BUILDING TECHNOLOGIES PROGRAM

Building America House Simulation Protocols

Robert Hendron and Cheryn Engebrecht
National Renewable Energy Laboratory

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Definitions

A/C	air-conditioning
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
DHW	domestic hot water
DOE	U.S. Department of Energy
DOE-2	building energy analysis program that can predict the energy use and cost for all types of buildings
DSE	distribution system efficiency
DUF	dryer usage factor
EER	energy efficiency ratio
EF	energy factor
ELA	effective leakage area
FFA	finished floor area
HP	heat pump
HSPF	heating seasonal performance factor
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
LBNL	Lawrence Berkeley National Laboratory
M	maintenance factor
MAT	monthly average temperature
MEF	modified energy factor
MEL	miscellaneous electric load
NCTH	New Construction Test Home
NREL	National Renewable Energy Laboratory
OA	outdoor air
RECS	Energy Information Administration Residential Energy Consumption Survey
RESNET	Residential Energy Services Network
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SLA	specific leakage area
TMY3	Typical Meteorological Year, Version 3
TREAT	Building energy software that performs hourly simulations for single-family, multi-family, and mobile homes
TRNSYS	The Transient Energy System Simulation Tool is software designed to simulate the transient performance of thermal energy systems
U-value	The thermal transmittance of a material, incorporating the thermal conductance of the structure along with heat transfer resulting from convection and radiation

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Introduction

Building America (BA) is an industry-driven research program sponsored by the U.S. Department of Energy (DOE) that applies systems engineering approaches to accelerate the development and adoption of advanced building energy technologies in new and existing residential buildings. This program supports multiple building research teams in the production of advanced residential buildings on a community scale. These teams use a systems engineering process to perform cost and performance assessments relative to each builder or retrofit contractor's standard practice; the overall goal is to significantly reduce energy use with only a nominal increase in initial construction costs. The energy efficiency concepts incorporated into these houses are evaluated by conducting successive design, test, redesign, and retest iterations, including cost and performance trade-offs; the result will be innovations that can be used cost effectively in production-scale housing.

Additional goals of the BA program are to:

- Encourage a systems engineering approach in the design and construction of new homes and retrofits.
- Accelerate the development and adoption of high-performance residential energy systems.
- Improve indoor air quality, comfort, and durability.
- Integrate clean, on-site power systems.

To measure progress toward these goals, cost and performance trade-offs are evaluated through a series of controlled field and laboratory experiments supported by energy analysis techniques that use test data to validate energy simulation models. This report summarizes the guidelines for developing and reporting these analytical results in a consistent and meaningful manner for all home energy uses. As BA teams develop innovative new technologies and systems approaches that move the program toward its research goals, this report will be evaluated and updated periodically to ensure that energy savings from these features are accurately credited.

The House Simulation Protocol document was developed to track and manage progress toward multi-year, average whole-building energy reduction research goals for new construction and existing homes, using a consistent reference point. These protocols provide a mechanism for tracking progress toward long-term research goals and ensuring that individual research projects are relevant to builder and retrofit contractor needs.

Standard user profiles for use in conjunction with these reference houses have been developed based on review of the available literature; the intent is to represent average occupant behavior. Additional analysis and end-use monitoring may be required to evaluate energy savings for specific occupants whose behaviors could vary from the average profiles defined in this document. The average relative savings for a community of houses are expected to be approximately the same as those calculated using the protocols in this document.

Purpose

As BA has grown to include a large and diverse cross-section of the home building and retrofit industries, it has become more important to develop accurate, consistent analysis techniques.

These are designed to help program partners perform design trade-offs and calculate energy savings for Post-retrofit and New Construction Test Houses (NCTHs) built as part of the program. Many useful approaches and tools are available to BA teams and partners for calculating energy savings. This document illustrates analysis methods that are proven to be effective and reliable in analyzing the energy use of advanced energy systems and of entire houses.

This document is divided into three sections. Section I provides information about design assumptions and analysis methods for new construction, including the Building America B10 Benchmark house and a NCTH house. Many other valid techniques and definitions have been developed by other organizations, and they can be very useful to builders for specialized applications. For example, the HERS rating procedure (RESNET 2006) must be followed to obtain an ENERGY STAR® rating for building energy efficiency. Section II provides similar information for the analysis of existing homes, both Pre-Retrofit and Post-Retrofit. Using as many aspects of the real houses as possible, this section also provides default values for components of the house with unknown performance characteristics. Section III provides information about standard operating conditions for the analysis of new and existing homes.

Analysis Tools

A key decision in any building energy analysis is which tool or program is used to estimate energy consumption. An hourly simulation is often necessary to fully evaluate the time-dependent energy impacts of advanced systems used in BA houses. Thermal mass, solar heat gain, and wind-induced air infiltration are examples of time-dependent effects that can be accurately modeled only by using a model that calculates heat transfer and temperature in short time intervals. An hourly simulation program is also necessary to accurately estimate peak energy loads. Because it has been specifically developed and tailored to meet BA's needs, BEopt (using either DOE-2 or EnergyPlus as the simulation engine) is the hourly simulation tool recommended for systems analysis studies performed under the DOE Building America program.

Teams are also encouraged to use other simulation tools when appropriate for specialized building simulation analysis, provided the tool has met the requirements of the Building Energy Simulation Test and Diagnostic Method in accordance with the software certification sections of RESNET (2006). Regardless of the tool selected, teams should present complete analysis results in accordance with the reporting guidelines described later in this report.

New Construction

To track progress toward aggressive multi-year, whole-house energy savings goals of 30%–50% for new homes, the National Renewable Energy Laboratory (NREL) developed the BA B10 Benchmark. The B10 Benchmark, referred to simply as the Benchmark in this report, is consistent with the 2009 International Energy Conservation Code (IECC), with additional definitions that allow the analyst to evaluate all residential end uses consistent with typical homes built in 2010. 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." A series of user profiles, intended to represent the behavior of a typical 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.

The following house designs shall be included as part of the analysis of a new home design:

B10 Benchmark. A reference case representing a house built to the 2009 IECC, as well as the federal appliance standards in effect as of January 1, 2010, and lighting characteristics and miscellaneous electric loads (MELs) most common in 2010. The Benchmark is used as the point of reference for tracking progress toward multi-year energy savings goals established by Building America.

New Construction Test House (NCTH). A research house or prototype house built as part of a community-scale project that includes advanced systems and design features built as part of the Building America program.

B10 Benchmark Specifications

The following sections summarize the definition of the Benchmark. 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 are available on the BA Web site (www1.eere.energy.gov/buildings/building_america/ perf_analysis.html). In addition, BEopt, a software package developed by NREL, automatically generates the Benchmark when the specifications for a NCTH 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 NCTH. 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, it should be modeled or hand-calculated separately from the building model and reasonable adjustments should be made to the whole-house simulation results. If no significant energy effect is associated with these elements, the NCTH and Benchmark should be modeled using similar approximations in an energy-neutral manner.

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) has 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 multifamily 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 U.S. Department of Energy Residential Energy Consumption Survey (RECS) (DOE 2005) database (except the requirement on the number of units).

Building Envelope

References to thermal envelope variables (such as R-values) stem from the IECC (ICC 2009) unless otherwise noted.

The Benchmark envelope specifications are:

- The same shape and size as the NCTH, except the Benchmark shall have 2-ft eaves for pitched roofs and no eaves for flat roofs. Roof slope shall be the same as the NCTH
- The same area of surfaces bounding conditioned space as the NCTH with the exception of unfinished attics, which shall be insulated at the attic floor and have a ventilation area of 1 ft^2 per 300 ft^2 ceiling area, and the crawlspace, which shall be unvented and insulated at the walls, regardless of the NCTH design. Finished attics shall be considered part of the living space, and shall have the same thermal boundary as the NCTH
- The same foundation type (slab, crawl space, or basement) as the NCTH
- The same basement wall construction type as the NCTH (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
- For each floor of the house, window area (AF), including framing, determined by Equation 1 for single-family homes, and by Equation 2 for multifamily homes (regardless of whether the hallways are interior or exterior). The coefficient for Equation 1 stems from the IECC 2009 reference building and a number of references mentioned in "Eliminating Window-Area Restrictions in the IECC" (Taylor et al. 2001).

$$A_{F,\ Liv} = 0.15 \times A_{ExWa,\ Liv} \qquad (1)$$

$$A_{F,\ Bsm} = 0.15 \text{ x } A_{ExWa,Bsm}$$

$$A_{F,\ Liv} = 0.30 \times A_{ExWa,\ Liv} \qquad (2)$$

$$A_{F,\ Bsm} = 0.30 \text{ x } A_{ExWa,Bsm}$$

where

$A_{F,\ Liv}$ = total window area for above-grade floors (ft^2)

$A_{F,\ Bsm}$ = total window area for basement walls (ft^2)

$A_{ExWa,Liv}$ = total exterior wall area of above-grade living space on a specific floor (ft^2)

$A_{ExWa,Bsm}$ = total basement exterior wall area

and where

Exterior wall is any wall that separates conditioned space from outside conditions. In cases where walls of multifamily units are adjacent to exterior hallways, this wall area will not be included due to the privacy issue.

Basement exterior wall is any above-grade basement wall that is exposed to outside conditions

- Thirty-three percent of the window area on each facade can be opened for natural ventilation.
- Either of two approaches may be used to achieve solar neutrality for the Benchmark:
  - Option 1: The calculated window area (see Equations 1 and 2) is distributed with the same proportion on each wall and on each floor as the NCTH. The energy use is calculated with the Benchmark house in each of four orientations rotated in 90-degree increments relative to the NCTH orientation (+0 degrees, +90 degrees, +180 degrees, +270 degrees), 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 NCTH.
- Thermal conductance of all thermal boundary elements equal to the requirements, expressed as R-values, of Section 402 of the 2009 IECC (ICC 2009), as summarized below. The climate zones in Table 1 refer to those specified in Table 301.1 of the 2009 IECC. Unless otherwise specified, these R-values only include insulation and not the effective R-value of the entire wall/ceiling assembly.
- The R-value for insulation in the opaque fraction of exterior (detached and attached) walls can be found in Table 1. The values for the rest of the wall assembly are ½-in. drywall (R-0.45), stud/cavity represented by the framing factors in Table 2, ½-in. plywood (R-0.62) and stucco (R-0.2).
- The above-grade exterior walls shall be light-frame 2 × 4 or 2 × 6 wood construction. The framing factors in Table 2 are representative of typical construction practices, and shall be used as inputs for the Benchmark model. Interior partition walls shall be light-frame (2 × 4) wood construction. For multifamily buildings, the framing between floors will be 2 × 10 wood construction.
- The R-value of an insulated ceiling shall be as specified in Table 1. However, if the building design does not allow sufficient space for the insulation (such as cathedral ceilings), R-30 insulation will be specified. The total area where the R-value is reduced for cathedral ceilings shall not exceed 500 ft^2 or 20% (whichever is less) of the total insulated ceiling area. If the NCTH includes an attic, the Benchmark shall have a vented attic with insulation flat on the attic floor (even if the NCTH has a cathedralized attic).
- R-value of an insulated floor above unconditioned space is specified in Table 1.

- R-values of walls in an insulated basement or unvented crawl space are specified in Table 1. In both cases, continuous insulation shall be used for the Benchmark.

R-values and depth of slab edge insulation for slab-on-grade construction are specified in Table 1. This R-value is for rigid foam insulation and does not include the slab itself or ground effects.

Table 1. Insulation R-Values
(excerpted from IECC 2009 unless otherwise noted)

Climate Zone	Ceiling R-Value	Frame Wall R-Value (Detached)	Frame Wall R-Value (Attached)*	Floor R-Value	Basement Wall R-Value	Crawl Space Wall R-Value	Slab R-Value and Depth
1	30	13	13	13	0	0	0
2	30	13	13	13	0	0	0
3	30	13	13	19	0**	5	0
4 except Marine	38	13	13	19	10	10	10, 2 ft
5 and Marine 4	38	13+5***	19	30	10	10	10, 2 ft
6	49	13+5	19	30	15	10	10, 4 ft
7 and 8	49	21	19	38	15	10	10, 4 ft

* R-values for attached homes are not extracted from IECC 2009; however, values are consistent with insulation available on the market and with the pattern presented in IECC 2009 for walls in detached housing.
** Basement wall insulation is required in dry regions of Region 3 (as defined in Section 301 in IECC 2009), but is not included in the Benchmark for ease of implementation and because basements in this region are uncommon.
*** "13+5" means R-13 cavity insulation combined with R-5 continuous insulating sheathing on the exterior of the wall.

Table 2. Benchmark Framing Factors

Enclosure Element	Frame Spacing (in. on center)	Framing Fraction (% area)
Walls (above grade)	16	23%
Floors/basement ceiling	16	13%
Ceilings below unconditioned space	24	11%

The assembly U-value and solar heat gain coefficient (SHGC) for vertical fenestration, including windows and sliding glass doors, shall be determined using Table 3. Values in Table 3 were determined using IECC 2009 in combination with values that reflect common window options on the market when IECC 2009 does not have a requirement. 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 3. Fenestration Assembly Characteristics

Climate Zone	Vertical Fenestration U-Value (U_F) (Btu/h·ft^2·°F)	Vertical Fenestration SHGC
1	0.40	0.30
2	0.40	0.30
3	0.40	0.30
4 except Marine	0.35	0.35
5 and Marine 4	0.35	0.35
6	0.35	0.35
7 and 8	0.35	0.35

The Benchmark shall include external shading based on the geometry of the home, including roof projections, self-shading, attached garages and enclosed porches, unless the simulation tool does not allow for geometry inputs. However, the Benchmark will not include external shading at any time from awnings, adjacent buildings, or vegetation, regardless of the simulation tool used.

