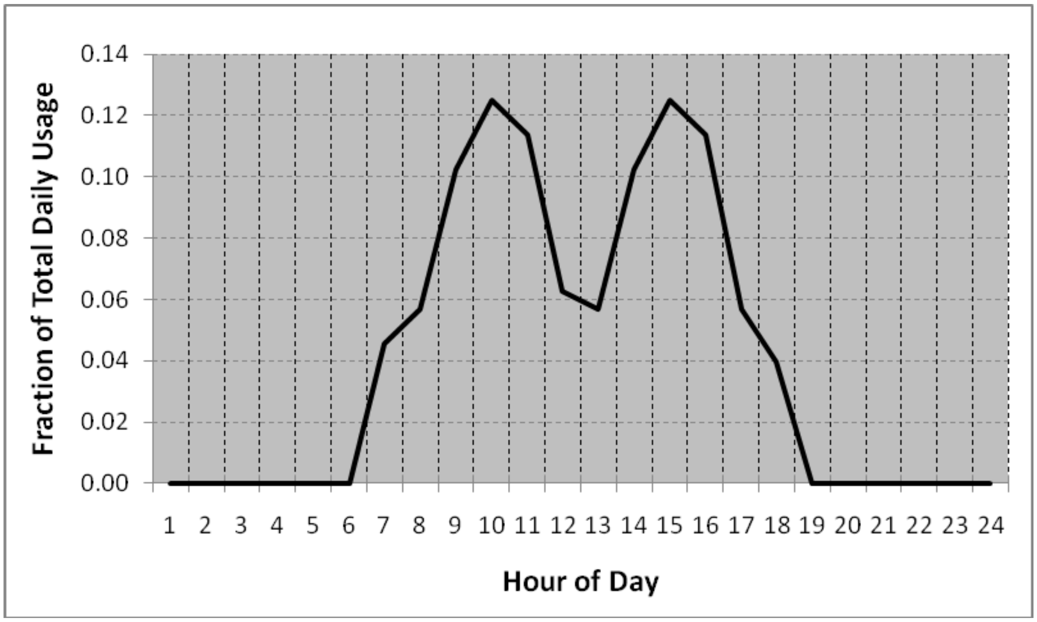


Figure 13. Central restroom sink hot water use profile

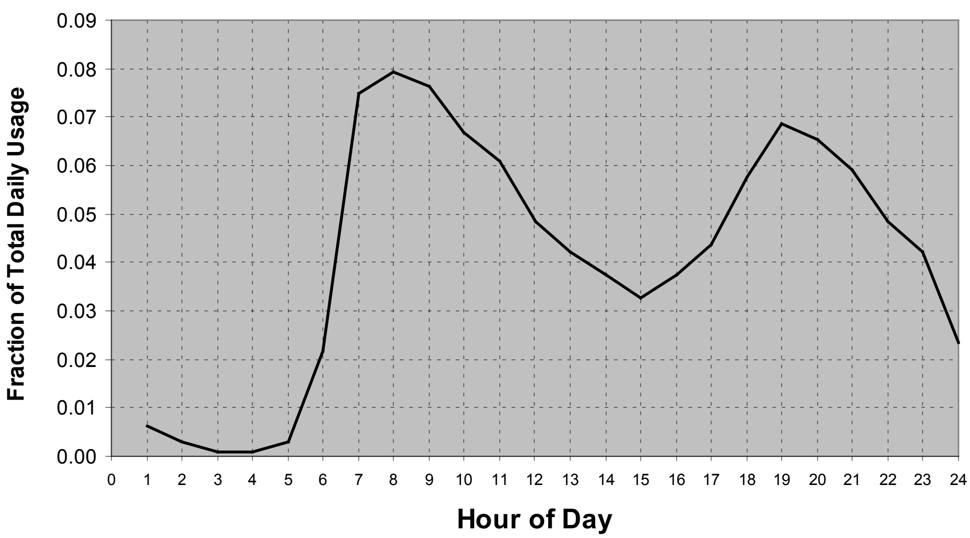


Figure 14. Combined domestic hot water use profile

For the central restroom in a multi-family building, the daily use depends on the number of full-time employees as well as the number of guests that come to look at the facilities (which can vary based on number and price of units, economics, and marketing). If these parameters are unknown to the analyst, three full-time employees may be assumed, each using the restroom three times per day, and 21 visitors, of whom one in three use restroom facilities (Gleick et al. 2003).

Based on these numbers, Figure 13, and values from Table 10, the total hot water consumption is a constant 11.3 gal/day for weekdays and Saturdays, and 0 gal/day on Sundays. This is equivalent to 3,526 gal/year.

Weekend/weekday multipliers for daily hot water use were derived from data collected in the 1200 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 in single-family homes or multi-family homes with in-unit clothes washers 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	Dishwasher	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, December 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 and number of bedrooms. This tool will soon be available for download from the BA performance analysis Web site, along with standard Benchmark event schedules for two-, three-, and four-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 Table 10 and Table 11. Additional characteristics of the Benchmark hot water events for a three-bedroom house are summarized in Table 12.

The mains water temperature for a typical house varies significantly depending on the location and time of year. Equation 5, based on TMY3 data for the location of the Prototype, shall be used to determine the daily mains water temperature for both the Benchmark and the Prototype:

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

where:

T_{mains}	=	mains (supply) temperature to DHW 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	=	$35 - 1.0 (T_{amb,avg} - 44)$.

Table 12. Benchmark Domestic Hot Water Event Characteristics and Constraints (three-bedroom house)

Characteristics	Sink	Shower	Bath	CW	DW
Average Duration (min)	0.62	7.81	5.65	3.05	1.53
Standard Deviation Duration (min)	0.67	3.52	2.09	1.62	0.41
Probability Distribution for Duration	Exponential	Log-Normal	Normal	Discrete	Log-Normal
Average Flow Rate (gpm)*	1.14	2.25	4.40	2.20	1.39
Standard Deviation Flow Rate (gpm)*	0.61	0.68	1.17	0.62	0.20
Probability Distribution for Flow Rate	Normal	Normal	Normal	Normal	Normal
Average 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
Maximum 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
Maximum Time Between Events in Load (min)				30	
Maximum 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)

This equation is based on analysis by Burch and Christensen (2007) of NREL using data for multiple locations, as compiled by Abrams and Shedd (1996), FSEC (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 5 shall be calculated using Equation 6.

Equation 6: **day# = 30 × month# - 15 ,**

Where:

month# = month of the year (1–12)

An example using Equations 5 and 6 to determine the monthly mains temperature profile for Chicago, Illinois, is shown in Figure 15.

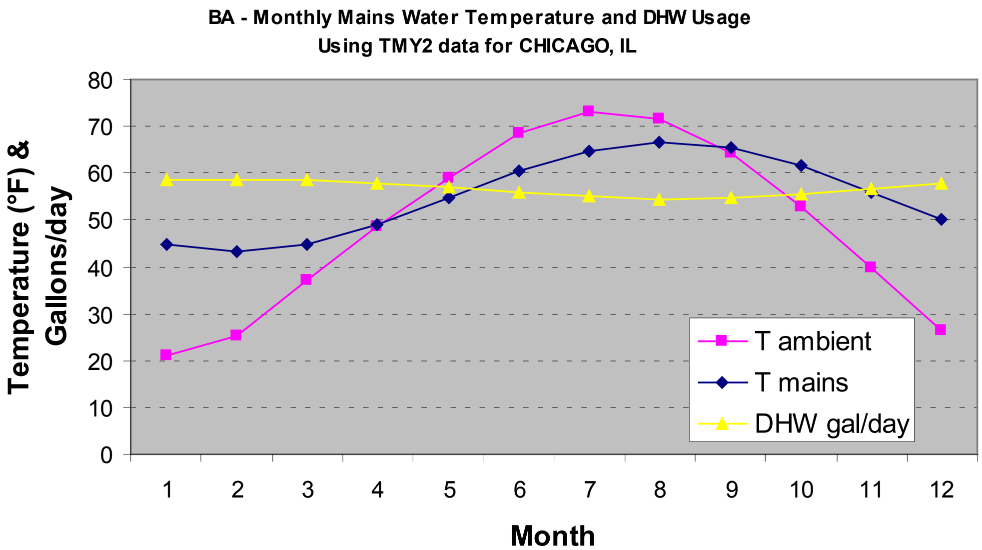


Figure 15. Mains temperature profile for Chicago

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 (DEG) 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	$N_{br}/2+½$
Recirculation loop	None
Location	Inside conditioned space

The daily internal heat gain caused by the Benchmark distribution system shall be calculated using Equation 7. The heat gain shall be applied using the combined hourly DHW profile in Figure 14.

Equation 7: $IHG(\frac{Btu}{day}) = \{IHG_{bench,avg} + 735 \times (N_{br} - 3)\} \times \left\{1 + \frac{1}{IHG_{bench,avg}} \times [362 + \{63 \times (N_{br} - 3)\}] \times sin\left(2\pi \times \left(\frac{Month}{12} + .3\right)\right)\right\}$

where:

$IHG_{bench,avg} = average\ daily\ heat\ gain\ for\ Benchmark\ DHW\ system = 4257\ Btu/day$

N_{br} = Number of bedrooms

Month = Number of the month (January = 1, etc.)

Air Infiltration and Ventilation

The hourly natural air change rate for a single-family home (detached or attached) Benchmark shall be calculated based on the specific leakage area (SLA) determined using Equation 8:

Equation 8: 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)

For a multi-family building, the SLA values for the Benchmark are specified in Table 14 (NREL 2009). These values include only leakage area to the outside. They do not consider the infiltration rates between apartments because other apartments are assumed to be space conditioned as well. However, the SLA values do consider how the unit's location (ground or top floor) affects the infiltration.

Table 14. Multi-Family Common Space and Residential Unit SLA Values for Benchmark

Room Type	SLA
Central Laundry	0.00019
Office	0.00036
Indoor Corridors	0.00007
Workout Room	0.00019
Central Restroom	0.00019
Multi-Purpose Room	0.00027
Residential Unit	0.00006+0.0009(T)

where:

T = Area of perimeter surfaces exposed to unconditioned space (including a ceiling or floor if unit is on top or bottom floor respectively)/total area of perimeter surfaces for the residential unit (including ceiling and floor area)

When specifying natural infiltration for a single family detached or attached 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 9 shall be used to make this adjustment.

Equation 9: $SLA_{overall} = [(CFA_{bsmt} \times SLA_{bsmt}) + (CFA_{a\text{-}g} \times SLA_{a\text{-}g})] / [CFA_{total}]$

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

For single-family houses, 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. 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 each house or housing unit.

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 (including those in central restrooms) 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.

For multi-family common spaces, the air ventilation rates required for the Benchmark are combinations of values suggested by ASHRAE 62.1 and NREL's Commercial Building Benchmark for 2009. Values to be used are shown in Table 15.

Table 15. Multi-Family Common Space Ventilation Rates

Room Type	Area Outdoor Air Rate (cfm/ft^2)
Central Laundry	0.12
Office	0.08
Indoor Corridors	0.05
Workout Room	0.06
Electrical Equipment Room	0.06
Multi-Purpose Room	0.06
Central Restroom	50 cfm per urinal/water closet

Lighting Equipment and Usage

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 in a similar manner. When combined with plug-in lighting, 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 16, including Huang and Gu (2002), the 1993 RECS (DOE 1996), an FSEC study (Parker et al. 2000), default lighting for Visual DOE software (Eley 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).

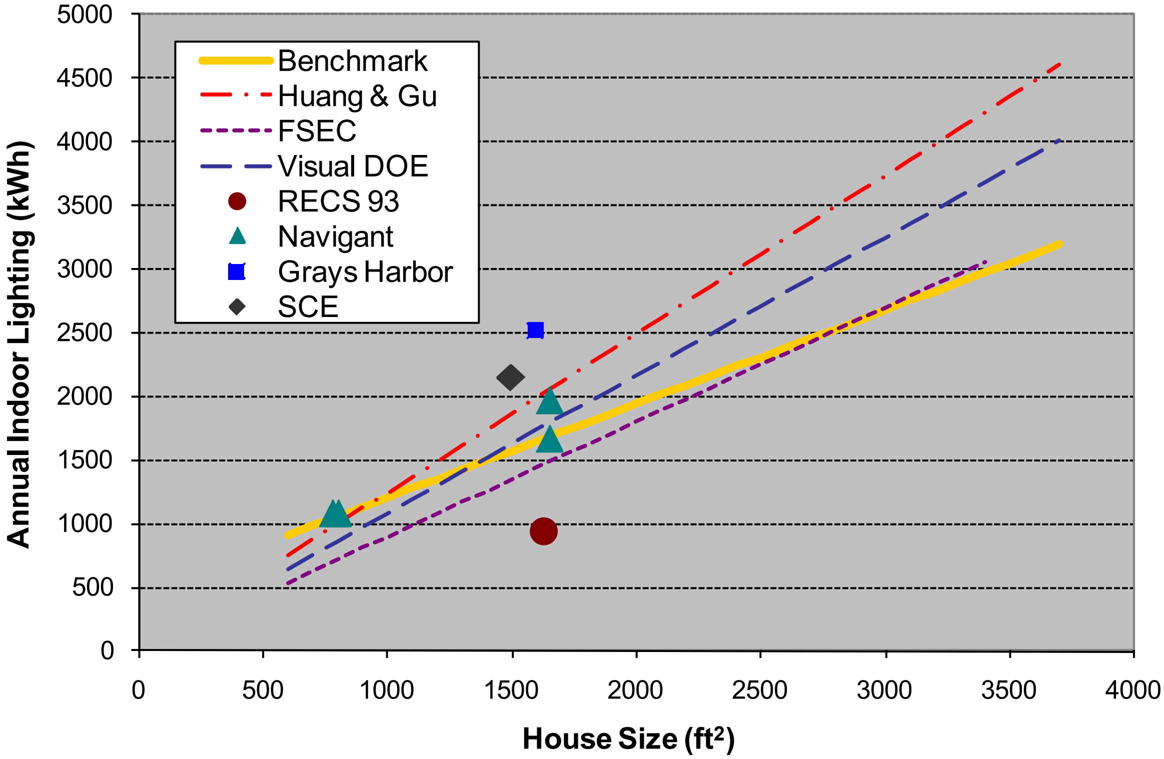


Figure 16. Comparison of Benchmark lighting equation to other references

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.

The Benchmark and Prototype lighting calculations have two options. The first option is a simpler method that is relatively consistent with previous Benchmark protocols. The second is more complicated, and uses a more sophisticated room-by-room analysis approach that factors in the amount of hard-wired lighting compared to the total lighting needed based on Illuminating Engineering Society of North America (IESNA) illumination recommendations, and adjusts plug-in lighting accordingly. If the project is a multi-family housing complex, Option 2 must be used.

Option 1:

The total annual hard-wired and plug-in lighting use for the Benchmark is determined using Equations 10–13. These equations were derived from detailed calculations using Option 2 for a cross-section of residential floor plans using typical fixtures and lamps.

Equation 10: **Interior hard-wired lighting = 0.8*(FFA × 0.737 + 467) kWh/yr,**

Equation 11: **Interior plug-in lighting = 0.2*(FFA × 0.737 + 467) kWh/yr,**

Equation 12: **Garage lighting = Garage Area × 0.3 + 29 kWh/yr,**

Equation 13: **Exterior lighting = FFA × 0.17 kWh/yr**

A percentage of this hard-wired lighting energy use is associated with each month (Table 16). The total kWh/yr found in Equations 10–13 are multiplied by each of these numbers to find the kilowatt-hours used for a given month.

Table 16. Monthly Multipliers for Hard-Wired Lighting

Month	Multiplier	Month	Multiplier
January	0.116	July	0.058
February	0.092	August	0.065
March	0.086	September	0.076
April	0.068	October	0.094
May	0.061	November	0.108
June	0.055	December	0.120

After dividing by the number of days in a month, one may obtain the kilowatt-hours per day. In Option 1, these numbers may then be applied to a normalized hourly profile (Figure 17 for interior, outdoor, and garage lighting) for a given day of that month and for an average city in the United States (St. Louis). The specific values for each month can be found online in the BA Analysis Spreadsheet.

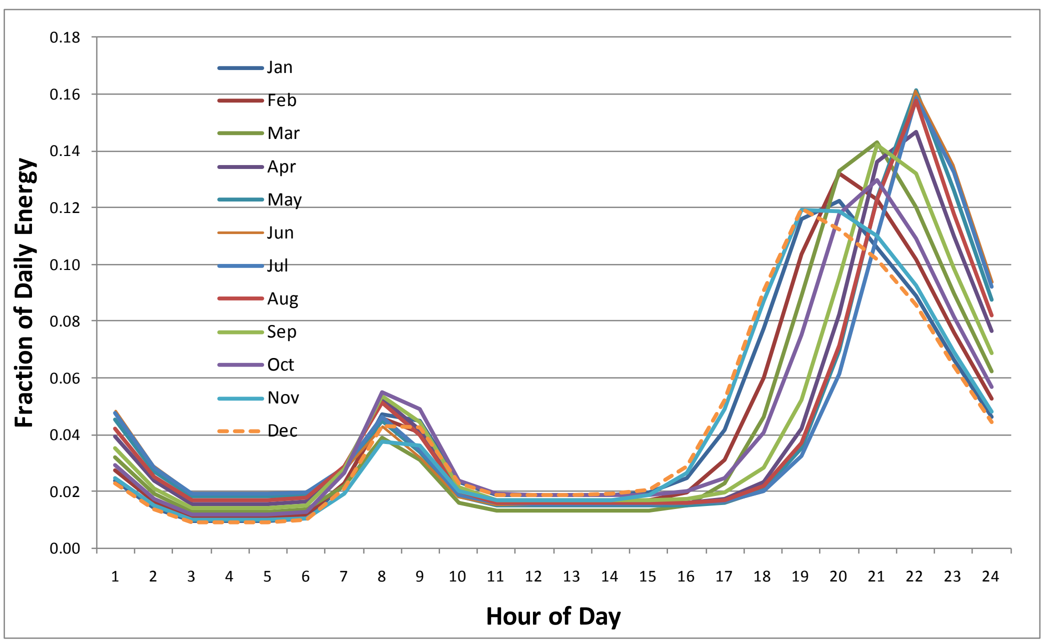


Figure 17. Normalized hourly lighting profile for a given month using Option 1

If a comprehensive lighting plan has not been developed for the Prototype house, and only fluorescent, LED, and incandescent lamps are installed, then a simplified approach may be used to estimate energy savings compared to the Benchmark using Equations 14–16. These equations use default assumptions for lamp and fixture characteristics, and it is assumed that the more efficient lamps are first applied to the room types with the highest average daily use.

Equation 14: Prototype interior hard wired lighting (kWh/yr) =

$$L_{HW} \times [(F_{Inc,HW}+0.14) + (F_{CFL,HW}-0.14) \times 0.27 + F_{LED,HW} \times 0.16 + F_{LF,HW} \times 0.17] \times SAF$$

where:

L_{HW} = hard-wired interior lighting for the Benchmark from Equation 10 (kWh/yr)
$F_{Inc,HW}$ = fraction of hard-wired interior lamps in the prototype that are incandescent
$F_{CFL,HW}$ = fraction of hard-wired interior lamps in the prototype that are compact fluorescent
$F_{LED,HW}$ = fraction of hard-wired interior lamps in the prototype that are LED
$F_{LF,HW}$ = fraction of hard-wired interior lamps in the prototype that are linear fluorescent

SAF = Smart replacement algorithm factor:
$1.4 \times F_{Inc}^4 - 2.4 \times F_{Inc}^3 + 1.7 \times F_{Inc}^2 - 0.7 \times F_{Inc} + 1$

Equation 15: Prototype garage lighting (kWh/yr) =

$$L_{GAR} \times [(F_{Inc,GAR}+0.14) + (F_{CFL,GAR}-0.14) \times 0.27 + F_{LED,GAR} \times 0.16 + F_{LF,GAR} \times 0.17]$$

where:

L_{GAR} = garage lighting for the Benchmark from Equation 12 (kWh/yr)
$F_{Inc,GAR}$ = fraction of lamps in the garage that are incandescent
$F_{CFL,GAR}$ = fraction of lamps in the garage that are compact fluorescent
$F_{LED,GAR}$ = fraction of lamps in the garage that are LED
$F_{LF,GAR}$ = fraction of lamps in the garage that are linear fluorescent

Equation 16: Prototype outdoor lighting (kWh/yr) =

$$L_{OUT} \times [(F_{Inc,OUT}+0.14) + (F_{CFL,OUT}-0.14) \times 0.27 + F_{LED,OUT} \times 0.16 + F_{LF,OUT} \times 0.17]$$

where:

L_{OUT} = outdoor lighting for the Benchmark from Equation 13 (kWh/yr)
$F_{Inc,OUT}$ = fraction of outdoor lamps that are incandescent
$F_{CFL,OUT}$ = fraction of outdoor lamps that are compact fluorescent
$F_{LED,OUT}$ = fraction of outdoor lamps that are LED
$F_{LF,OUT}$ = fraction of outdoor lamps that are linear fluorescent

Option 2:

The Benchmark and Prototype lighting energy use for Option 2 are both calculated using the BA Analysis Spreadsheet found online. The Benchmark uses fixed values for peak illumination levels (Table 18), operating hours per day per room (Table 22), average efficacies for a given room type, fraction of hard-wired lighting per room type, and primary fixture type (Table 17). All other parameters are user inputs that are used by both the Benchmark and the Prototype.