The area and location of opaque exterior doors shall be the same as the NCTH, with door U-value equal to 0.20 Btu/h·ft^2·°F (air-to-air).

Solar absorptivity is equal to 0.60 for opaque areas of exterior walls, and 0.75 for roofs.

Total emittance of opaque areas of exterior walls and roofs is equal to 0.90.

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 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 NCTH, as shown in Table 4.

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, the EER for the Benchmark shall be calculated using Equation 3. If the actual EER for the NCTH is not readily available, Equation 3 may also be used to make an approximate conversion from SEER to EER (Wassmer 2003):

$$\text{EER} = -0.02 \times \text{SEER}^2 + 1.12 \times \text{SEER} \quad (3)$$

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

Table 4. Benchmark Space Conditioning Equipment Efficiencies

NCTH 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	7.7 HSPF**/13 SEER air source heat pump
Air source heat pump (split)	Heating/Cooling	7.7 HSPF/13 SEER air source heat pump
Air source heat pump (package)	Heating/Cooling	7.7 HSPF/13 SEER air source heat pump
Other electric*** or no system	Heating	7.7 HSPF/13 SEER air source heat pump
Split system central air conditioner (or mini-split air conditioner)	Cooling	13 SEER air conditioner
Single package air conditioner	Cooling	13 SEER air conditioner
Room air conditioner	Cooling	9.0 EER room air conditioner
Other type or no air conditioner	Cooling	13 SEER air conditioner

* Annual Fuel Utilization Efficiency
** Heating seasonal performance factor
*** For NCTHs with electric resistance heating, the Benchmark shall have a 7.7 HSPF/13 SEER air source heat pump for both heating and cooling, regardless of the cooling system in the NCTH.

The Benchmark shall not have a whole-house fan.

Regardless of whether the NCTH actively controls relative humidity, the Benchmark shall include a stand-alone dehumidifier with an energy factor (EF) of 1.2 l/kWh. Sensible heat generated by the dehumidifier shall be added to the internal heat gains.

The Benchmark air handler shall have power consumption equal to 0.364 W/cfm.

The Benchmark shall include an air distribution system with the properties listed in Table 5. The location of the ductwork in the Benchmark is based on the type of foundation used for the NCTH. If the simulation tool does not permit the input of duct specifications to the level of detail used in Table 5, 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 5 and the procedures in the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 152 (ASHRAE 2004). NREL modified a spreadsheet developed by Lawrence Berkeley National Laboratory (LBNL) and integrated it into the BA Analysis Spreadsheet to assist with this calculation.

Table 5. Duct Locations and Specifications for the Benchmark

	NCTH Foundation Type	Benchmark Duct Specification	
		One-Story	**Two-Story or Higher**
Supply duct surface area (ft^2)	All	0.27 × FFA*	0.20 × FFA
Return duct surface area (ft^2)	All	0.05 × $N_{returns}$ × FFA (Maximum of 0.25 × FFA)	0.04 × $N_{returns}$ × FFA (Maximum of 0.19 × FFA)
Rupply/return duct insulation (inside thermal envelope)**	All	None	
Supply duct insulation within attic	All	R-8	
Supply/return duct insulation (all other locations)	All	R-6	
Duct material	All	Sheet metal	
Duct leakage excluding air handler (inside and outside)	All	10% of air handler flow (9% supply, 1% return)	
Air handler leakage (inside and outside)	All	5% of air handler flow (1% supply, 4% return)	
Percent of duct/air handler leakage imbalance (supply minus return) made up by outside air (OA)	Slab-on-grade or raised floor	100% OA[+++]	37% OA[+++]
	Basement or crawl space	0% OA[+]	0% OA[+]
	Multi-family	100% OA[+]	100% OA[+]
Supply duct location	Slab-on-grade or raised floor	100% attic[d]	65% attic[++], 35% conditioned space
	Crawlspace	100% crawlspace	65% crawlspace, 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[d]	100% Attic[++]
	Crawlspace	100% crawlspace	100% crawlspace
	Basement	100% basement	100% basement
	Multi-family	100% conditioned space	100% conditioned space

* Finished floor area (ft^2)

**Thermal envelope includes everything within the insulation boundary. If the space between a basement and the living area is insulated, or there is no insulation at either the walls or ceiling of the basement, the basement is considered outside of the thermal envelope and ducts within that space have R-6 insulation.

[+]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.

[++] If the NCTH does not have an attic, then this percentage of duct leakage is assumed to be in an attached garage. If the NCTH does not have an attached garage, then the leakage is assumed to be in conditioned space.

[+++] If the NCTH does not have an attic or attached garage, the leakage is assumed to be in conditioned space and the leakage imbalance shall be made up of 0% outside air.

Domestic Hot Water

The specifications in Table 6 and Table 7 shall be used for the domestic hot water (DHW) system in the Benchmark. For a multifamily building with a central hot water system, the Benchmark shall have individual systems using the same fuel type. Storage and burner capacity are determined using the guidelines recommended in the *HVAC Applications Handbook* (ASHRAE 2007a); these are based on the minimum capacity permitted by the Department of Housing and Urban Development and the Federal Housing Administration (HUD 1982). EF is consistent with the Federal standard for the corresponding fuel type and storage capacity (DOE 2001a). An example set of DHW specifications based on a typical three-bedroom, two-bathroom NCTH is shown in Table 8. The BA Analysis Spreadsheet developed by NREL automates many of the equations discussed in the following paragraphs, and calculates the correct DHW inputs for the TRNSYS computer program, including standby heat loss coefficient. The spreadsheet has a comprehensive set of inputs and outputs that can be used to help calculate DHW properties for the NCTH (Burch and Erickson 2004).

Table 6. Characteristics of Benchmark DHW System

	Water Heater Fuel Type in NCTH	
	Electric	**Gas**
Storage capacity (V) (gallons)	See Table 7. Benchmark DHW Storage and Burner Capacity	See Table 7. Benchmark DHW Storage and Burner Capacity
EF*	0.97 – (0.00132 × V)	0.67 – (0.0019 × V)
RE**	1.00	0.78
Burner capacity	See Table 7. Benchmark DHW Storage and Burner Capacity	See Table 7. Benchmark DHW Storage and Burner Capacity
Fuel type	Same as NCTH***	
Tank location	Same as NCTH	

* Energy factor

** Recovery efficiency

*** If the NCTH 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 7. Benchmark DHW Storage and Burner Capacity
(ASHRAE 2007b)

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

Table 8. Example Characteristics of a Benchmark DHW System
(based on an NCTH with three bedrooms and two bathrooms)

	Water Heater Fuel Type in NCTH	
	Electric	**Gas**
Storage capacity (V) (Gallons)	50	40
EF	0.904	0.594
RE	1.00	0.78
Burner Capacity	5.5 kW	36,000 Btu/h
Fuel Type	Same as NCTH	
Tank Location	Same as NCTH	

Five major end uses are identified for DHW: showers, baths, sinks, dishwasher, and clothes washer. If the builder does not provide a clothes washer, the Benchmark clothes washer shall be included in both the Benchmark and NCTH 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 9. 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. 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; CEC 2002; Christensen et al. 2000). The relationship between the number of bedrooms and hot water usage was derived from the 1997 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) *Moisture Control in Buildings* (ASTM 1994) manual. 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 9. DHW Consumption by End Use

End Use	End Use Water Temperature	Water Use	Sensible Heat Gain	Latent Heat Gain
Clothes washer	water heater setpoint	$2.35 + 0.78 \times N_{br}$ gal/day (hot only)	0*	0*
Common laundry	water heater setpoint	2.47 gal/day/housing unit (hot only)	0*	0*
Dishwasher	water heater setpoint	$2.26 + 0.75 \times N_{br}$ gal/day (hot only)	0*	0*
Shower (both standard and low-flow)	110°F	$14.0 + 4.67 \times N_{br}$ gal/day (hot and 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	110°F	$3.5 + 1.17 \times N_{br}$ gal/day (hot and cold)	$185 + 62 \times N_{br}$ Btu/day	0**
Sinks	110°F	$12.5 + 4.16 \times N_{br}$ gal/day (hot and 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	110°F	$0.028 \times N_{units}$ gal/day (hot and 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.

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 typical meteorological year (TMY3) location and number of bedrooms. This tool is available for download from the BA Performance Analysis Web site, along with standard Benchmark event schedules for two-, three-, and four-bedroom houses. The events generated by the spreadsheet are consistent with the average daily volumes calculated based on Table 9. Additional characteristics of the Benchmark hot water events for a three-bedroom house are summarized in Table 10.

Table 10. Example Characteristics of Benchmark DWH Events and Constraints
(based on an NCTH with three bedrooms)

Characteristics	Sink	Shower	Bath	CW	DW
Average duration (min)	0.62	8.5 for standard fixtures 6.8 for low-flow fixtures**	5.65	0.96	1.38
Standard deviation duration (min)	0.67	3.52	2.09	0.51	0.37
Probability distribution for duration	Exponential	Log-Normal	Normal	Discrete	Log-Normal
Average flow rate (gpm)*	1.14	2.25 for standard fixtures 1.85 for low-flow fixtures**	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	2.18	1.93
Average daily volume (gal/day)*	25	28	7	4.7	4.5
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				

Derived from AWWA 1200 house total water study (AWWA 1999)

Derived from a 20 house hot water study conducted by Aquacraft (Aquacraft 2008)

Derived from other values in this document

Engineering judgment

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

** Low flow showerheads have a flow rate less that 2 gpm.

Hot water distribution system design can have a significant impact on wait times for hot water, interior heat gains from pipes, and total water heating energy. NREL and Davis Energy Group analyzed a wide range of distribution system types, and developed a set of equations to assist with the calculation of whole-house energy savings for improved distribution systems. The basic characteristics of the Benchmark distribution system are summarized in Table 11. Treatment of other distribution system types is discussed in the "Modeling the NCTH" section of this report.

Table 11. Benchmark DHW Distribution System Characteristics

Branching Configuration	Trunk and Branch
Material	Copper
Pipe insulation	None
Pipe lengths and diameters	Based on 2010 ft^2 NCTH house layout developed by Davis Energy Group 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 4. The heat gain shall be applied using the combined hourly DHW profile in Figure 9.

$$\text{IHG (Btu/day)} = \{IHG_{bench,avg} + 735 \times (N_{br} - 3)\} \times \{1 + 1/IHG_{bench,avg} \times [362 + \{63 \times (N_{br} - 3)\}] \times \sin(2\pi \times (\text{Month}/12 + 0.3))\} \quad (4)$$

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 5:

$$SLA = ELA/CFA = 0.00036 \quad (5)$$

where

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

CFA = conditioned floor area (ft^2)

When specifying natural infiltration for a single-family detached or attached Benchmark with either a directly or an indirectly conditioned basement, the SLA shall be adjusted to account for the in-ground portions of the walls of the conditioned basement. Equation 6 shall be used to make this adjustment.

$$SLA_{overall} = [(CFA_{bsmt} \times SLA_{bsmt}) + (CFA_{a\text{-}g} \times SLA_{a\text{-}g})]/[CFA_{total}] \quad (6)$$

where

SLA = ELA (ft^2)/CFA (ft^2)

$SLA_{a\text{-}g}$ = SLA_{std} (where subscript 'a-g' indicates above-grade floors)

SLA_{bsmt} = SLA_{std} × (above-grade basement wall area)/(total basement wall area)

SLA_{std} = 0.00036

For single-family houses, this can be calculated by zone, applying SLA_{bsmt} to the basement and SLA_{std} to the above-grade floors 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.

For a multi-family building, the SLA values for the Benchmark are specified in Table 12 (NREL 2009). These values include leakage area to the outside only. 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 12. 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)

Additional air exchange whole-house mechanical ventilation shall be calculated assuming a single point exhaust ventilation system with the same ventilation rate used for the NCTH, up to a maximum value consistent with the rate recommended by ASHRAE Standard 62.2 (ASHRAE 2007b). Whole-house mechanical ventilation air shall be added to the natural infiltration rate in quadrature, assuming no heat recovery. Ventilation fan energy use for the Benchmark shall be calculated using a fan efficiency of 0.5 W/cfm.

In addition to whole-house ventilation, the Benchmark shall include a kitchen range hood, spot ventilation fan in each bathroom, and exhaust from the clothes dryer. The flow rates of the kitchen and bathroom fans shall be the same as those in the NCTH, and their efficiency shall be 0.50 W/cfm. The flow rate for the clothes dryer fan shall be 100 cfm. The kitchen range hood is assumed to operate 60 min/ day (between 6:00 p.m. and 7:00 p.m.), and each bathroom fan (including those in central restrooms) is assumed to operate 60 minutes per day (between 7:00 a.m. and 8:00 a.m.). The clothes dryer fan will operate for 60 minutes per day between 11:00 a.m. and 12:00 p.m. 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 13.

Table 13. Multi-Family Common Space Ventilation Rates

Room Type	Ventilation 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

For the Benchmark lighting budget, 66% of all lamps are incandescent, 21% are compact fluorescent, and the remaining 13% are T-8 linear fluorescent (KEMA 2009). In all calculations, a 10% takeback is included in the form of an increase in operating hours when incandescent lamps are replaced with energy-efficient lamps (Greening et al. 2000).