Table 17. Fixed Values for Benchmark Calculation for Option 2

Room Type	Average Efficacy (lm/W)	Fraction Hard-Wired	Primary Fixture Type
Bathroom	16.9	1.00	Vanity
Bedroom	16.6	0.61	Closed Ceiling
Closet	16.4	1.00	Bare Bulb
Dining Room	15.7	1.00	Chandelier
Family Room	22.9	0.50	Indirect Ceiling
Garage	39.7	1.00	Bare Bulb
Hall/Stairs	15.6	1.00	Closed Ceiling
Kitchen	31.6	1.00	Closed Ceiling
Living Room	16.8	0.29	Indirect Ceiling
Home Office	23.1	0.61	Rangehood/Task
Utility /Laundry	24.9	1.00	Bare Bulb
Unfinished Basement	15.6	1.00	Bare Bulb
Outdoor	14.4	1.00	Outdoor
Other	37.7	1.00	Globe
Multi-Family Common Spaces			
Common Laundry	15	1.00	Utility/Strip
Office	15	0.61	Utility/Strip
Indoor Corridor	15	1.00	Closed Ceiling
Workout Room	15	1.00	Utility/Strip
Equipment Room	15	1.00	Utility/Strip
Central Restroom	15	1.00	Recessed Downlight
Multi-Purpose Room	15	0.50	Recessed Downlight
Outdoor Walkway	15	1.00	Globe
Outdoor Stairs	15	1.00	Globe
Parking Garage	15	1.00	Closed Ceiling (Utility)
Open Parking	15	1.00	Outdoor Wall Mount
Common Mail	15	1.00	Globe
Elevator	15	1.00	Recessed Downlight

Option 2 uses a location-dependent normalized hourly interior hard-wired lighting profile derived from a 100-house study in the United Kingdom. The study was used to derive the effects of the city location (sunrise and sunset) as well as the month of the year (e.g. December versus June). For illustration purposes only, an example of one detailed set of profiles for International Falls, Minnesota, is shown in Figure 18. Other profiles can be calculated using the spreadsheet available on the BA Web site (http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html). Profiles generated using the spreadsheet are normalized, and must be combined with annual lighting energy values, which are calculated separately.

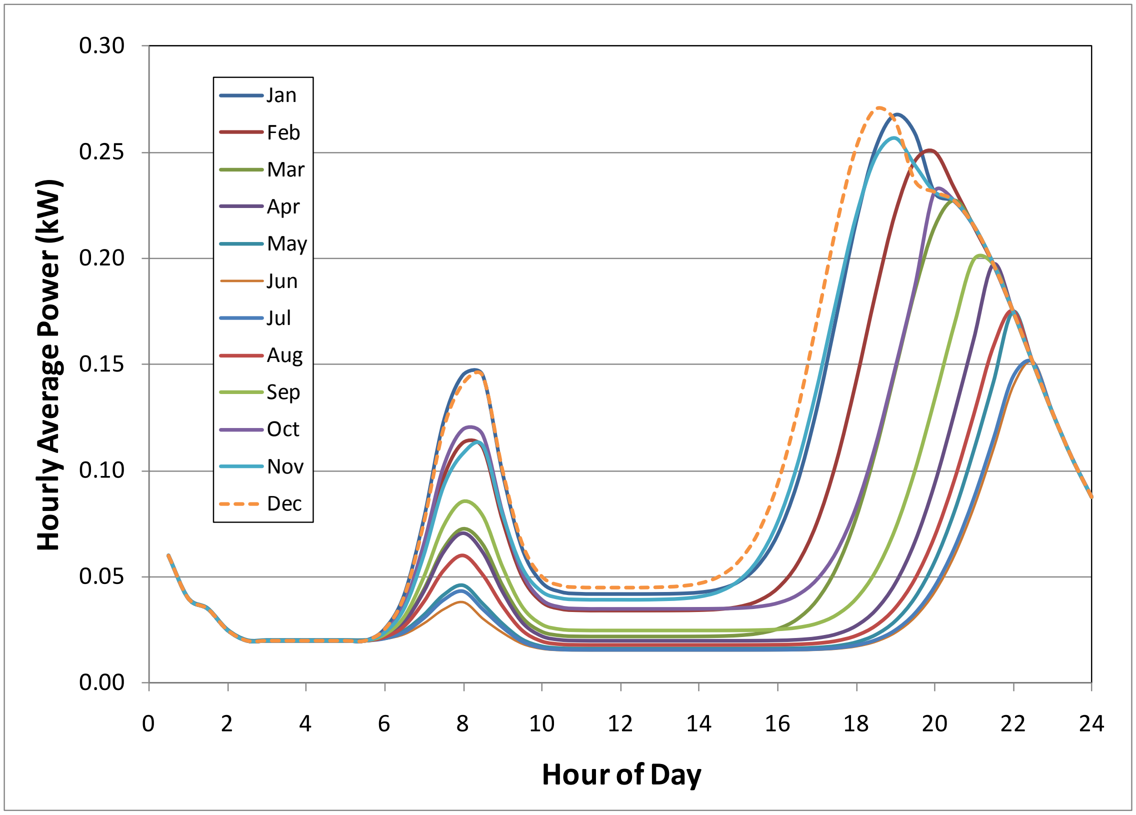


Figure 18. Interior and garage lighting profile (International Falls, Minnesota)

In Option 2, the plug-in lighting for the Prototype house (or unit) is determined by the difference between the required footcandles (Table 18 and Table 19) for a given room type and the total installed hard-wired footcandles for that room. Efficacy values for the Benchmark (See Table 17) are used as defaults for the plug-in lighting in the Prototype.

To use Option 2, details such as lamp type (e.g., incandescent versus compact florescent) and fixture type (e.g., track versus pendant light) must be known variables. Default values for all relevant variables are also available in the BA spreadsheet. The analyst may override any default values if better information is available and the revisions are documented. It is important to note that for the Prototype, rooms that contain more lighting than is recommended by Table 18 and Table 19 will be penalized.

The illuminance for each room type is based on an engineering interpretation of the horizontal illuminance levels in the IESNA Lighting Handbook (Rea et al. 1993). Values for each indoor space type, for all housing types, are shown in Table 18. Note that some of the entries include a series of several room types with similar illuminance requirements. For simplicity, in the tables that follow and in the BA Analysis Spreadsheet, the first room type in each series will be used as shorthand for all similar room types. Multi-family common space illumination values are found in Table 19. Note: All footcandle levels are measured at a three-foot work plane for most indoor spaces and on the ground for hallways.

For outdoor lighting, there is no footcandle requirement. Instead, the total lumens used for the Prototype are also used for the Benchmark. Savings are then based on the efficacy of the lamps used in the Prototype compared to the Benchmark.

Table 18. Single- and Multi-Family Illumination by Room Type

Room Type	Lighting Requirements (footcandles)	Room Type	Lighting Requirements (footcandles)
Bathroom	17.5	Hall, Stairway, Foyer	3.0
Bedroom	8.8	Kitchen, Breakfast Nook	22.5
Closet	5.0	Living Room, Great Room	8.8
Dining Room	5.0	Home Office, Den, Study	15.5
Family Room, Recreation Room	8.8	Utility Room	17.5
Garage	8.8	Other, Library	8.8
		Unfinished Basement	5.0

Table 19. Multi-Family Common Space Illumination

Area Type	Lighting Requirements (footcandles)
Common Laundry	30
Common Office	30
Indoor Corridor	15
Workout Room	15
Equipment Room	30
Central Restroom	15
Multi-Purpose room	15

Source: IESNA Lighting Handbook, Security Lighting for People, Property & Spaces

The illumination at the horizontal plane can be determined by Equation 15. This calculation is required for all indoor spaces, and is automated in the BA analysis spreadsheet.

Equation 15: Horizontal Illuminance (footcandles) = (lumens/lamp) × N_{La} × COU × LLF/(FFA of room)

where:

N_{La} = number of lamps in the room
COU = coefficient of utilization (Table 20)
LLF = light loss factor (0.8 for all fixture types)
FFA = finished floor area of the room

Default COUs for common fixture types are listed in Table 20 for rooms with a room cavity ratio of 0.5, ceiling reflectance of 80%, and wall reflectance of 50%. The BA Analysis Spreadsheet can be used to estimate COU for other room shapes.

Table 20. Coefficient of Utilization by Fixture Type

Fixture Type	Picture of Fixture Type	Default Coefficient of Utilization
Accent/Wall Washing		0.30
Bare Bulb		0.46
Chandelier		0.40
Lensed Ceiling (Closed Ceiling)		0.23
Downlight Pendant		0.58
Globe	 (Source: NREL PIX)	0.35*
Inverted Pendant or Inverted Ceiling		0.44
LED	 (Source: iStockphoto.com)	0.85

Outdoor	 (Source: NREL PIX)	N/A
Rangehood/Task		0.29
Recessed Downlights		0.36
Track		0.43
Utility (Strip)		0.43
Vanity		0.42*

*Estimated using engineering interpretation of the IES Handbook (Rea et. al. 1993)
**Pictures and COU values in Table 20 provided by Lithonia (http://www.lightathome.com) unless otherwise noted.

Once the fixture type and room characteristics are defined, the efficacy (lumen per watt) is used to determine if the footcandle requirement is met in a particular room. These values will be different depending on the type of lamp that is used in a given fixture. Using multiple references, default values for common lamp types were developed for both the Benchmark and Prototype lamps (Table 21). These defaults may be modified for the Prototype with sufficient justification.

For Either Option:

The lighting plans for the Prototype and Benchmark shall use the hours of operation listed in Table 22, 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.

For common areas in multi-family buildings, the lighting operating hours are 24 h/day, every day of the year for the central laundry room, indoor corridors, and elevators. Outdoor lighting should be scheduled to operate from dusk to dawn. Specific hours will depend on location and time of year, but an example for St. Louis is shown in Figure 19. The other common room lighting hours are shown in Figure 20. The lighting profile for a multi-purpose room is the same as for an office.

Table 21. Default Efficacy by Lamp Type

Lamp Type	Default Efficacy
Incandescent	15
Linear Fluorescent (T5)	104
Linear Fluorescent (T8)	88
Linear Fluorescent (T12)	82
Compact Fluorescent (CFL)	55
Miscellaneous Fluorescent	85
High Pressure Sodium	90
Metal Halide	75
Light-Emitting Diode (LED)	50

Table 22. Average Lighting Operating Hours for Room Types (based on a sample of 161 homes in the Pacific Northwest)

Room Type	**Operation (Hours/Day/Room)**		**Room Type**	**Operation (Hours/Day/Room)**	
	Single Family	Multi-Family		Single Family	Multi-Family
Bathroom	1.67	1.68	Kitchen	2.85	2.48
Bedroom	1.11	1.18	Living Room	2.56	2.82
Closet	0.95	0.61	Office	1.45	1.15
Dining Room	2.43	2.97	Outdoor	2.70	N/A
Family Room	1.78	1.22	Utility Room	1.59	1.12
Garage	1.82	N/A	Other	0.78	N/A
Hall	1.45	1.2	Unfin. Bsmt	0.78	N/A

Source: Navigant Consulting 2002

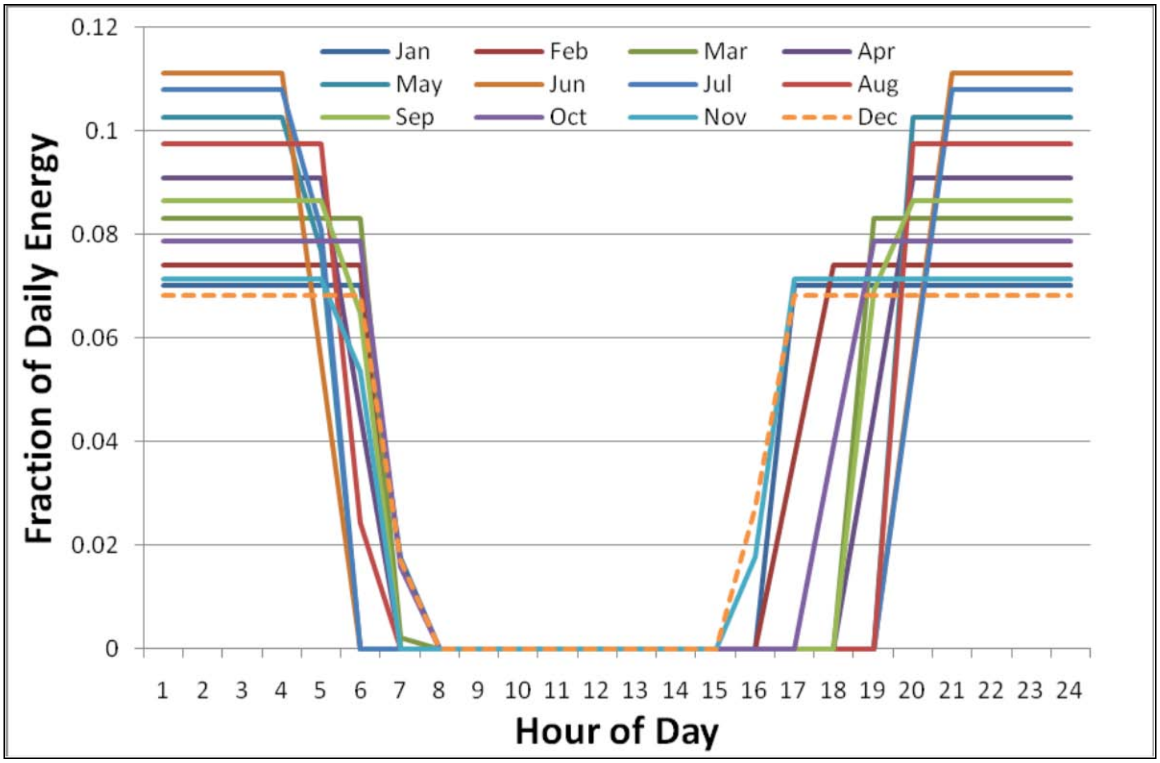


Figure 19. Normalized hourly profile for outdoor areas in multi-family housing

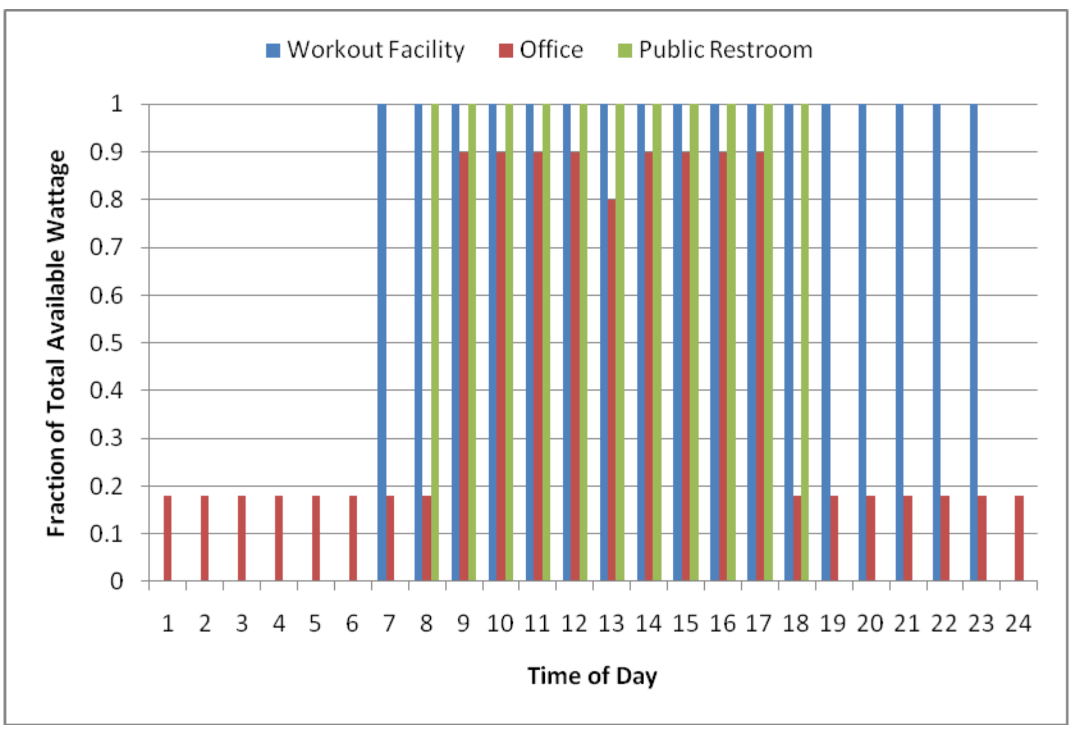


Figure 20. Percentage of total wattage turned on per hour of day for common areas in multi-family housing

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 23 (Jiang et al. 2008 and Sachs 2005 for multi-family). 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, except the clothes washer in cases where the Prototype is a housing unit in a multi-family building with a common laundry room. 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 met 1990s National Appliance Energy Conservation Act appliance standards, and several other studies.

For a house of typical size (1000–3000 ft^2), the loads from the occupants and most appliances are assumed to be a function of the number of bedrooms 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 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 age of homeowner) and removing end uses that are disaggregated in the Benchmark (such as lighting and clothes dryer). The resulting multipliers are listed in Table 24. The multiplier is 1.0 for all states not listed because insufficient information is available about the magnitude of MELs in those states.

MELs 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 MELs encountered in a typical house. Approximately 100 MELs in this category are listed in Table 25. 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 23. Annual Appliance and Miscellaneous Electric Loads for the Benchmark[4]

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
Variable 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
Multi-Family Common Space Miscellaneous Electric Loads				
Office	3.2*FFA		1.00	0.00
Workout Room	9.8*FFA		1.00	0.00
Corridor/Restroom/Mech.	0			
Elevator	1,900		1.00	0.00
	Multi-Purpose Room Miscellaneous Electric Loads			
Television	673**		1.00	0.00
Refrigerator	669		1.00	0.00
Dishwasher	52*		0.60	0.15
Range (Electric)	62.4*		0.40	0.30
Range (Gas)		4.6*	0.30	0.20
Microwave	78*		1.00	0.00

*Assuming 1 h/wk use (Data from appliance usage list from PSNH: The Northeast Utility System)
**Assuming on during office hours (Data from appliance usage list from PSNH: The Northeast Utility System)

Table 24. 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

[4] End-use loads in this table include only energy used within the machine. Associated DHW 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 25. 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 (G	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			**3170**

The hourly, normalized load shape for combined residential equipment use is shown in Figure 21, 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 and dishwasher), we have also developed a series of normalized hourly profiles for major appliances and MELs, shown in Figure 22 to Figure 29. 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 Figure 6 to Figure 9).

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, 1800-ft^2, three-bedroom house in Memphis, Tennessee. Internal sensible and latent loads from appliances and plug loads shall be modeled using the same hourly profiles 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.