The Benchmark and NCTH lighting calculations have two options: (1) a simpler method that is based on a smart lamp replacement approach; and (2) a more complicated method that 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) (Rea et al. 2000) 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 7–10. These equations were derived from detailed calculations using Option 2 for a cross-section of residential floor plans using typical fixtures and lamps.

$$\text{Interior hard-wired lighting} = 0.8*(\text{FFA} \times 0.542 + 334) \text{ kWh/yr,} \quad (7)$$

$$\text{Interior plug-in lighting} = 0.2*(\text{FFA} \times 0.542 + 334) \text{ kWh/yr,} \quad (8)$$

$$\text{Garage lighting} = \text{Garage Area} \times 0.08 + 8 \text{ kWh/yr,} \quad (9)$$

$$\text{Exterior lighting} = \text{FFA} \times 0.145 \text{ kWh/yr} \quad (10)$$

A percentage of this lighting energy use is associated with each month (Table 14). The total kWh/yr found in Equations 7–10 are multiplied by each of these numbers to find the kilowatt-hours used for a given month.

Table 14. 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 1 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.

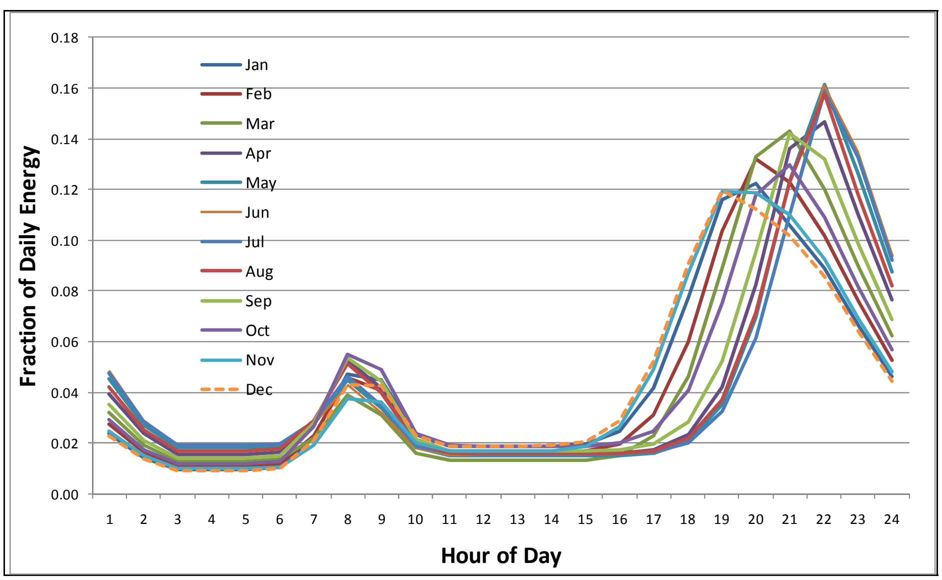


Figure 1. Normalized hourly lighting profile for a given month using Option 1

If a comprehensive lighting plan has not been developed for the NCTH house, and only fluorescent, light-emitting diode (LED), and incandescent lamps are installed, a simplified approach may be used to estimate energy savings compared to the Benchmark using Equations 11–13. These equations use default assumptions for lamp and fixture characteristics, and we assume that the more efficient lamps are first applied to the room types with the highest average daily use. A take-back effect of 10% in the form of increased operating hours for energy-efficient lighting is also applied.

$$\text{NCTH interior hard wired lighting (kWh/yr)} = L_{HW} \times \{[(F_{Inc,HW}+0.34) + (F_{CFL,HW}-0.21) \times 0.27 + F_{LED,HW} \times 0.30 + (F_{LF,HW} -0.13) \times 0.17] \times SAF \times 0.9 + 0.1\} \quad (11)$$

where

L_{HW}	=	hard-wired interior lighting for the Benchmark from Equation 7 (kWh/yr)
$F_{Inc,HW}$	=	fraction of hard-wired interior lamps in the NCTH that are incandescent
$F_{CFL,HW}$	=	fraction of hard-wired interior lamps in the NCTH that are compact fluorescent
$F_{LED,HW}$	=	fraction of hard-wired interior lamps in the NCTH that are LED
$F_{LF,HW}$	=	fraction of hard-wired interior lamps in the NCTH that are linear fluorescent
SAF	=	Smart replacement algorithm factor: $1.1 \times F_{Inc}^4 - 1.9 \times F_{Inc}^3 + 1.5 \times F_{Inc}^2 - 0.7 \times F_{Inc} + 1$

$$\text{NCTH garage lighting (kWh/yr)} = L_{GAR} \times \{[(F_{Inc,GAR}+0.34) + (F_{CFL,GAR}-0.21) \times 0.27 + F_{LED,GAR} \times 0.30 + (F_{LF,GAR} -0.13) \times 0.17] \times 0.9 + 0.1\} \quad (12)$$

where

L_{GAR}	=	garage lighting for the Benchmark from Equation 9 (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

$$\text{NCTH outdoor lighting (kWh/yr)} = L_{OUT} \times \{[(F_{Inc,OUT}+0.34) + (F_{CFL,OUT}-0.21) \times 0.27 + F_{LED,OUT} \times 0.30 + (F_{LF,OUT} -0.13) \times 0.17] \times 0.9 + 0.1\} \quad (13)$$

where

L_{OUT}	=	outdoor lighting for the Benchmark from Equation 10 (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 NCTH lighting energy use for Option 2 are both calculated using the BA Analysis Spreadsheet. The Benchmark uses fixed values for recommended room lighting levels (Table 16), operating hours per day per room (Table 20), average efficacies for a given room type, fraction of hard-wired lighting per room type, and primary fixture type (Table 15). All other parameters are user inputs that are used by both the Benchmark and the NCTH.

Table 15. Fixed Values for Benchmark Calculation for Option 2

Room Type	Average Efficacy (lm/W)	Fraction Hard-Wired	Primary Fixture Type
Bathroom	29.3	1.00	Vanity
Bedroom	26.9	0.61	Closed ceiling
Closet (large)	33.9	1.00	Bare bulb
Dining room	21.3	1.00	Chandelier
Family room	27.6	0.50	Indirect ceiling
Garage	73.7	1.00	Bare bulb
Hall/stairs	24.5	1.00	Closed ceiling
Kitchen	47.0	1.00	Closed ceiling
Living room	27.6	0.29	Indirect ceiling
Home office	33.5	0.61	Closed ceiling
Utility /laundry	45.6	1.00	Bare bulb
Unfinished basement	56.2	1.00	Bare bulb
Outdoor	25.6	1.00	Outdoor
Other	46.3	1.00	Globe
Multi-Family Common Spaces			
Common laundry	24.3	1.00	Utility/strip
Office	24.3	0.61	Utility/strip
Indoor corridor	24.3	1.00	Closed ceiling
Workout room	24.3	1.00	Utility/strip
Equipment room	24.3	1.00	Utility/strip
Central restroom	24.3	1.00	Recessed downlight
Multipurpose room	24.3	0.50	Recessed downlight
Outdoor walkway	24.3	1.00	Globe
Outdoor stairs	24.3	1.00	Globe
Parking garage	24.3	1.00	Closed ceiling (utility)
Open parking	24.3	1.00	Outdoor wall mount
Common mail	24.3	1.00	Globe
Elevator	24.3	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 (Stokes et al 2004). 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 2. Other profiles can be calculated using the spreadsheet available on the BA Web site. Profiles generated using the spreadsheet are normalized, and must be combined with annual lighting energy values, which are calculated separately.

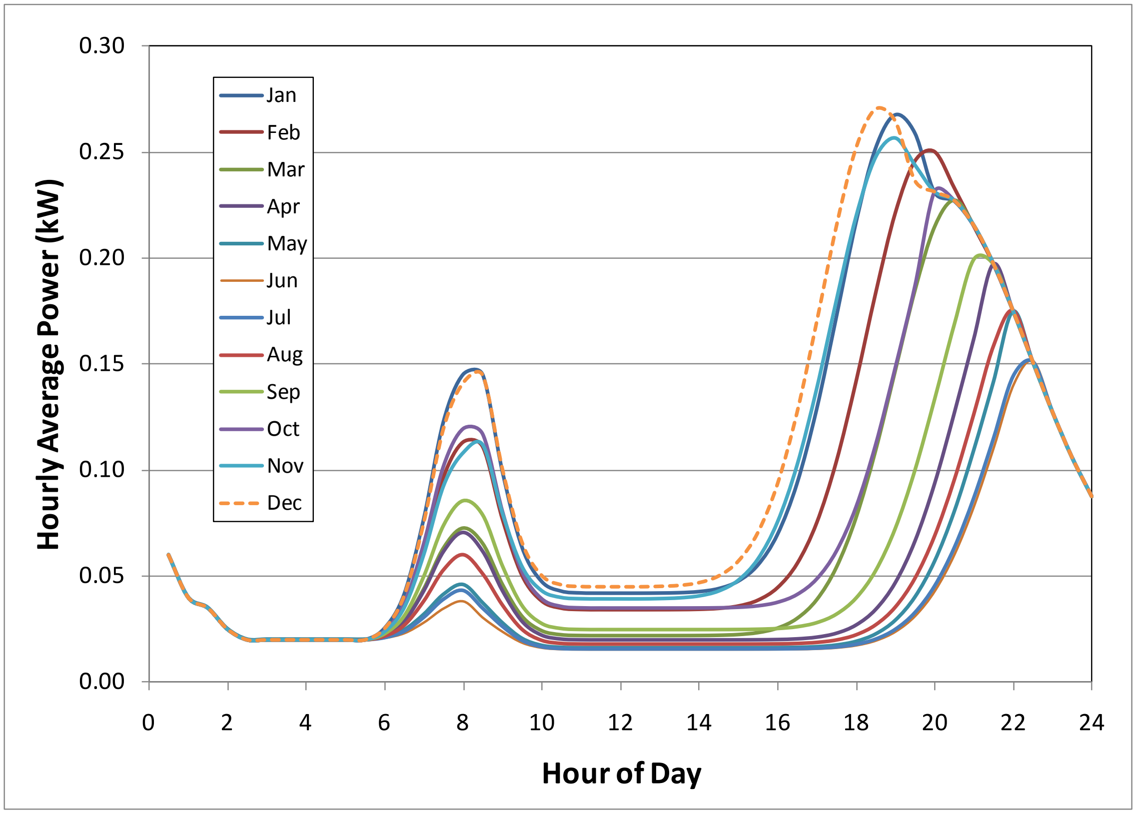


Figure 2. Interior and garage lighting profile (International Falls, Minnesota)

In Option 2, the plug-in lighting for the NCTH (or housing unit) is determined by the difference between the required footcandles (fc) (Table 16 and Table 17) for a given room type and the total installed hard-wired footcandles for that room. Efficacy values for the Benchmark (See Table 15) are used as defaults for the plug-in lighting in the NCTH, but may be changed with sufficient justification.

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 Analysis Spreadsheet. The analyst may override any default values if better information is available and the revisions are documented. For the NCTH, rooms that contain more lighting than is recommended by Table 16 and Table 17 will be penalized.

The illuminance for each room type is based on an engineering interpretation of the horizontal illuminance levels by Rea et al. (2000). Values for each indoor space type, for all housing types, are shown in Table 16. Some 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 17. 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 NCTH are also used for the Benchmark. Savings are then based on the efficacy of the lamps used in the NCTH compared to the Benchmark.

Table 16. Single- and Multi-Family Room Lighting Levels

Room Type	Lighting Requirements (fc)	Room Type	Lighting Requirements (fc)
Bathroom	17.5	Hall, stairway, foyer	3.0
Bedroom	12.5	Kitchen, breakfast nook	19.0
Closet	5.0	Living room, great room	6.0
Dining room	6.5	Home office, den, study	11.8
Family room, recreation room	8.8	Utility room	17.5
Garage	5.0	Other, library	12.5
		Unfinished basement	5.0

Table 17. 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
Multipurpose room	15

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

The illumination at the horizontal plane can be determined by Equation 14. This calculation is required for all indoor spaces, and is automated in the BA Analysis Spreadsheet.

$$\text{Horizontal Illuminance (fc)} = (\text{lumens/lamp}) \times N_{La} \times COU \times LLF/(\text{FFA of room}) \quad (14)$$

where

N_{La} = number of lamps in the room

COU = coefficient of utilization (Table 18)

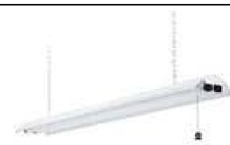
LLF = light loss factor (0.8 for all fixture types)

FFA = finished floor area of the room

Default COUs for common fixture types are listed in Table 18 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 18. 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
Inverted pendant or indirect ceiling		0.44
Kitchen surface fixture		0.46

Fixture Type	Picture of Fixture Type	Default Coefficient of Utilization
LED	 (Source: iStockphoto.com)	0.75
Rangehood/task		0.29
Recessed downlights (assumes a white reflector)	 	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 18. Coefficient of Utilization by Fixture Type provided by Lithonia (www.lithonia.com) unless otherwise noted. Used by permission.

Once the fixture type and room characteristics are defined, the efficacy (lumens/Watt) is used to determine if the footcandle requirement is met in a particular room. These values will differ depending on the type of lamp that is used in a given fixture. We used multiple references to develop default values for common lamp types for the Benchmark and NCTH lamps (Table 19). These defaults may be modified for the NCTH with sufficient justification.