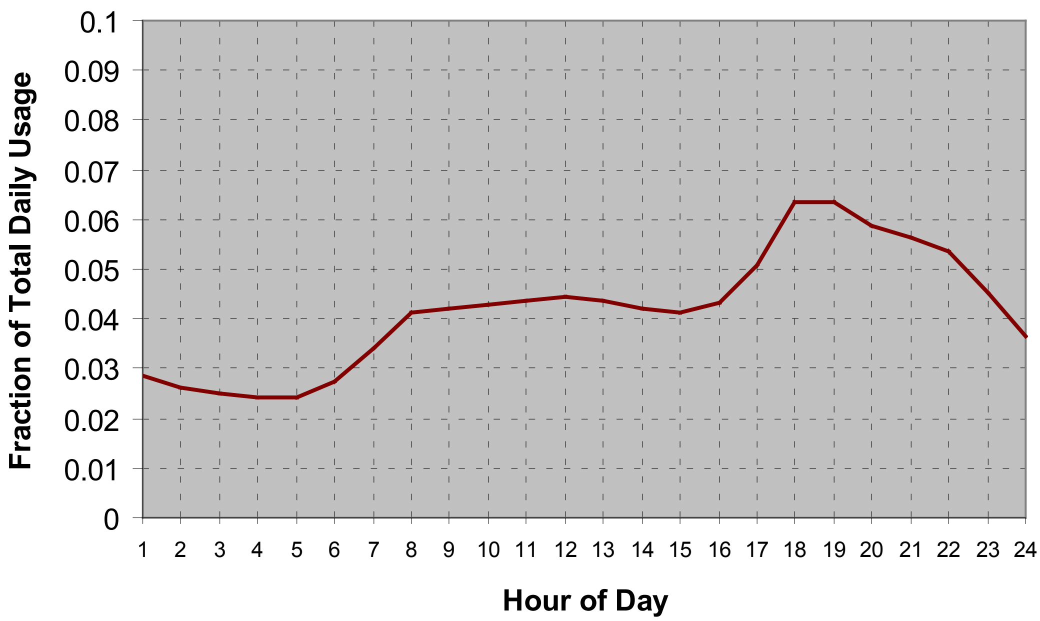


Figure 21. Total combined residential equipment profile (Pratt et al. 1989)

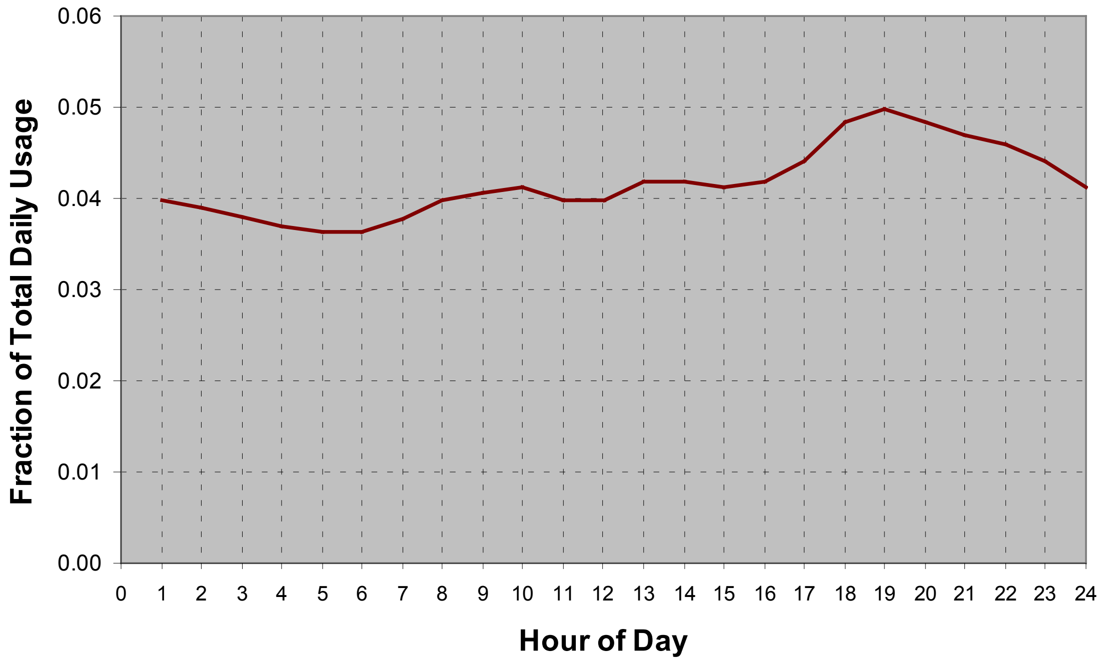


Figure 22. Refrigerator normalized energy use profile (Pratt et al. 1989)

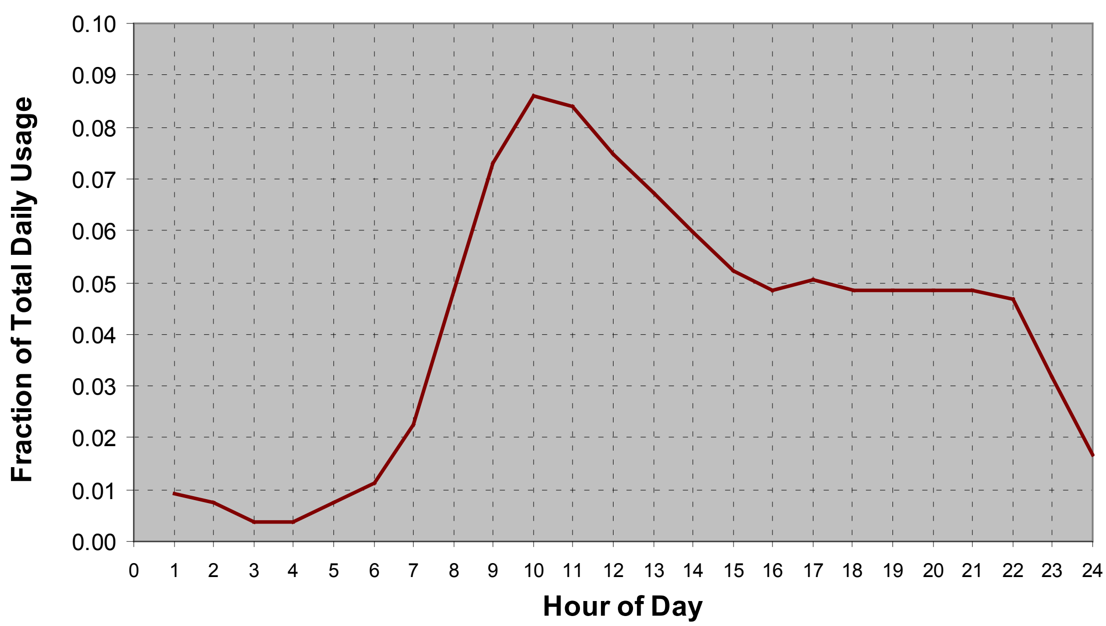


Figure 23. Clothes washer normalized machine energy use profile (Pratt et al. 1989)

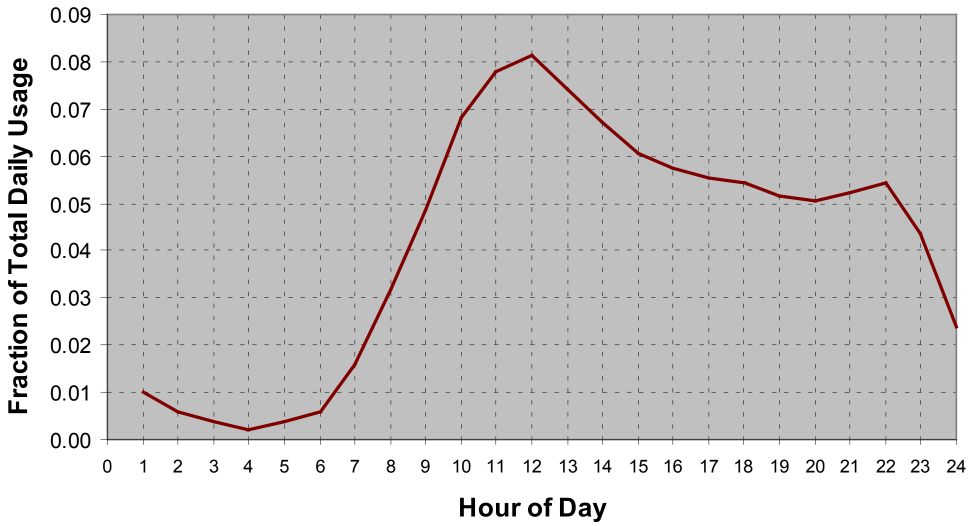


Figure 24. Clothes dryer normalized energy use profile (Pratt et al. 1989)

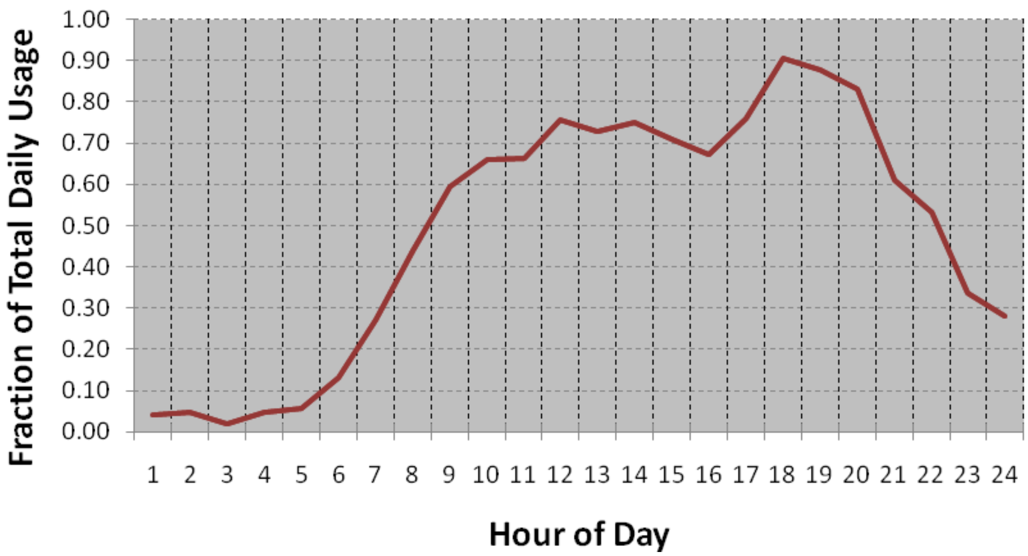


Figure 25. Common laundry clothes washer normalized energy use profile (Toronto 1999)