Table 19. 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

For Either Option:

The lighting plans for the NCTH and Benchmark shall use the hours of operation listed in Table 20, unless the NCTH includes specific design measures, such as occupancy sensors, dimming switches, or a building automation system, that alter the operating time of the lighting system.

Table 20. Average Lighting Operating Hours for Room Types

Room Type	Operation (Hours/Day/Room)		Room Type	Operation (Hours/Day/Room)	
	Single-Family	Multi-Family		Single-Family	Multi-Family
Bathroom	1.79	1.80	Kitchen	2.99	2.60
Bedroom	1.18	1.25	Living room	2.72	3.00
Closet	1.05	0.67	Office	1.51	1.20
Dining room	2.52	3.08	Outdoor	2.91	N/A
Family room	1.82	1.25	Utility room	1.72	1.21
Garage	1.98	N/A	Other	0.80	N/A
Hall	1.53	1.27	Unfinished Basement	0.98	N/A

Source: Navigant Consulting 2002, after applying a 10% takeback for average efficacy improvements.

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 3. The other common room lighting hours are shown in Figure 4. The lighting profile for a multi-purpose room is the same as for an office.

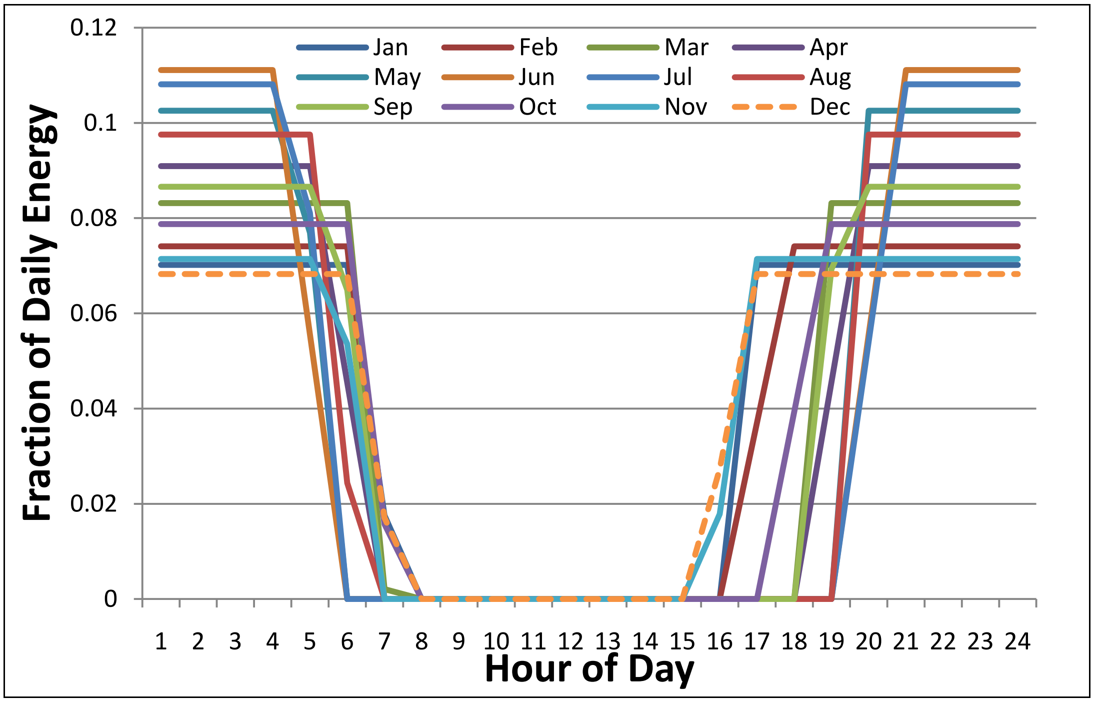


Figure 3. Normalized hourly profile for outdoor areas in multi-family housing

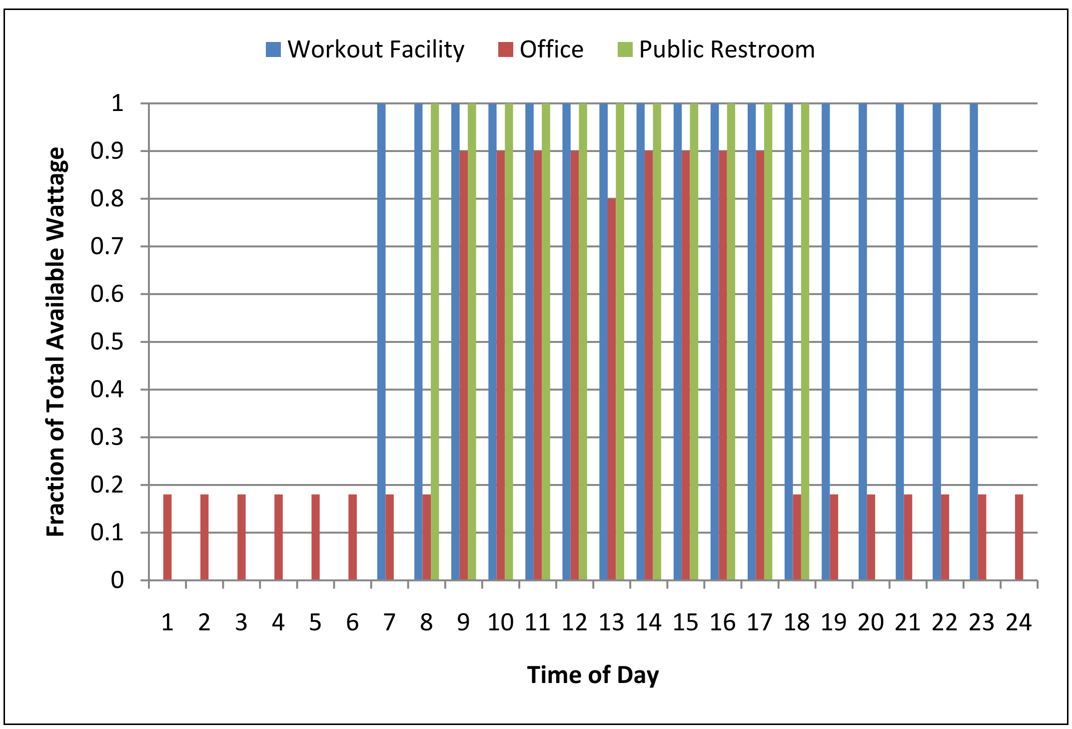


Figure 4. Percentage of total wattage turned on per hour of day for common areas in multi-family housing

Appliances and Miscellaneous Electric Loads

As with lighting, several characteristics must be defined for appliances and miscellaneous electric loads (MELs): the amount, schedule, location, fraction that becomes a sensible load, and fraction 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 21 (Jiang et al. 2008 and Sachs 2005 for multi-family). We assumed for modeling purposes that all major appliances are present in both the Benchmark and the NCTH, even in cases where the builder does not provide all appliances (except the clothes washer in cases where the NCTH is a housing unit in a multi-family building with a common laundry room). Not all 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. For appliances covered by federal appliance standards, the loads were derived by NREL from EnergyGuide labels for typical models available on the market that met the minimum standards in effect as of January 1, 2010. The California Energy Commission Appliance Database (CEC 2010) was used for appliances that are not covered by federal standards. Sensible and latent heat loads are estimates based on engineering judgment.

The loads from most appliances and MELs are assumed to be a function of the number of bedrooms and the FFA. 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.

NREL developed a methodology for calculating energy savings associated with the most common MELs in a typical house (Hendron and Eastment 2006). Approximately 100 MELs in this category are listed in Table 22. If the analyst chooses to use anything other than the Benchmark MEL values for the NCTH, he or she must use the BA Analysis Spreadsheet for new construction 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 NCTH, 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 NCTH 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 21. Annual Appliance Loads and MELs for the Benchmark[1]

Appliance	Electricity (kWh/yr)	Natural Gas (therms/yr)	Sensible Load Fraction	Latent Load Fraction
Refrigerator	434		1.00	0.00
Clothes washer (3.2 ft^3 drum)	$38.8 + 12.9 \times N_{br}$		0.80	0.00
Clothes dryer (electric)	$538.2 + 179.4 \times N_{br}$		0.15	0.05
Clothes dryer (gas)	$43 + 14.3 \times N_{br}$	$19.5 + 6.5 \times N_{br}$	1.00 (Electric) 0.10 (Gas)	0.00 (Electric) 0.05 (Gas)
Dishwasher (8 place settings)	$87.6 + 29.2 \times N_{br}$		0.60	0.15
Range (electric)***	$250 + 83 \times N_{br}$		0.40	0.30
Range (gas)****	$40 + 13.3 \times N_{br}$	$14.3 + 4.8 \times N_{br}$	0.30	0.20
Miscellaneous loads (gas/electric house)	$1595 + 248 \times N_{br} +$ $0.426 \times FFA$	$3.7 + 0.6 \times N_{br} +$ $0.001 \times FFA$	0.734	0.16
Miscellaneous loads (all-electric house)	$1703 + 266 \times N_{br} +$ $0.454 \times FFA$		0.734	0.16
Multi-Family Common Space MELs				
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
	MultiPurpose Room Miscellaneous Electric Loads			
Television	673**		1.00	0.00
Refrigerator	434		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)
*** Assuming 74% EF cooktop, 11% EF oven
**** Assuming 40% EF cooktop, 5.8% EF oven with electronic ignition

Table 22. Example of Benchmark Annual Consumption for MELs and Gas Loads
(based on an NCTH with three bedrooms and 1,920 ft^2)

MEL	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Hard-Wired			
Fan (ceiling)	1.840	84.1	154.7
Air handler standby losses	0.800	67.2	53.8
Hvac controls	1.000	20.3	20.3
Home security system	0.235	61.3	14.4

[1] 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 can assist with the calculation of this split for an energy-efficient clothes washer or dishwasher based on the Energy Guide label.

MEL	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Ground fault circuit interrupter (GFCI)	3.850	6.2	23.9
Sump pump	0.099	40.0	3.9
Heat lamp	0.010	13.0	0.1
Garage door opener	0.266	35.0	9.3
Carbon monoxide detector	0.260	17.5	4.6
Smoke detectors	0.840	3.5	2.9
Garbage disposal	0.404	10.0	4.0
Doorbell	0.670	44.0	29.5
Home Entertainment			
First color TV	0.890	309.7	275.7
Second color TV	0.610	169.9	103.7
Third color TV	0.340	125.4	42.6
Fourth color TV	0.150	120.3	18.0
Fifth or more color TV	0.060	76.4	4.6
Digital TV	0.330	391.9	129.3
VCR	1.255	47.2	59.2
DVD player or recorder/player	1.192	30.0	35.7
DVD/VCR combo	0.333	49.8	16.6
Video gaming system	0.312	20.4	6.4
Clock radio	1.345	14.9	20.1
Boombox/portable stereo	0.348	16.8	5.8
Compact stereo	0.661	81.3	53.8
Component/rack stereo	0.434	121.4	52.7
Power speakers	0.296	24.4	7.2
Subwoofer	0.099	68.3	6.7
Radio	0.493	9.1	4.5
Equalizer	0.049	14.7	0.7
Satellite dish box	0.230	125.9	29.0
Cable box	0.574	134.1	77.0
Personal video recorders	0.013	236.5	3.1
Home theater (HTIB)	0.217	88.7	19.3
Kitchen			
Microwave	0.879	131.2	115.4
Freezer	0.342	935.0	319.8
Extra refrigerator	0.221	1100.0	243.6
Coffee maker	0.610	61.2	37.3
Toaster oven	0.336	32.3	10.8
Toaster	0.904	45.9	41.5
Waffle iron	0.325	25.0	8.1
Blender	0.788	7.0	5.5
Can opener	0.650	3.0	2.0
Electric grill	0.010	180.0	1.8
Hand mixer	0.877	2.0	1.8
Electric griddle	0.256	6.0	1.5
Popcorn popper	0.305	5.0	1.5
Espresso machine	0.069	19.0	1.3
Instant hot water dispenser	0.006	160.0	1.0
Hot plate	0.236	30.0	7.1
Food slicer	0.414	1.0	0.4
Electric knife	0.374	1.0	0.4
Broiler	0.010	80.0	0.8
Deep fryer	0.148	20.0	3.0

MEL	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Bottled water	0.010	300.0	3.0
Trash compactor	0.010	50.0	0.5
Slow cooker/crock pot	0.581	16.0	9.3
Home Office			
Laptop PC (Plugged In)	0.287	72.1	20.7
Desktop PC w/Speakers	0.906	234.0	212.1
PC monitor	0.906	85.1	77.1
Printer (laser)	0.049	92.5	4.5
Printer (inkjet)	0.660	15.5	10.2
Dot matrix printer	0.030	115.0	3.5
DSL/cable modem	0.359	52.6	18.9
Scanner	0.050	49.0	2.4
Copy machine	0.086	25.0	2.1
Fax machine	0.115	326.3	37.6
Multifunction device	0.217	58.8	
Bathroom			
Hair dryer	0.861	41.1	35.4
Curling iron	0.532	1.0	0.5
Electric shaver	0.243	1.0	0.2
Electric toothbrush charger	0.078	11.5	0.9
Beard trimmer	0.067	1.0	0.1
Garage and Workshop			
Auto block heater	0.007	250.0	1.8
Lawn mower (electric)	0.059	42.9	2.5
Heat tape	0.030	100.0	3.0
Kiln	0.020	50.0	1.0
Pipe and gutter heaters	0.010	53.0	0.5
Shop tools	0.130	26.4	3.4
Cordless power tool chargers	0.443	16.0	7.1
Other			
Humidifier	0.128	100.0	12.8
Waterbed	0.023	1095.9	24.7
Small freshwater aquarium (5–20 gal)	0.024	105.0	2.5
Medium freshwater aquarium (20–40 gal)	0.024	180.0	4.3
Large freshwater aquarium (40-60 gal)	0.024	340.0	8.1
Small marine aquarium (5–20 gal)	0.002	245.0	0.6
Medium marine aquarium (20–40 gal)	0.002	615.0	1.5
Large marine aquarium (40–60 gal)	0.002	740.0	1.8
Vacuum cleaner (upright)	0.983	42.2	41.5
Clock	0.956	26.0	24.8
Cordless phone charger	1.557	27.3	42.6
Cell phone charger	1.739	3.5	6.0
Electric blanket	0.286	120.0	34.3
Answering machine	0.568	33.5	19.0
Battery charger – camcorder	0.557	2.3	1.3
Battery charger – digital camera	0.032	7.2	0.2
Battery charger – PDA	0.183	6.1	1.1
Battery charger – toy	0.002	12.8	0.0
Battery charger – two-way radio	0.200	3.9	0.8
Battery charger – MP3 player	0.200	5.6	1.1
Battery charger – stand-alone	0.075	1.0	0.1
Fan (portable)	0.946	11.3	10.7

MEL	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Air cleaner	0.217	65.7	14.2
Vacuum cleaner (cordless)	0.183	41.0	7.5
Heating pads	0.670	3.0	2.0
Surge protector/power strip	0.360	3.9	1.4
Timer (lighting)	0.280	20.1	5.6
Timer (irrigation)	0.050	45.2	2.3
Iron	0.922	52.7	48.6
Baby monitor	0.100	22.8	2.3
Large Uncommon MELs and MGLs			
Pool heater (electric)	0.004	2300.0	8.3
Pool pump (electric)	0.075	1102.0	82.3
Hot tub/spa (electric heating and pump)	0.048	2040.7	97.4
Hot tub/spa pump (electric for gas spa)	0.038	460.0	17.5
Well pump (electric)	0.127	400.0	50.8
Gas fireplace	0.032	1760.0	57.0
Gas grill	0.029	879.0	25.5
Gas lighting	0.012	1671.0	19.6
Pool heater (gas)	0.014	6506.0	87.8
Hot tub/spa heater (gas)	0.011	2374.0	25.6
Other	1.000	9.4	9.4
Total MEL Load			**3373**

Site Generation

There is rarely any site electricity generation in a 2010 vintage house. This is a reflection of the low market penetration of site electricity systems. Therefore, all electricity for the Benchmark is purchased from the local utility.

Modeling the NCTH

The NCTH is modeled either as-designed or as-built, depending on the status of the project. All parameters for the NCTH 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 NCTH shall be calculated based on blower door testing conducted in accordance with ASTM (2003). 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.

If the NCTH does not have a cooling system, but there is a non-zero cooling load, the NCTH shall be modeled assuming a standard 13 SEER air conditioner connected to the heating ducts. If the NCTH does not have a duct system for heating, the air conditioner shall be modeled as a ductless 9 EER 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.

A flow rate of 100 cfm shall be used for the NCTH clothes dryer if the actual flow rate is unknown. If the dryer flow rate for the NCTH is known, the actual NCTH flow rate shall be used. Interaction with whole-house infiltration shall be included in the model.

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 NCTH is not readily available, Equation 15 may be used to make an approximate conversion from SEER to EER (Wassmer 2003):

$$EER = -0.02 \times SEER^2 + 1.12 \times SEER \quad (15)$$

If the NCTH has a hot water distribution system different from the Benchmark (see Table 11), the equations in Table 18 of the December 2008 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 9. 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 NCTH.

If the builder does not provide a clothes washer in the NCTH house, housing unit, or a common laundry room, the NCTH shall be modeled with the Benchmark clothes washer and dryer in an appropriate location.

The optional DHW event characteristics for the Benchmark (see Table 10) may be modified if the NCTH 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 NCTH if the Standard DHW Event Schedules are not used.

Energy-saving appliances or other equipment may reduce hot water consumption for certain end uses, decrease the internal sensible and latent loads, or affect the hourly operating profiles. Energy savings calculations for the NCTH must take these effects into account using operating conditions based on rules developed for DOE residential appliance standards (DOE 2003a), 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 16:

$$\text{Clothes washer cycles per year} = (392) \times (½+N_{br}/6) \times 12.5 \text{ lb}/W_{test} \quad (16)$$

where

W_{test} = maximum clothes washer test load weight found in 10 CFR Part 430, Subpart 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 17:

$$\text{Clothes dryer cycles per year} = \text{DUF} \times \text{clothes washer cycles per year} \quad (17)$$

where

DUF = 0.84.

The dishwasher annual operating cycles are similarly calculated, using Equation 18:

$$\text{Dishwasher cycles per year} = (215) \times (½ + N_{br}/6) \quad (18)$$

The BA Analysis Spreadsheet automates the calculations for 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 NCTH 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 may be credited only if an EF 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 23) divided by the EF, plus 40 + 13.3 × N_{br} kWh/yr for gas ranges with electric glo-bar ignition. This calculation is also automated in the BA Analysis Spreadsheet. If the EF is unknown for a new range, the NCTH energy use for cooking is assumed to be the same as for the Benchmark.

Table 23. Useful Cooking Energy Output for Gas and Electric Ranges

State	Useful Cooking Energy Output
Electric cooktop	86.5 + 28.9 × N_{br} kWh/yr
Electric oven	14.6 + 4.9 × N_{br} kWh/yr
Gas cooktop	2.64 + 0.88 × N_{br} therms/yr
Gas oven	0.44 + 0.15 × N_{br} therms/yr

Modifications to the Benchmark lighting profile and operating hours caused by occupancy sensors or other controls may be considered for the NCTH, but negative and 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 NCTH are documented in the Benchmark 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 NCTH 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 NCTH, 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.

Existing Homes

This section provides a proposed set of guidelines for estimating the energy savings achieved by a package of retrofits or an extensive rehabilitation of an existing home. BA developed a set of typical operating conditions that will be used for a building simulation model to objectively compare energy use before and after a series of retrofits is completed. Actual occupant behavior is extremely important for determining the cost effectiveness of a retrofit package, especially if the homeowner is paying the bills. But for tracking progress toward programmatic goals, and for comparing the performance of one house to another, a hypothetical set of occupants with typical behavioral patterns must be used.

Certain field test and audit methods are also described. These tests help establish accurate building system performance characteristics that are needed for a meaningful simulation of whole-house energy use. Several sets of default efficiency values have also been developed for certain older appliances that cannot be easily tested and for which published specifications are not readily available.

Analysis Tools Specific to Existing Buildings

Most simulation tools that are useful for new residential construction are also applicable to residential retrofit analysis. Certain tools such as TREAT offer additional features such as side-by-side comparisons, automated efficiency package recommendations, and utility bill analysis/reconciliation. Further information about TREAT and a number of other useful tools for retrofit analysis of both residential and commercial buildings can be found in the DOE Energy Software Tools Directory (www.eere.energy.gov/buildings/tools_directory).

NREL does not recommend that utility bills be heavily relied on as a tool for model validation in the context of research houses, except as an approximate check of model accuracy. There are two important reasons for this position:

It is extremely difficult to accurately determine occupant behavior during the time period reflected in the utility bills.

The large number of uncertain input parameters allows multiple ways to reconcile the model with the small number of utility bills, and there is no reliable methodology for performing this calibration because the problem is mathematically undetermined.

Instead, detailed inspections, short-term testing, and long-term monitoring should be used to the greatest extent possible to minimize the uncertainty in model inputs. Default values may be used when certain building features are inaccessible (wall insulation) or efficiency characteristics cannot be readily determined through inspection or short-term testing (furnace AFUE). The effects of maintenance and repairs should always be considered when using default values for equipment efficiency or the amount of insulation.

Throughout the remainder of this section, the term *Pre-Retrofit Case* refers to the state of an existing house immediately before it undergoes a series of upgrades, repairs, additions, or renovations. These measures may be limited to a focused set of energy efficiency improvements to the house or may be part of a larger remodeling or gut rehabilitation effort. The term *Post-Retrofit Case* refers to the same existing house after the package of improvements is complete.

Pre-Retrofit Specifications

Any element of the Pre-Retrofit Case that is not specifically addressed in the following sections, or is not changed as part of the package of energy efficiency measures, is assumed to be the same as the Post-Retrofit Case.

Building Envelope

To the extent possible, all building envelope components (including walls, windows, foundation, roof, and floors) for the Pre-Retrofit Case shall be based on physical inspections, audits, design specifications, or measured data. Co-heating (Judkoff et al. 2000), or infrared imaging during cold weather can provide useful information about the insulation quality of the house without damaging the building envelope. A short-term monitoring test (STEM) can provide the overall building loss coefficient and thermal mass (Judkoff et al. 2000), but in most retrofit scenarios a STEM test is overly expensive and would not provide data that could be easily factored into a detailed building simulation.

If detailed envelope characteristics cannot be obtained, then insulation levels consistent with the local energy code at the time of construction shall be used. If no energy code was in effect, or the code cannot be readily obtained, then the following default specifications may be used:

- R-values for cavity insulation in exterior 2 × 4 or 2 × 6 wood frame walls from Table 24.

Table 24. Default R-Values for Framed Wall Cavity Insulation
(based in part on Huang and Gu 2002)

Framed Wall Construction Type	Year of Construction			
	1990+	1980–1989	1950–1979	Pre-1950
2 × 4	13	11	0	0
2 × 6	19	17	0	0

R-values for cavity insulation in closed rafter roofs from Table 25.

Table 25. Default R-Values for Cavity Insulation in Cathedral Ceilings and Closed-Rafter Roofs

Roof Construction Type	Year of Construction				
	1990+	1980–1989	1950–1979	Pre-1950	Pre-1920
2 × 6	13	9	0	0	0
2 × 10	19	15	0	0	0

- R-values for cavity insulation in floors over unconditioned space from Table 26.

Table 26. Default R-Values for Floors Above Conditioned Spaces
(based in part on Huang and Gu 2002)

BA Climate Region	Year of Construction				
	1990+	1980–1989	1950–1979	Pre-1950	Pre-1920
Cold, Very Cold, Subarctic, Marine	23	23	0	0	0
All others	0	0	0	0	0

- Insulation thickness in all other locations shall be measured, and the default nominal R-values per inch and R-value derating in Table 27 shall be applied. The derating is consistent with Grade III installation quality (RESNET 2006)

Table 27. Default R-Values for Common Insulation Types
(DOE 2003a; E-Star Colorado 2005, REM/Rate Version 12.41)

Insulation Material	Nominal R-Value/in.	R-Value Derating
High density fiberglass batt	3.8/in.	19%
Low density fiberglass batt	3.1/in.	19%
Loose fill fiberglass	3.2/ in.	19%
Cellulose (blown, wet or dry)	3.7/in.	19%
Expanded polystyrene (eps)	4.0/in.	0%
Extruded polystyrene (xps)	5.0/in.	0%
Open cell polyurethane foam	3.6/in.	0%
Closed cell polyurethane foam	6.5/in.	0%
Rigid polyisocyanurate	7.2/in.	0%

- Default U-values for vertical fenestration, including windows and sliding glass doors, from Table 4 in Chapter 15 of ASHRAE (2009).
- Total assembly SHGC for vertical fenestration from Table 10 in Chapter 15 of ASHRAE (2009).
- Default solar absorptivity equal to 0.60 for opaque areas of exterior walls and from Table 28 for opaque areas of roofs.

Table 28. Default Solar Absorptances for Common Roofing Surfaces
(Parker et al. 2000).

Roof Material	Absorptance	Roof Material	Absorptance
Composition Shingles		Wood Shingles	
Dark	0.92	Dark	0.90
Medium	0.85	Medium	0.80
Light	0.75		
		Concrete/Cement	
Tile/Slate		Dark	0.90
Dark	0.90	Medium	0.75
Medium	0.75	Light	0.60
Terra cotta	0.65	White	0.30
Light	0.60		
White	0.30	Membrane	
		Dark	0.90
Metal		Medium	0.75
Dark	0.90	Light	0.60
Medium	0.75	White	0.30
Galvanized, unfinished	0.70		
Light	0.60	Built-up (gravel surface)	
Galvalum, unfinished	0.35	Dark	0.92
White	0.30	Medium	0.85
		Light	0.75

- Default total infrared emittance of exterior walls and roofs equal to 0.90.
- The default framing factors in Table 29 may be used for houses using wood construction.

Table 29. Default Wood Framing Factors

Enclosure Element	Frame Spacing (in. on center)	Framing Fraction (% area)
Living space walls	16	23%
Basement walls	16	18%
Floors/basement ceilings	16	13%
Attics/top floor ceilings	24	11%

Space Conditioning/Air Distribution Equipment

To the extent possible, the performance characteristics (efficiency and capacity) of all space conditioning components (including heating system, cooling system, dehumidification, air handler, and ducts) for the Pre-Retrofit Case shall be based on physical inspections, audits, design specifications, and measured data. An estimate of AFUE for a furnace or Heating

Seasonal Performance Factor (HSPF) for a heat pump can be estimated by performing a co-heating test to determine the building loss coefficient (Judkoff et al. 2000), then measuring the gas or electricity input over a period of time with known inside and outside temperatures. Because thermal mass and solar effects complicate this approach, it should ideally be conducted under near steady-state conditions at night. Field audit procedures for heating equipment have also been developed by LBNL (Szydlowski and Cleary 1988). Cooling efficiency is much more difficult to measure directly, and in most cases the manufacturers published data must be used, or default values if published performance data are not available.