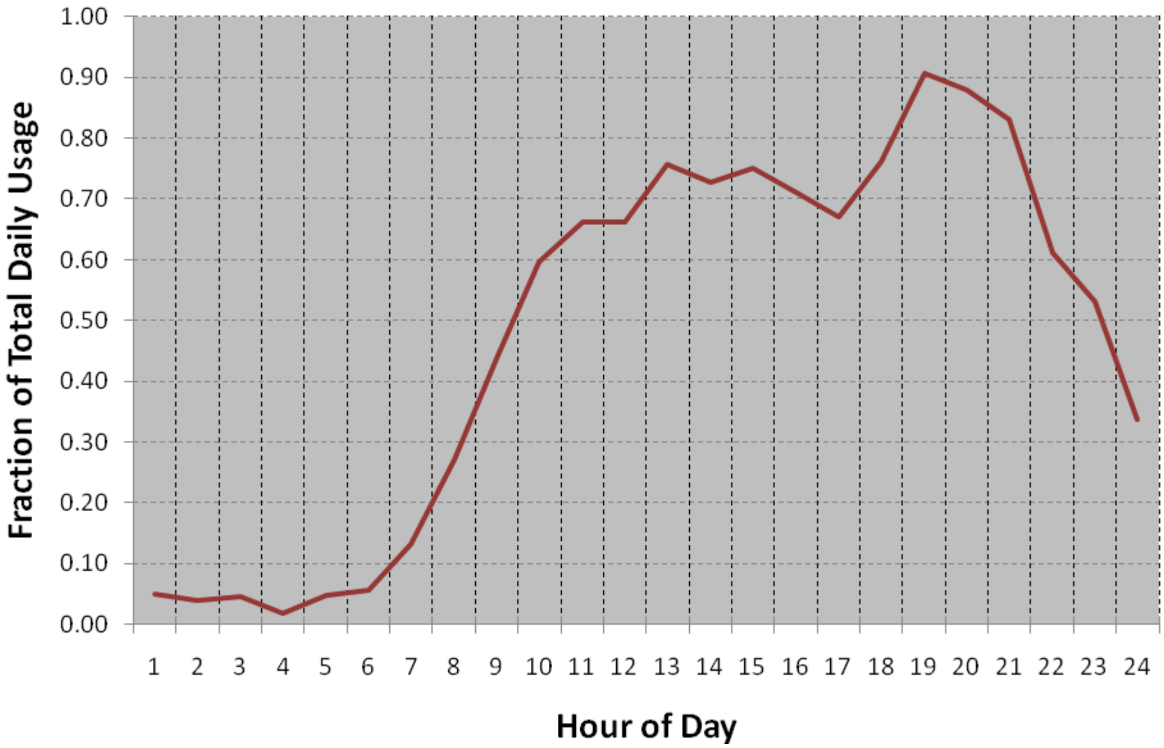


Figure 26. Common laundry clothes dryer normalized energy use profile (shifted one hour relative to clothes washer)

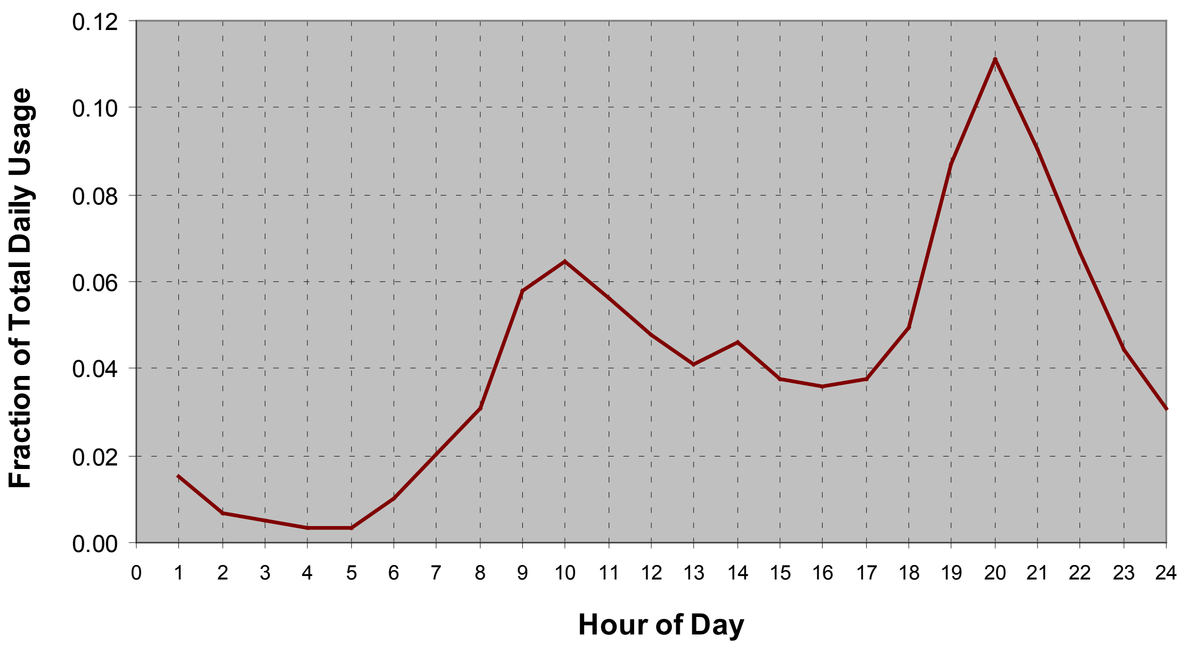


Figure 27. Dishwasher normalized energy use profile (Pratt et al. 1989)

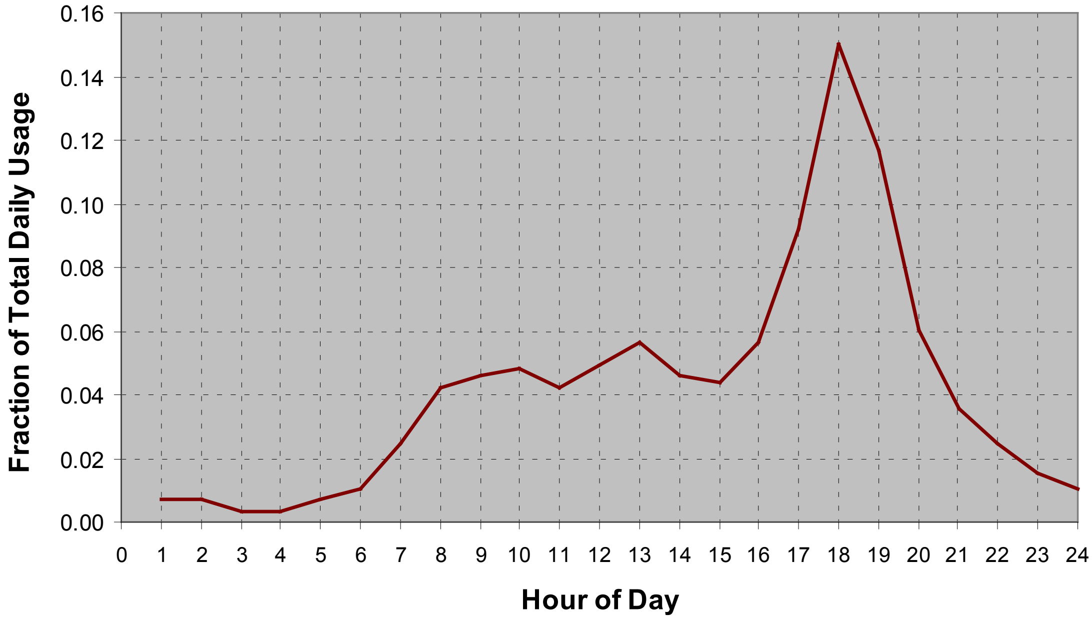


Figure 28. Range/oven normalized energy use profile (Pratt et al. 1989)

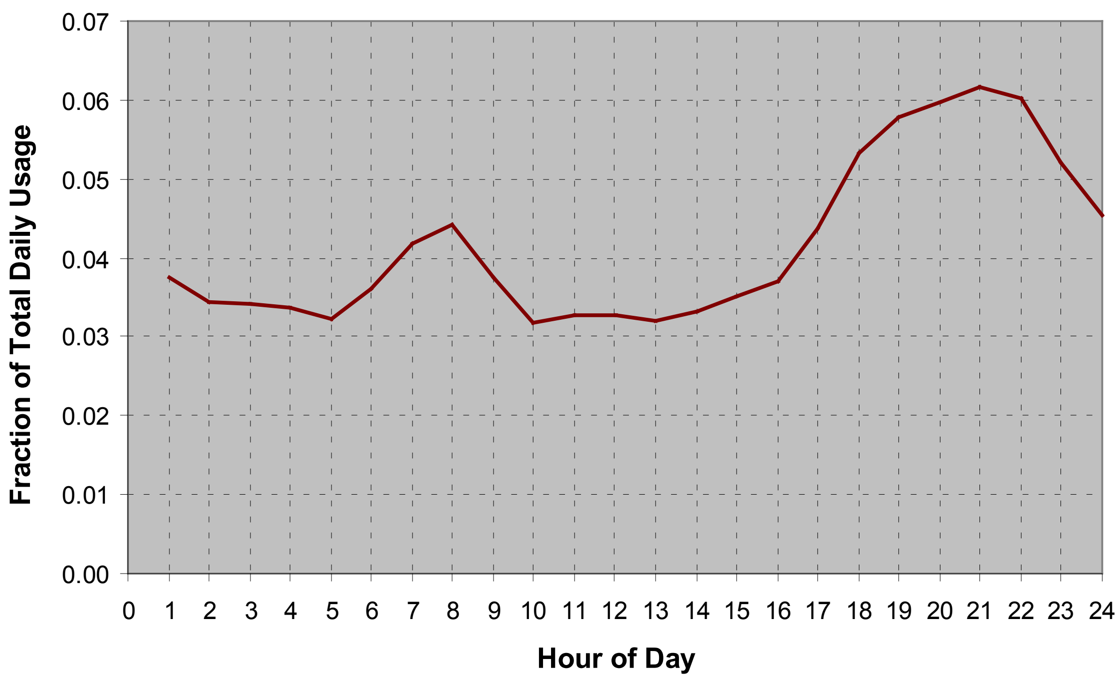


Figure 29. Miscellaneous electric loads normalized energy use profile

Site Generation

A review of data from the Energy Information Administration (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 ELA 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 and multi-family 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, then 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.

The openable window area shall be 33% unless specific provisions have been taken to increase this percentage, for example by installing hinged casement windows.

If the actual EER for the Prototype is not readily available, Equation 16 may be used to make an approximate conversion from SEER to EER (Wassmer 2003):

Equation 16: $$\mathbf{EER = -0.02 \times SEER^2 + 1.12 \times SEER}$$

If the Prototype has a hot water distribution system different from the Benchmark (see Table 13), the equations in Table 18 of the 2009 Benchmark Definition (Hendron 2008) shall be used to determine the change in daily hot water volume, the internal heat gain, the change in recovery load on the water heater, and any special pump energy. These calculations are automated in the BA Analysis Spreadsheet. For any distribution system type not listed, other than centralized DHW in multi-family housing, 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 centralized DHW systems, a detailed analysis is required to estimate distribution losses and pump energy.

For all distribution systems, the heat gain, recovery load, and pump energy shall be applied using the combined hourly DHW profile in Figure 14. 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 builder does not provide a clothes washer in the Prototype house, housing unit, or a common laundry room, the Prototype shall be modeled with the Benchmark clothes washer and dryer in the appropriate location.