Default furnace or boiler system efficiency may be calculated using Equation 19 in conjunction with the parameters in Table 30 if the actual efficiency of the equipment is unknown and cannot be readily obtained through field testing (for example, if the audit is conducted in the summer, the heating system is broken, or testing would be cost prohibitive). Typical base values for AFUE were obtained from ASHRAE (2008), EPRI (1987), and the Technical Support Documents for the National Appliance Energy Conservation Act appliance standards (DOE 2004a). Default AFUE values for system configurations not listed in Table 29 may be estimated using these references. Estimates of degradation rates are partly based on the E-Source Space Heating Technology Atlas (E-Source 1993).

$$\text{AFUE} = (\text{Base AFUE}) \times (1\text{-M})^{\text{age}} \qquad (19)$$

where

Base AFUE = Typical efficiency of Pre-Retrofit equipment when new

M = Maintenance factor

Age = Age of equipment in years, up to a maximum of 20 years

For example, the default AFUE for a 10-year-old, poorly maintained oil furnace with a conventional burner would be calculated as follows:

$$\text{AFUE} = (71) \times (1\text{-}0.025)^{10} = 55\%.$$

Auxiliary electricity use for furnaces and boilers, including blowers and controls, shall be measured directly if possible. If accurate measurements cannot be made, the default values of auxiliary electricity use in Table 31 may be used.

Table 30. Default Furnace and Boiler System Efficiencies
(gas refers to either natural gas or propane)

Type of Space Heating Equipment	Base AFUE*	Maintenance Factor (M)	
		Annual Professional Maintenance	Seldom or Never Maintained
Condensing gas furnace	90	0.005	0.015
Gas furnace, direct vent or forced draft combustion, electronic ignition, in conditioned space	80	0.005	0.015
Gas furnace, natural draft combustion, vent damper, electronic ignition, in conditioned space	78	0.005	0.015
Gas furnace, natural draft combustion, standing pilot light, in conditioned space	75	0.005	0.015
Gas furnace, natural draft combustion, standing pilot light, no vent damper, in unconditioned space	64	0.005	0.015
Gas hot water boiler, natural draft combustion, standing pilot light	80	0.005	0.015
Gas steam boiler	81	0.005	0.015
Condensing gas boiler	90	0.005	0.015
Gas hot water/fan coil combo system	80	0.005	0.015
Gas boiler/tankless coil combo system	80	0.005	0.015
Gas space heater, fan type	73	0.005	0.015
Gas space heater, gravity type	60	0.005	0.015
Oil furnace, flame retention burner, vent dampers, in conditioned space	81	0.01	0.025
Oil furnace, conventional burner, no vent dampers, in conditioned space	71	0.01	0.025
Oil hot water boiler, forced draft combustion	80	0.01	0.025
Oil steam boiler	82	0.01	0.025
Electric resistance furnace or boiler, conditioned space	100	0	0
Electric resistance furnace or boiler, unconditioned space	98	0.001	0.001
Electric resistance baseboard heating	100	0	0
Electric space heater	100	0	0

* Combined Appliance AFUE or combo systems

Table 31. Default Heating System Blower and Auxiliary Electricity Consumption

Type of Heating Equipment	Electricity/Capacity
Gas furnace (including mobile home furnace and PSC motor)	9.2 (kWh/yr)/(kBtu/h)
Gas hot water boiler with hydronic distribution	1.1 (kWh/yr)/(kBtu/h)
Gas boiler with forced air distribution	9.2 (kWh/yr)/(kBtu/h)
Oil furnace (with PSC motor)	8.0 (kWh/yr)/(kBtu/h)
Oil hot water boiler with hydronic distribution	2.3 (kWh/yr)/(kBtu/h)
Electric furnace	Included in AFUE

A cooling system shall only be included in the Pre-Retrofit model if one is present in the actual test house before retrofits are installed. Analysis based on equivalent comfort is encouraged as valuable supplemental information, but is not used for the primary analysis relative to BA energy savings targets.

The default air conditioner and heat pump efficiencies in Table 32 may be used if the actual efficiency cannot be calculated or measured. Base values for SEER, EER, and HSPF were obtained from the engineering analysis of appliance standards for air conditioners and heat pumps (DOE 2002), and from Wenzel et al. (1997). Default efficiencies for equipment not listed in the table may either be interpolated or estimated by referring to the original references.

Table 32. Default Air-Conditioning and Heat Pump Efficiencies

Type of Air Conditioning or Heat Pump Equipment	Base SEER	Base EER	Base HSPF	Maintenance Factor (M)	
				Annual Professional Maintenance	Seldom or Never Maintained
Split central air conditioner, two-speed reciprocating compressor, electronically commutated air handler motor (BPM), thermostatic expansion valve, fan coil	14	10.5		0.01	0.02
Split central air conditioner, single-speed scroll compressor, BPM air handler motor, cased coil	12	10.8		0.01	0.03
Split central air conditioner, single-speed reciprocating compressor, PSC air handler motor, cased coil (after 1991)	10	9.3		0.01	0.03
Split central air conditioner, single-speed reciprocating compressor, PSC air handler motor, cased coil (1981–1991)	8	7.7		0.01	0.03
Split central air conditioner, single-speed reciprocating compressor, PSC air handler motor, cased coil (before 1981)	6.5	6.4		0.01	0.03
Split heat pump, single-speed scroll compressor, BPM air handler motor, thermostatic expansion valve	14	10.5	8.0	0.01	0.03
Split heat pump, single-speed reciprocating compressor, PSC air handler motor (after 1991)	10	9.3	7.1	0.01	0.03
Split heat pump, single-speed reciprocating compressor, PSC air handler motor (1981–1991)	8	7.7	6.6	0.01	0.03
Split heat pump, single-speed reciprocating compressor, PSC air handler motor (before 1981)	6.5	6.4	6.0	0.01	0.03
Packaged central air conditioner, single-speed reciprocating compressor, PSC air handler motor	10	9.1		0.01	0.03
Packaged heat pump, single-speed reciprocating compressor, PSC air handler motor	10	9.1	6.8	0.01	0.03
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor, < 20,000 Btu/h (after 1991)		9.75		0.01	0.03

Type of Air Conditioning or Heat Pump Equipment	Base SEER	Base EER	Base HSPF	Maintenance Factor (M)	
				Annual Professional Maintenance	Seldom or Never Maintained
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor, ≥ 20,000 Btu/h (after 1991)		8.5		0.01	0.03
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor (1981–1991)		7.5		0.01	0.03
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor (before 1981)		6.5		0.01	0.03
Room electric heat pump, louvered sides, single-speed compressor, PSC fan motor, < 20,000 Btu/h		9		0.01	0.03
Room electric heat pump, louvered sides, single-speed compressor, PSC fan motor, ≥ 20,000 Btu/h		8.5		0.01	0.03
Direct evaporative cooling		25		0.02	0.05

Adjustments to efficiency related to age and quality of maintenance shall be applied in accordance with Equation 20. Performance degradation rates for cooling systems are based in part on a study done by LBNL for the California Energy Commission (Matson et al. 2002).

$$\text{EFF} = (\text{Base EFF}) \times (1\text{-M})^{\text{age}} \qquad (20)$$

where

Base EFF = Typical efficiency of pre-retrofit equipment when new (SEER, EER, or HSPF)

M = Maintenance factor

Age = Age of equipment in years, up to a maximum of 20 years.

For houses with air ducts, the Pre-Retrofit Case shall be modeled using data collected through visual inspections, physical measurements, and duct leakage testing. Default values for duct leakage shall not be used. Pressurized duct leakage testing shall be conducted in accordance with ASTM (2007). Tracer gas testing of the air distribution system is encouraged when possible, and shall be conducted in accordance with Hancock et al. (2002).

If the simulation tool does not permit the input of detailed duct specifications, then two values (one for heating, one for cooling) of seasonal DSE shall be estimated and applied to the heating and cooling system efficiencies to represent expected energy losses from ducts. The DSE values shall be estimated using the procedures in ASHRAE (2004a).

For houses with hydronic space heating or cooling systems, a distribution efficiency of 95% shall be applied to the appliance efficiency, representing a small amount of energy loss through the pipes.

Domestic Hot Water

To the extent possible, the specifications of the DHW system in the Pre-Retrofit Case shall be based on audits, design specifications, physical measurements, and test data. Published data from the manufacturer provides the most reliable estimate of EF, because in-situ testing introduces several uncontrolled variables (such as water use and ambient temperature) that usually make a reliable measurement of standby loss impossible. The procedures to measure recovery efficiency and standby losses described by LBNL (Szydlowski and Cleary 1988) may be used in conjunction with the Building America Analysis Spreadsheet to give a rough estimate of EF. If EF cannot be determined by making direct measurements or examining the published performance data, the default specifications in Table 33 may be used, with age and maintenance adjustments in accordance with Equation 21. These defaults were largely derived from technical support documents for the Federal appliance standard for water heaters (DOE 2000a).

Table 33. Default DHW EFs, Based on Known Equipment Characteristics
(gas refers to either natural gas or propane)

Type of Water Heating Equipment	Base EF	Maintenance Factor (M)	
		Annual Professional Maintenance	Seldom or Never Maintained
Gas water heater, 40 gallon tank, pilot light, natural draft combustion, poorly insulated, no heat traps, poor heat recovery from flue.	0.45	0.005	0.01
Gas water heater, 40 gallon tank, pilot light, natural draft combustion, 1” insulation, no heat traps, standard flue baffling.	0.54	0.005	0.01
Gas water heater, 40 gallon tank, intermittent ignition, forced draft combustion, 3” insulation, heat traps, enhanced flue baffling, flue/vent dampers	0.64	0.005	0.01
Gas instantaneous water heater*	0.76	0.005	0.01
Oil water heater, 32 gallon tank, intermittent ignition, forced draft combustion, poorly insulated, no heat traps, poor heat recovery from flue.	0.53	0.005	0.01
Oil water heater, 32 gallon tank, interrupted ignition, forced draft combustion, 3” insulation, heat traps, enhanced flue baffling.	0.61	0.005	0.01
Electric water heater, 50 gallon tank, poorly insulated, no heat traps.	0.79	0.001	0.002
Electric water heater, 50 gallon tank, 1.5” insulation, heat traps.	0.87	0.001	0.002
Electric water heater, 50 gallon tank, 3” insulation, heat traps.	0.90	0.001	0.002
Electric instantaneous water heater*	0.91	0	0

* Tankless water heaters are derated by 8% due to thermal losses that aren’t reflected in the standard DOE rating procedure.

$$EF = (Base\ EF) \times (1-M)^{age} \quad (21)$$

where

Base EF = Typical efficiency of pre-retrofit equipment when purchased

M = Maintenance factor

Age = Age of equipment in years, up to a maximum of 20 years.

The BA Analysis Spreadsheet calculates the correct DHW inputs for the TRNSYS computer program, including standby heat loss coefficient, given basic equipment characteristics (EF, RE, etc.) (Burch 2004). Five major end uses have been identified for DHW: showers, sinks, baths, dishwasher, and clothes washer (see Table 34). For showers, baths, and sinks, the specified volume is the same as the value defined for the Benchmark and represents the combined volume of hot and cold water. For clothes washers and dishwashers, the BA Analysis Spreadsheet shall be used to estimate the Pre- and Post-Retrofit hot water consumption based on standard operating conditions and information listed on the EnergyGuide label.

Table 34. Default DHW Consumption by End Use

End Use	End-Use Water Temperature	Water Usage	Sensible Heat Gain	Latent Heat Gain
Clothes washer	Water heater set point	Calculated using MEF* in Table 36	0*	0**
Common laundry	Water heater set point	Calculated using MEF in Table 36	0*	0**
Dishwasher	Water heater set point	Calculated using EF in Table 35	0**	0**
Shower (standard and low-flow)	110°F	$14.0 + 4.67 \times N_{br}$ gal/day	$741 + 247 \times N_{br}$ Btu/day	$703 + 235 \times N_{br}$ Btu/day ($0.70 + 0.23 \times N_{br}$ pints/day)
Bath	110°F	$3.5 + 1.17 \times N_{br}$ gal/day	$185 + 62 \times N_{br}$ Btu/day	0***
Sinks	110°F	$12.5 + 4.16 \times N_{br}$ gal/day	$310 + 103 \times N_{br}$ Btu/day	$140 + 47 \times N_{br}$ Btu/day ($0.14 + 0.05 \times N_{br}$ pints/day)
Office/public sink	110°F	$0.028 \times N_{units}$ gal/day	$0.69 \times N_{units}$ Btu/day	$0.314 \times N_{units}$ Btu/day ($3.14 \times 10^{-4} \times N_{units}$ pints/day)

* Modified energy factor

** Sensible and latent heat gains from appliances are included in the section titled, "Appliances and Miscellaneous Electric Loads."

** Negligible compared to showers and sinks.

If no EnergyGuide label is available, he default EF values for dishwashers (see Table 35) or modified energy factor (MEF) for clothes washers (see Table 36) shall be used for the Pre-Retrofit Case.