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 17:

Equation 17: $$\text{Clothes washer cycles per year} = (392) \times (½+N_{br}/6) \times 12.5\ \text{lb}/W_{test}$$

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 18:

Equation 18: $$\text{Clothes dryer cycles per year} = DUF \times \text{Clothes washer cycles per year}$$

where:

DUF = 0.84.

The dishwasher annual operating cycles are similarly calculated, using Equation 19:

Equation 19: $$\text{Dishwasher cycles per year} = (215) \times (½ + N_{br}/6)$$

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 uses 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 annual useful cooking energy output as defined in the same test procedure (see Table 26) divided by the energy factor. 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.

Table 26. Useful Cooking Energy Output for Gas and Electric Ranges

State	Useful Cooking Energy Output
Electric Cooktop	173.1 kWh/yr
Electric Oven	29.3 kWh/yr
Gas Cooktop	5.28 therms/yr
Gas Oven	0.89 therms/yr

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.

The lighting calculations necessary for the Prototype are documented in the Lighting Equipment and Usage section of this report.

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).

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 Building America, 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 humidity ratio is below the indoor humidity ratio. The natural ventilation rate shall be calculated using the Sherman-Grimsrud model. Twenty percent of the maximum openable 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 air changes per hour. 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 the 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 Building America Analysis Spreadsheet posted on the Building America Web site.

The occupancy schedule is defined with the same level of detail as other internal load profiles. For typical Building America houses, the number of occupants for single-family and multi-family dwellings shall be estimated based on the number of bedrooms using Equations 20 and 21, respectively.

Equation 20: $$\text{Number of occupants} = 0.59 \times N_{br} + 0.87$$

Equation 21: $\textbf{Number of occupants} = 0.92 \times N_{br} + 0.63$

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 (see Table 27). The occupant heat gains are based on ASHRAE recommendations (ASHRAE 2001a). The average hourly occupancy profile is shown in Figure 30, and an example set of detailed hourly occupancy curves is shown in Figure 31.

Table 27. Peak Sensible and Latent Heat Gain From Occupants (ASHRAE 2001a)

Multiple Zones	Internal Load (Btu/person/h)	
	Sensible Load	Latent Load
Living Area	230	190
Bedroom Area	210	140
Common Laundry	250	200
Office	250	200
Workout Room	710	1090
Central Restroom	245	155
Single Zone	**Internal Load (Btu/person/h)**	
Sensible Load	220	
Latent Load	164	

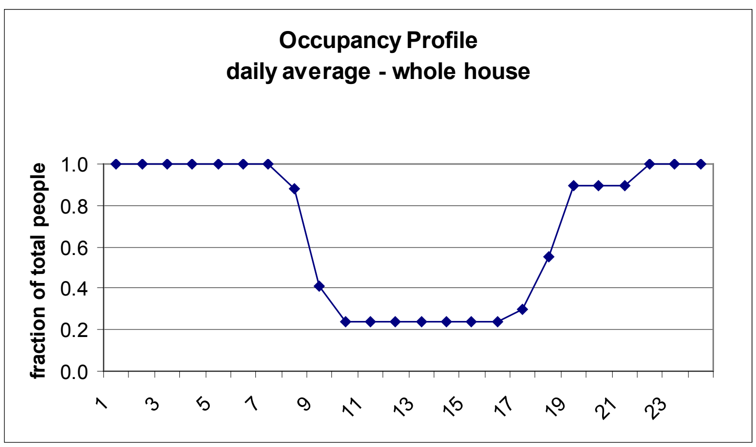


Figure 30. Average hourly load profile from occupants for all day types and family types (16.5 h/day/person total)

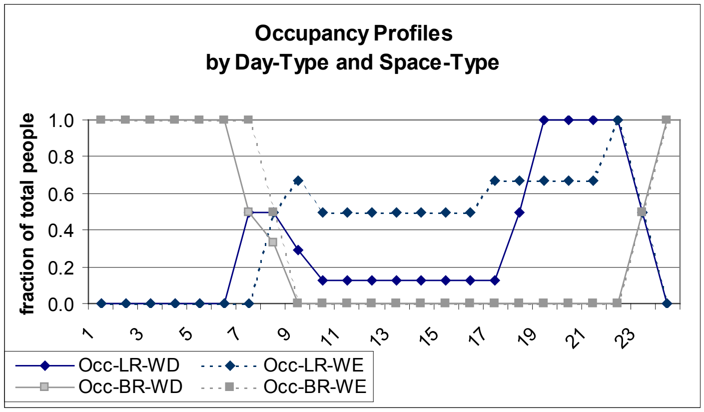


Figure 31. Detailed hourly load profiles resulting from occupants being in different parts of the house on weekdays (WD) and weekends (WE)

For common areas in multi-family buildings, an example occupancy profile is shown in Figure 32. The maximum occupancy for the common laundry room is equal to the number of washing machines. The maximum occupancy for the workout room should be 3 unless otherwise documented. The maximum occupancy for the office and central restroom will be 3 and 0.33 respectively. (Partial person is due to a maximum of 2 people per hour at 10 minutes each). The load profiles for the office and central restroom are modeled as zero for Sundays and holidays.

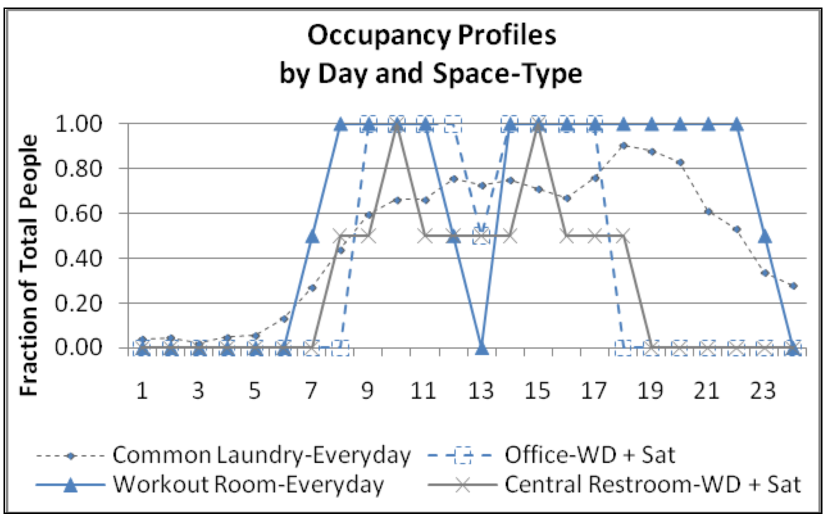


Figure 32. Detailed hourly load profiles resulting from occupants being in different common spaces on specific days of the week

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.

- The internal mass of furniture and contents shall be equal to 8 lb/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 to 2005[5] 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.

[5] Analytic Studies Division, National Renewable Energy Laboratory (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 Building America analysis. The following tables shall be supplied with the analysis report for every Building America Prototype.

Table 28 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 29, along with percent energy savings for each end use. End uses are described in more detail in Table 30.

Table 28. 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 29. Example Summary of Source Energy Consumption by End Use Using BA Research Benchmark

					Source Energy Savings					
	Estimated Annual Source Energy				Percent of End Use			Percent of Total		
End Use	Benchmark (MBtu/yr)	Region (MBtu/yr)	Builder (MBtu/yr)	Proto (MBtu/yr)	BA Base	Reg Base	Bldr Base	BA Base	Reg Base	Bldr Base
Space Heating	115	116	116	45	61%	61%	61%	23%	23%	23%
Space Cooling	28	25	25	9	67%	63%	63%	6%	5%	5%
DHW	50	50	50	14	72%	72%	72%	12%	12%	12%
Lighting	32	32	32	12	61%	61%	61%	6%	6%	6%
Appliances & 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 30. 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, MELs	Cooking, gas clothes dryer, gas fireplace
OA Ventilation	Ventilation fans, air handler during ventilation mode	None
Site Generation	Photovoltaic electric generation	None

* heat pump
** air-conditioning

For attached and multi-family housing, the energy use for all units shall be combined with the energy associated with common areas and any centralized space conditioning or hot water systems. This applies to both the Benchmark units and the Prototype units. Energy savings shall be calculated on a whole-building or whole-complex basis, and each unit shall be deemed to have the same percent energy savings.

The "Percent of End Use" columns in Table 29 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 22, using the site-to-source multipliers in Table 31.

Equation 22: $$\textbf{Source MBtu} = \textbf{kWh} \times 3.412 \times M_e / 1000 + \textbf{therms} \times M_g / 10 + \textbf{MBtu} \times M_o,$$

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 31).

For the purpose of determining whether the Joule energy savings criteria are met, a house size multiplier shall be applied to all Benchmark source energy consumption calculations for Building America homes (or units) that are attempting to achieve 50% energy savings or more. The adjusted Benchmark Source energy (Equation 23) assumes that a typical house size is 2400 ft^2 with three bedrooms.

Equation 23: Adjusted Benchmark Source MBtu = (M_{size}) × Source MBtu

where:

$$M_{size} = (N_{br}/3)^{0.071} \times (2400/\text{Floor Area})^{0.184}$$

Table 31. 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 32 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 32. This represents the estimated energy cost savings of the Prototype house compared to the Benchmark house based on current local utility costs.

Table 32. Example Measure Savings Report[6] Using BA 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	29950	0	306.9		$ 2,995		$ 2,950			
Regional Std Practice	29712	0	304.4	1%	$ 2,971	1%	$ 2,927			
Builder Std Practice (BSP)	29712	0	304.4	1%	$ 2,971	1%	$ 2,927			
BSP + improved walls	27779	0	284.6	7%	$ 2,778	7%	$ 2,736	7%	$ 190.4	$ 190
BSP ++ Low-E Windows	25810	0	264.5	14%	$ 2,581	14%	$ 2,542	13%	$ 193.9	$ 384
BSP ++ Smaller A/C (5 -> 4 tons)	25420	0	260.5	15%	$ 2,542	15%	$ 2,504	14%	$ 38.4	$ 423
BSP ++ Inc. Bsmt Wall Insulation	25170	0	257.9	16%	$ 2,517	16%	$ 2,479	15%	$ 24.6	$ 447
BSP ++ Ground Source HP (+DHW)	19331	0	198.1	35%	$ 1,933	35%	$ 1,904	35%	$ 575.1	$ 1,023
BSP ++ Solar DHW	17718	0	181.5	41%	$ 1,772	41%	$ 1,745	40%	$ 158.9	$ 1,181
BSP ++ Lighting, Appl. & Plug	15690	0	160.8	48%	$ 1,569	48%	$ 1,545	47%	$ 199.8	$ 1,381
Site Generation										
BSP ++ PV	8288	0	84.9	72%	$ 829		$ 816	72%	$ 729.0	$ 2,110

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:

Incremental cost of builder standard practice (see Hendron et al 2004) relative to minimum code, plus,

Incremental cost of the Prototype relative to builder standard practice;

Or,

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:

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

1. First cost only (do not include replacement or maintenance costs) .
2. Financed as part of a 30-year mortgage at an interest rate of 7%.
3. First cost shall be the estimated mature cost of new technologies at 5% market penetration in new homes.
4. 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.
5. 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.
6. The cost of HERS ratings or other energy-related third-party certifications shall be included in the Prototype cost.
7. 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).