Table 35. Default Dishwasher Characteristics

Equipment Characteristics	EF (load/kWh)
Power dry optional, multi-tier spray device, load size and soil level controls	0.6
Power dry optional, multi-tier spray device, no load size or soil level controls	0.43
Power dry always, single-tier spray device, no load size or soil level controls	0.24

Table 36. Default Standard Size (~2.5 ft^3) Clothes Washer Characteristics

Equipment Characteristics	Modified EF (ft^3/kWh)
Horizontal axis, cold rinse option, automatic fill, thermostatically controlled mixing valve, improved water extraction	1.62
Vertical axis, cold rinse option, automatic fill, thermostatically controlled mixing valve, improved water extraction	1.02
Vertical axis, cold rinse option, water level option, standard mixing valve	0.64
Vertical axis, no cold rinse option, no water level option	0.47

Analysis of advanced hot water systems may be conducted using the more detailed hot water event schedules described in the New Homes section. Analysis of common laundry facilities, common restrooms, and central hot water systems in multi-family housing shall comply with the guidelines in the New Homes section.

Air Infiltration and Ventilation

The ELA for the Pre-Retrofit Case shall be calculated based on blower door testing conducted in accordance with ASTM (2003). If the whole-house simulation tool being used cannot calculate hourly infiltration based on effective leakage area, an annual average natural infiltration rate may be used based on the guidelines in ASHRAE (1988), Section 5, and ASHRAE (1993), Section 4.

Whole-house mechanical ventilation, if present, and spot ventilation for bathrooms, kitchen ranges, and dryer exhausts shall be modeled using the same guidelines described for an NCTH.

Lighting

The total annual lighting budget for the Pre-Retrofit case shall be determined by conducting an audit of light fixtures and bulbs inside and outside the house. Either Option 1 or Option 2 may be used, as described in the Lighting section under New Construction. When using the simplified approach (Option 1), the Pre-Retrofit lighting energy shall be calculated using Equations 7-13, which assumes the installed illumination levels are the same as the Benchmark. When using Option 2, all requirements for analyzing lighting in NCTHs shall be applied to the Pre-Retrofit case, except the horizontal illumination levels calculated based on the actual installed lighting shall be used instead of those recommended by IESNA. The BA Analysis Spreadsheet shall be used to calculate lighting energy for the Pre-Retrofit case when using Option 2.

Appliances and Miscellaneous Electric Loads

To the extent possible, actual specifications for all major appliances should be obtained through inspection. Spot electricity measurements may be performed for loads that are relatively constant when operating, such as refrigerators and freezers. A more standardized procedure for calculating average daily electricity use for refrigerators was developed by LBNL (Szydlowski 1988). If EnergyGuide labels are not used, it is important that the same refrigerator audit procedures are used for both the Pre- and Post-Retrofit Cases to ensure a fair comparison.

If EnergyGuide labels are available for dishwashers or clothes washers, the BA Analysis Spreadsheet shall be used to estimate annual energy use. If EnergyGuide labels cannot be located or do not exist for certain major appliances (e.g., ovens and clothes dryers), the default EFs in Tables 35–40 shall be used. These defaults were derived from historical appliance efficiency studies (DOE 2004b; EPRI 1986; Wenzel et al. 1997) and technical support documents for recent changes to Federal appliance standards (DOE 1993, DOE 2000b). If the specific equipment type is not listed in the default tables, the efficiency may either be interpolated based on listed equipment or estimated using the original reference sources. The default efficiencies must be used in conjunction with the BA Analysis Spreadsheet to estimate annual electricity and hot water use.

For kitchen ranges, the annual energy use shall be calculated by dividing the Useful Cooking Energy Output (see Table 41) by the EF. For gas ranges with electric glo-bar ignition, an additional $40 + 13.3 \times N_{br}$ kWh/yr shall be included.

Table 37. Default Gas Clothes Dryer Characteristics
(assumes typical clothes washer capacity and remaining moisture content).

Equipment Characteristics	EF (lb/kWh)
Cool-down mode, intermittent ignition, automatic termination control, improved door seal, well insulated	2.67
Cool-down mode, intermittent ignition, timer control, improved door seal, well insulated	2.40
No cool-down mode, pilot light, timer control, poor door seal, poorly insulated	2.00

Table 38. Default Electric Clothes Dryer Characteristics
(assumes typical clothes washer capacity and remaining moisture content).

Equipment Characteristics	EF (lb/kWh)
Cool-down mode, automatic termination control, improved door seal, well insulated	3.10
No cool-down mode, timer control, poor door seal, poorly insulated	2.95

Table 39. Default Gas Oven/Cooktop Characteristics

Equipment Characteristics	EF
Cooktop: intermittent ignition, sealed burner Oven: spark ignition, not self cleaning, improved door seals, reduced vent rate, high density insulation	Cooktop: 42.0% Oven: 6.2%
Cooktop: intermittent ignition, open burner Oven: electric glo-bar ignition, self cleaning	Cooktop: 40.0% Oven: 5.8%
Cooktop: pilot lights Oven: pilot light, not self-cleaning, standard door seals, standard vent rate, standard insulation	Cooktop: 18.8% Oven: 3.5%

Table 40. Default Electric Oven/Cooktop Characteristics

Equipment Characteristics	EF
Cooktop: reflective pans, flat coil elements Oven: self-cleaning, improved door seals	Cooktop: 77.7% Oven: 10.2%
Cooktop: solid disc elements Oven: not self-cleaning, improved door seals, reduced vent rate, high density insulation	Cooktop: 74.2% Oven: 12.1%
Cooktop: non-reflective pans, rounded coil elements Oven: not self-cleaning, standard door seals, standard vent rate, standard insulation	Cooktop: 73.7% Oven: 10.9%

Table 41. Useful Cooking Energy Output for Gas and Electric Ranges

State	Useful Cooking Energy Output
Electric cooktop	$86.5 + 28.9 \times N_{br}$ kWh/yr
Electric oven	$14.6 + 4.9 \times N_{br}$ kWh/yr
Gas cooktop	$2.64 + 0.88 \times N_{br}$ therms/yr
Gas oven	$0.44 + 0.15 \times N_{br}$ therms/yr

If the retrofit package does not include improvements to MELs, the package of MELs defined for the Benchmark shall be used for the Pre-Retrofit Case, regardless of the actual MELs present in the house.

If MEL improvements are included in the retrofit package, analysts must use the more detailed methodology in the BA Analysis Spreadsheet.

The fraction of end-use energy converted into internal sensible and latent loads is shown in Table 42. Not all 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.

Table 42. Default Internal Loads From Appliances and Small Electric End Uses in the Pre-Retrofit Case

Appliance	Sensible Load Fraction	Latent Load Fraction
Refrigerator	1.00	0.00
Freezer	1.00	0.00
Clothes washer	0.80	0.00
Clothes dryer (electric)	0.15	0.05
Clothes dryer (gas)	1.00 (electric component) 0.10 (gas component)	0.00 (electric component) 0.05 (gas component)
Dishwasher (8 place settings)	0.60	0.15
Range (electric)	0.40	0.30
Range (gas)	0.30	0.20
MELs	0.73	0.16

For appliances and MELs in common areas of multi-family housing, the same guidelines described for new homes shall be used.

Site Generation

If the Pre-Retrofit Case includes site electricity generation equipment, such as a fuel cell, photovoltaic system, or wind turbine, then the total energy production shall be calculated using a generally accepted engineering methodology.

Modeling the Post-Retrofit Case

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

- Any house characteristics that are unknown or not part of the package of energy efficiency improvements shall be the same as the Pre-Retrofit Case.
- Insulation installation quality shall be factored into the model of the Post-Retrofit Case.
- The ELA for the Post-Retrofit Case shall be calculated based on blower door testing conducted in accordance with ASTM (2003). If the whole-house simulation tool cannot calculate hourly infiltration based on ELA, an annual average natural infiltration rate may be used based on the guidelines in ASHRAE Standard 119, Section 5, and ASHRAE Standard 136, Section 4.
- For cooling equipment, the energy efficiency ratio (EER) should be used with part-load performance characteristics in the annual simulation whenever possible. SEER is less desirable for an annual simulations, but is often the only information that is publicly available about a cooling system. If the actual EER for the Post-Retrofit Case is not readily available, Equation 22 may be used to make an approximate conversion from SEER to EER (Wassmer 2003).

$$EER = -0.02 \times SEER^2 + 1.12 \times SEER \quad (22)$$

Whole-house mechanical ventilation, if present, and spot ventilation for bathrooms, kitchen ranges, and dryer exhausts shall be modeled using the same guidelines described for an NCTH.

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 Post-Retrofit Case must take these effects into account using operating conditions based on rules developed for DOE residential appliance standards (DOE 2004), 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 23:

$$\text{Clothes washer cycles per year} = (392) \times (½ + N_{br}/6) \times 12.5\ \text{lb}/W_{test} \quad (23)$$

where

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

A DUF is applied to the clothes washer cycles to determine the number of annual dryer cycles, using Equation 24:

$$\text{Clothes dryer cycles per year} = \text{DUF} \times \text{Clothes washer cycles per year} \quad (24)$$

where

DUF = 0.84.

The dishwasher annual operating cycles are similarly calculated, using Equation 25:

$$\text{Dishwasher cycles per year} = (215) \times (½ + N_{br}/6) \quad (25)$$

The BA Analysis Spreadsheet automates energy use calculations for appliances. The spreadsheet includes tabs to help analysts calculate energy savings for efficient clothes washers, clothes dryers, and dishwashers. It calculates the split between hot water and machine energy based on the EnergyGuide label, estimates dryer energy savings for clothes washers that reduce remaining moisture content, adjusts energy use for the assumption that both hot water and cold water temperatures for the house 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 use are calculated.

Energy savings for a new range or oven may only be credited if an EF has been determined in accordance with the DOE test procedures for cooking appliances (DOE 1993). Annual energy consumption is then estimated as the annual useful cooking energy output (see Table 41) divided by the energy factor, plus $40 + 13.3 \times N_{br}$ kWh/yr for gas ranges with electric glo-bar ignition. If the EF is unknown for a new range, the Post-Retrofit energy use for cooking is assumed to be the same as the Pre-Retrofit Case.

Lighting energy use for the Post-Retrofit Case may be calculated using either Option 1 or Option 2, as discussed in Lighting section for New Construction. When using Option 1, illumination levels are assumed to be the same as the Pre-Retrofit Case, which are the same as the Benchmark. When using Option 2, , the Post-Retrofit Case uses the actual installed illumination levels, which may be different from the Pre-Retrofit illumination levels. For Option 2, the BA Analysis Spreadsheet must be used.

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

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

For the Post-Retrofit Case, 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.

Operating Conditions

The following operating conditions and other assumptions shall apply to all simulations conducted for official Building America reporting purposes, including the analysis of both new homes and retrofits of existing homes, unless otherwise specified.

Vacation Periods

Fourteen vacation days shall be used in the analysis, defined as May 26–28, August 12–18, and December 22–25. Unless otherwise specified, operating conditions are the same during these periods as during other periods.

Space Conditioning

The heating setpoint (T_s) shall be determined using either Table 43 (with interpolation) or Equation 26.

$$T_s = T_{oc} - \left(T_{oc} - T_{reg}\right) \times BLR \tag{26}$$

where

T_s	=	Heating thermostat setting, °F
T_{oc}	=	Optimal comfort temperature = 73.5°F according to the Fanger comfort model (ASHRAE 2004b) assuming: • Clothing level: 1.0 CLO (Trousers, long-sleeved shirt, T-shirt, sweater) • Activity level: 1.1 MET (1.0 = Seated, quiet; 1.2 = Standing, relaxed)
T_{reg}	=	Regional reference temperature, from Table 43
BLR	=	Building load ratio, from Equation 27

Table 43. Thermostat Setting for Space Heating (T_s)

Zone *	Regional	Building Load Ratio (BLR)										
	T_{reg}	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5
Subarctic	70.4	71.9	71.6	71.3	71.0	70.7	70.4	68.8	67.2	65.6	64.1	62.5
Very Cold	70.6	72.0	71.8	71.5	71.2	70.9	70.6	69.1	67.7	66.2	64.8	63.3
Marine	70.8	72.2	71.9	71.6	71.4	71.1	70.8	69.5	68.2	66.8	65.5	64.2
Cold	71.3	72.4	72.2	72.0	71.7	71.5	71.3	70.2	69.1	68.0	66.9	65.8
Mixed-Dry	71.9	72.7	72.5	72.4	72.2	72.1	71.9	71.1	70.3	69.5	68.7	67.9
Mixed-Humid	72.1	72.8	72.6	72.5	72.4	72.2	72.1	71.4	70.6	69.9	69.2	68.5
Hot-Dry	72.3	72.9	72.8	72.7	72.6	72.4	72.3	71.7	71.1	70.6	70.0	69.4
Hot-Humid	73.2	73.3	73.3	73.3	73.2	73.2	73.2	73.0	72.9	72.7	72.6	72.4

* Climate zone based on PNNL 2007

For the Benchmark, BLR = 1 by definition. For the Test House (either NCTH, Pre-Retrofit, or Post-Retrofit), Equation 27 shall be used to calculate the BLR:

$$\text{BLR} = \frac{\text{BLC}/\eta}{(\text{BLC}/\eta)_{\text{BM}}} \tag{27}$$

where

BLC	=	Building load coefficient (Btu/°F·h)
η	=	Combined heating and distribution system efficiency
BM	=	Benchmark

The building load coefficient (BLC) and the equipment efficiency (η) for the Benchmark and the Test House shall be calculated using generally accepted engineering methods. The heating efficiency shall be calculated using Equation 28:

$$\eta = \eta_h \times \text{DSE} \tag{28}$$

where

η_h	=	AFUE for a furnace or boiler
η_h	=	HSPF × 0.293 for a heat pump
η_h	=	1 for electric resistance heating
DSE	=	distribution system efficiency

The cooling set point shall be determined based on the heating and cooling degree days for the project location using Table 44. These values are based on thermostat set points reported by homeowners in the 2005 RECS (DOE 2005).