References

Abrams, D.W. and Shedd, A.C. 1996. "Effect of Seasonal Changes in Use Patterns and Cold Inlet Water Temperature on Water Heating Load." *ASHRAE Transactions*, AT-96-18-3.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1988. Air Leakage Performance for Detached Single-Family Residential Buildings, ASHRAE Standard 119-1988, Atlanta, GA.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 1992. "Thermal Environmental Conditions for Human Occupancy," ASHRAE Standard 55-1992, Atlanta, GA.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1993. A Method of Determining Air Change Rates in Detached Dwellings, ASHRAE Standard 136-1993, Atlanta, GA.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1999. *HVAC Applications Handbook.* Atlanta, GA: ASHRAE.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2001a. *Fundamentals Handbook*. Atlanta, GA: ASHRAE.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 2001b. "Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems," Proposed ASHRAE Standard 152P, Atlanta, GA.

American Water Works Association (AWWA). 1999. "Residential End Uses of Water." Denver, CO: AWWA.

Anderson, R. 2008. "Summary of Technical Reporting Requirements for 2009 BA AOP Proposals and Project Management Plans (Updated: 9/01/08)." Building America Internal Report. Golden, CO: National Renewable Energy Laboratory.

Anderson, R. and Roberts, D. 2008. "Maximizing Residential Energy Savings: Net Zero Energy Home (ZEH) Technology Pathways." NREL Technical Report TP-550-44547. Golden, CO: National Renewable Energy Laboratory.

Becker, B.R. and Stogsdill, K.E.. 1990. "Development of Hot Water Use Data Base." ASHRAE Transactions, Vol. 96, Part 2, pp. 422-427. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

Burch, J. and Christensen, C. 2007. "Towards Development of an Algorithm for Mains Water Temperature." Proceedings of the 2007 ASES Annual Conference, Cleveland, OH.

Burch, J. and Erickson, P. 2004 (Draft). "Deriving Inputs for Storage Tank Water Heater Models from Rating Data." Conference paper. Golden, CO: National Renewable Energy Laboratory.

Burch, J. and Salasovich, J. 2002. "Flow Rates and Draw Variability in Solar Domestic Hot Water Usage." *Proceedings of the Solar 2002 Conference Including Proceedings of the 31st ASES Annual Conference and Proceedings of the 27th National Passive Solar Conference*, 15-20 June 2002, Reno, Nevada. Boulder, CO: American Solar Energy Society, Inc. (ASES); pp. 287-292; NREL Report No. CP-550-31779.

California Energy Commission (CEC). 2002. *California Building Energy Efficiency Standards, Part 1, Measure Analysis and Life Cycle Cost*, CEC, Sacramento, CA.

Christensen, C., Barker, G., and Thornton, J. 2000. *Parametric Study of Thermal Performance of Integral Collector Storage Solar Water Heaters*. NREL Report No. CP-550-28043. Conference paper. Golden, CO: National Renewable Energy Laboratory.

Davis Energy Group (DEG). 2006. *Prototype Floor Plans – Hot Water Distribution System Layouts*. Report to Lawrence Berkeley National Laboratory under funding by the California Energy Commission. Davis, CA: Davis Energy Group.

Deru, M. and Torcellini, P. 2007. Source Energy and Emission Factors for Energy Use in Buildings. NREL/TP-550-38617. Golden, CO: NREL

Eley Associates. 2002. Visual DOE Version 3.1. San Francisco, CA: Eley Associates.

Gleick, P.H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Kao-Cushing, K., and Mann, A. 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California. Prepared for Pacific Institute for Studies in Development, Environment and Security. Oakland, CA.

Hendron, R., Anderson, R., Judkoff, R., Christensen, C., Eastment, M., Norton, P., Reeves, P., and Hancock, E. 2004. *Building America Performance Analysis Procedures, Rev. 1*. NREL/TP-550-35567, NREL, Golden, CO.

Huang, J., and Gu, L. 2002 (Draft). *Prototypical Residential Buildings to Represent the US Housing Stock.* Berkeley, CA: Lawrence Berkeley National Laboratory.

International Code Council (ICC). 2003. International Energy Conservation Code 2003. Falls Church, VA: ICC.

Jiang, W., Jarnagin, R.E., Gowri, K., McBride, M., Liu, B. 2008. Technical Support Document: The Development of the Advanced Energy Design Guide for Highway Lodging Buildings. Richland, WA: Pacific Northwest National Laboratory.

Kolb, G. 2003. Private communication. Sandia National Laboratories, Albuquerque, NM.

Lithgow, M., Filey, D., Kaszczij, R., Liotta, J., Den-Elzen, P. 1999. Multi-Unit Residential Clothes Washer Replacement Pilot Project. Prepared by the City of Toronto Works and Emergency Services and the Toronto Community Housing Corporation., Toronto, Canada.

Manclark, B., and Nelson, M. 1992. *The Grays Harbor PUD Compact Fluorescent Maximization Study.* Grays Harbor, WA: Grays Harbor Public Utility District.National Renewable Energy Laboratory. 2009. “Benchmark Midrise Apartment NewV1(2).1_3.1(SI).” Golden, CO.

National Research Center (NRC). 2002. “A National Study of Water & Energy Consumption in Multifamily Housing: In-Apartment Washers vs. Common Area Laundry Rooms.” Multi-housing Laundry Association. Boulder, CO.

Navigant Consulting. 2002. *U.S. Lighting Market Characterization: Volume 1: National Lighting Inventory and Energy Consumption Estimate*. Washington, DC: Navigant Consulting.

Parker, D. 2002. *Research Highlights from a Large Scale Residential Monitoring Study in a Hot Climate* (and personal communication). FSEC-PF369-02. Cocoa, FL: Florida Solar Energy Center.

Parker, D., Sherwin, J.R., and Anello, M.T. September 2000. FPC Residential Monitoring Project: Assessment of Direct Load Control and Analysis of Winter Performance. Prepared for the Florida Power Corporation, FSEC-CR-1112-99. Cocoa, FL.

Pratt, R., Conner, C., Richman, E., Ritland, K., Sandusky, W., and Taylor, M. 1989. "Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest – End-Use Load and Consumer Assessment Program (ELCAP)," DOE/BP-13795-21, Pacific Northwest National Laboratory, Richland, WA.

Rea, M., et al. 1993. *Lighting Handbook, Eighth Edition*. New York, NY. Section 3, Chapter 11: Illuminance Selection.

Residential Energy Services Network (RESNET). 2002. "Mortgage Industry National Home Energy Rating Systems Accreditation Standards." Chapter 3, pp. 29-54. San Diego, CA: RESNET.

Roth, K.W., McKenney, K., Ponoum, R., and Paetsch, C. 2007. *Residential Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential.* Prepared for the Building Technologies Program, GS-23F-0064L, Cambridge, MA.

Sachs, H.M. 2005. *Opportunities for Elevator Energy Efficiency Improvements*. American Council for an Energy-Efficient Economy. Washington D.C. (Lightly-loaded low-rise hydraulic elevator doing 100,000 starts per year.)

Southern California Edison (SCE). 1993. *Final Report: Residential Lighting Study (Inventory Results).* Rosemead, CA: SCE.

Steven Winter Associates, Inc. (SWA). 1995. *Simplified Multizone Blower Door Techniques for Multifamily Buildings.* NYSERDA Report # 95-16. Norwalk, CT: SWA.

Stokes, M., Rylatt, M., Lomas, K. 2004. "A simple model of domestic lighting demand." Energy and Buildings. Vol. 36. pp. 103-116. Institute of Energy and Sustainable Development, United Kingdom.

U.S. Department of Energy (DOE). 1996. *Residential Lighting Use and Potential Savings*. DOE/EIA-0555(96)/2. Washington, DC: DOE.

U.S. Department of Energy (DOE). 1997. Code of Federal Regulations Title 10, Energy, Part 430, "Energy Conservation Program for Consumer Products: Test Procedure for Kitchen Ranges, Cooktops, Ovens, and Microwave Ovens; Final Rule." Washington, D.C.: DOE.

U.S. Department of Energy (DOE). 1999. "1997 Residential Energy Consumption Survey." Available online at http://www.eia.doe.gov/emeu/recs/pubs.html (accessed December 2009), Washington, DC: DOE.

U.S. Department of Energy (DOE). 2001. Annual Energy Outlook 2002. Washington, DC: DOE.

U.S. Department of Energy (DOE). 2002. "Residential Energy Efficiency and Appliance Standards." http://www.eere.energy.gov/consumerinfo/refbriefs/ee8.html (accessed May 2004). Washington, DC: DOE.

U.S. Department of Housing and Urban Development (HUD). 1982. "Minimum Property Standards for One- and Two-Family Living Units." No. 4900.1-1982. Washington, DC: HUD.

U.S. Environmental Protection Agency (EPA). 2006. *Savings Calculator – Dehumidifier*. Available at http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/CalculatorConsumerDehumidifier.xls. Washington, DC: Environmental Protection Agency.

Wassmer, M. 2003. "A Component-Based Model for Residential Air Conditioner and Heat Pump Energy Calculations." Masters Thesis, University of Colorado at Boulder.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
January 2010	Technical Report	

4. TITLE AND SUBTITLE	
Building America Research Benchmark Definition: Updated December 2009	**5a. CONTRACT NUMBER** DE-AC36-08-GO28308
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) R. Hendron and C. Engebrecht	**5d. PROJECT NUMBER** NREL/TP-550-47246
	5e. TASK NUMBER BE101001
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	NREL/TP-550-47246
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 and on-site power production of up to 30%, the U.S. Department of Energy Residential Buildings Program and the National Renewable Energy Laboratory 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, 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 chasing a "moving target." We expect energy codes to become more and more 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.

15. SUBJECT TERMS
benchmark; building america; ba; hers; home energy rating system; single-family housing; multi-family housing

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
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)