Table 44. Cooling Set Points as a Function of Climate

Heating/Cooling Degree Day Range	Cooling Set Point
HDD > 7000, CDD < 2000	75.0°F
7000 > HDD > 5500, CDD < 2000	74.5°F
5499 > HDD > 4000, CDD < 2000	74.4°F
4000 > HDD, CDD < 2000	75.4°F
4000 > HDD, CDD ≥ 2000	76.6°F

where

HDD	=	heating degree days, base 65°F
CDD	=	cooling degree days, base 65°F

A night-time heating set-back of 4°F shall be applied from 10:00 p.m. to 6:00 a.m. every day. A heating set-back of 7°F shall be applied when occupants are away, assumed to be all day during vacation periods. The vacation period set-back shall take precedence over the night-time set-back.

A cooling set point increase of 5°F shall be applied all day during vacation periods.

Heating and cooling shall only occur during certain months of the year in accordance with the guidelines presented below. Alternate operating profiles may be acceptable with sufficient justification. The heating and cooling seasons shall be determined on the basis of the monthly average temperatures (MATs) and the 99% (annual, not seasonal) winter and summer design temperatures, based on TMY3 data or ASHRAE 2009 for the nearest location, in accordance with the following procedures:

Step 1. MAT Basis

The heating system shall be enabled for a month in which the MAT is less than 66°F.

The cooling system shall be enabled for a month in which the MAT is greater than 66°F.

Step 2. Winter Design Temperatures and Summer Design Temperatures

The heating system shall be enabled in December and January if the winter design temperature is less than or equal to 59°F, regardless of the outcome in Step 1 above.

The cooling system shall be enabled in July and August regardless of the outcome in Step 1 above.

Step 3. Swing Season Adjustment

If, based on Steps 1 and 2, there are consecutive months in which the cooling system is disabled the first month and enabled the following month, the heating system shall be enabled for the second month.

If, based on Steps 1 and 2, there are consecutive months in which the heating system is disabled the first month and enabled the following month, the cooling system shall be enabled for the second month.

One month shall be added to the start of the cooling season determined based on Steps 1 and 2, unless the cooling season is year-round.

Weather data shall be based on TMY3 data from 1991 to 2005 or equivalent data for the nearest weather station.

Set point for dehumidification (applies to all new homes, and to existing homes where humidity is controlled): 60% relative humidity (no lower limit).

The natural cooling 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 OA flow can maintain the cooling set point, the outdoor humidity ratio is less than 0.0115, and the outdoor relative humidity is less than 70%. The ventilation rate for natural cooling shall be calculated using the Sherman-Grimsrud model (Sherman and Grimsrud 1980). Twenty percent of the maximum openable area for windows on each façade and on each floor shall be open. Windows are assumed to be closed once the indoor temperature drops to within 1°F of the heating set point, or if the air change rate exceeds 20 air changes per hour. If local circumstances (pollution, high humidity, security, community standards, etc.) discourage window operation, a more appropriate schedule is acceptable, as long as the same natural cooling schedule is applied to both the Benchmark and the NCTH.

Interior shading multiplier = 0.7

Domestic Hot Water

The hot water set point shall be 130°F, and the mixed temperature for showers, sinks, and baths shall be 110°F.

Hourly hot water use profiles for individual hot water end uses are shown in Figure 5 to Figure 12. For software tools that do not accept this level of detail, the combined hourly hot water profile may be used (see Figure 13). The numerical values for normalized hourly hot water use can be found in the BA Analysis Spreadsheet.

The combined hourly profile is based on a 1990 study conducted by Becker and Stogsdill (1990), which included hot water data from several earlier studies. The profiles for the clothes washer and dishwasher are based on the electrical end use measurements in the End-Use Load and Consumer Assessment Program 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). We assume 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 NREL (2009).

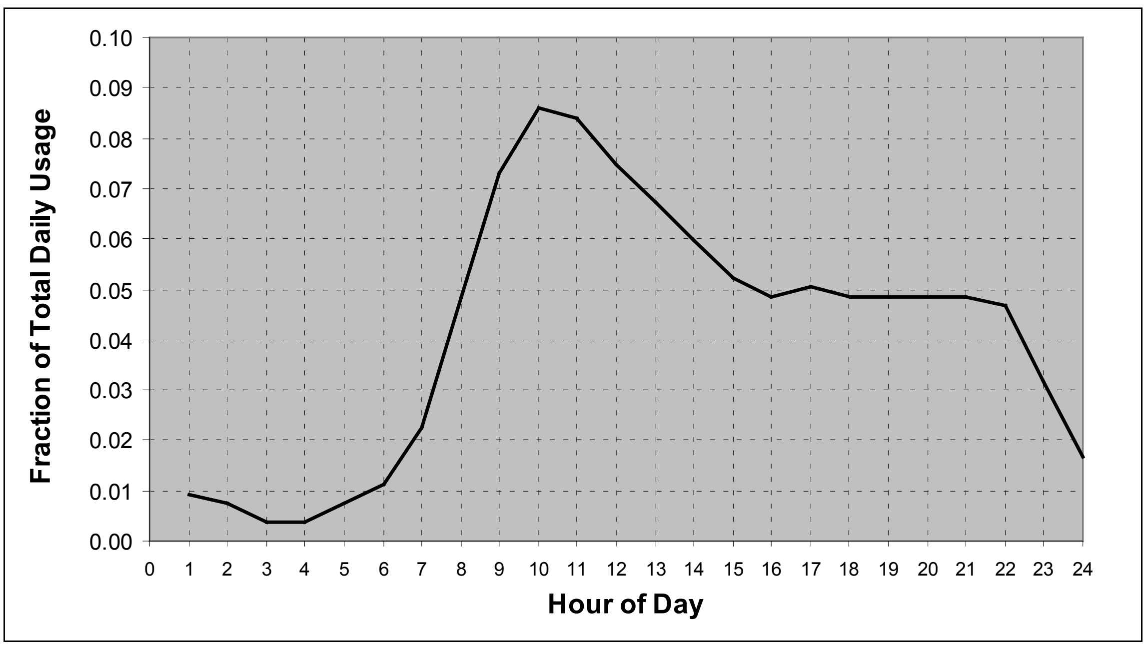


Figure 5. Clothes washer hot water use profile

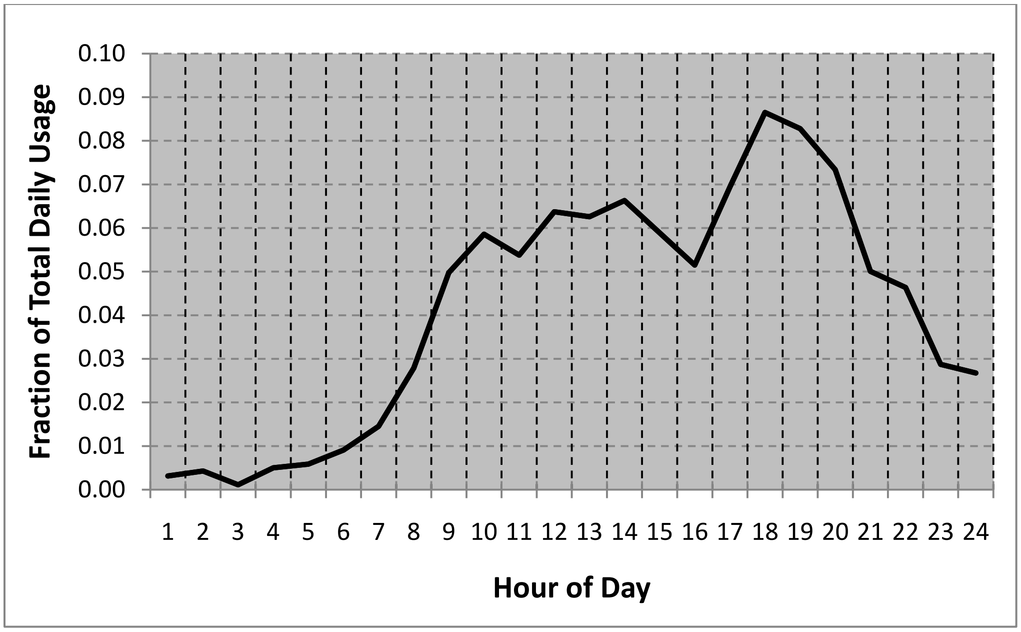


Figure 6. Multi-family common laundry hot water use profile: weekday

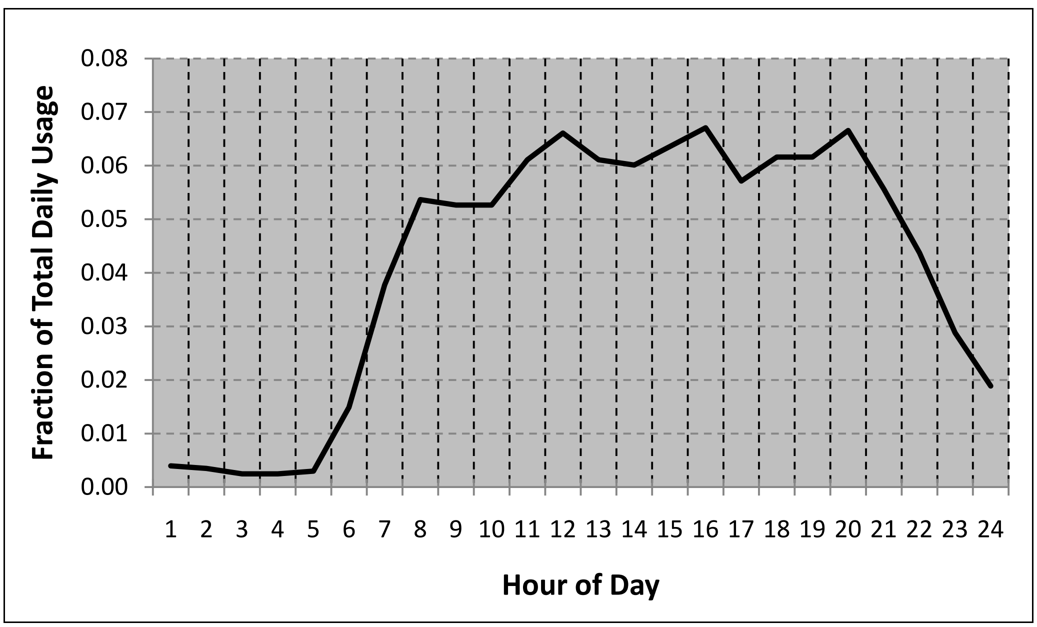


Figure 7. Multi-family common laundry hot water use profile: weekend

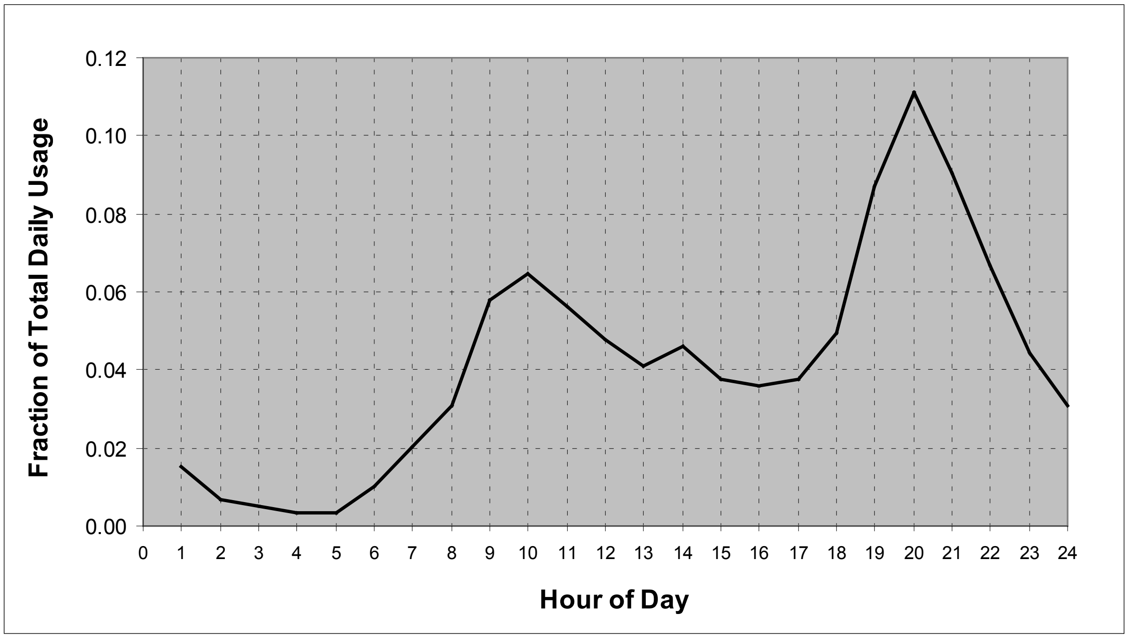


Figure 8. Dishwasher hot water use profile

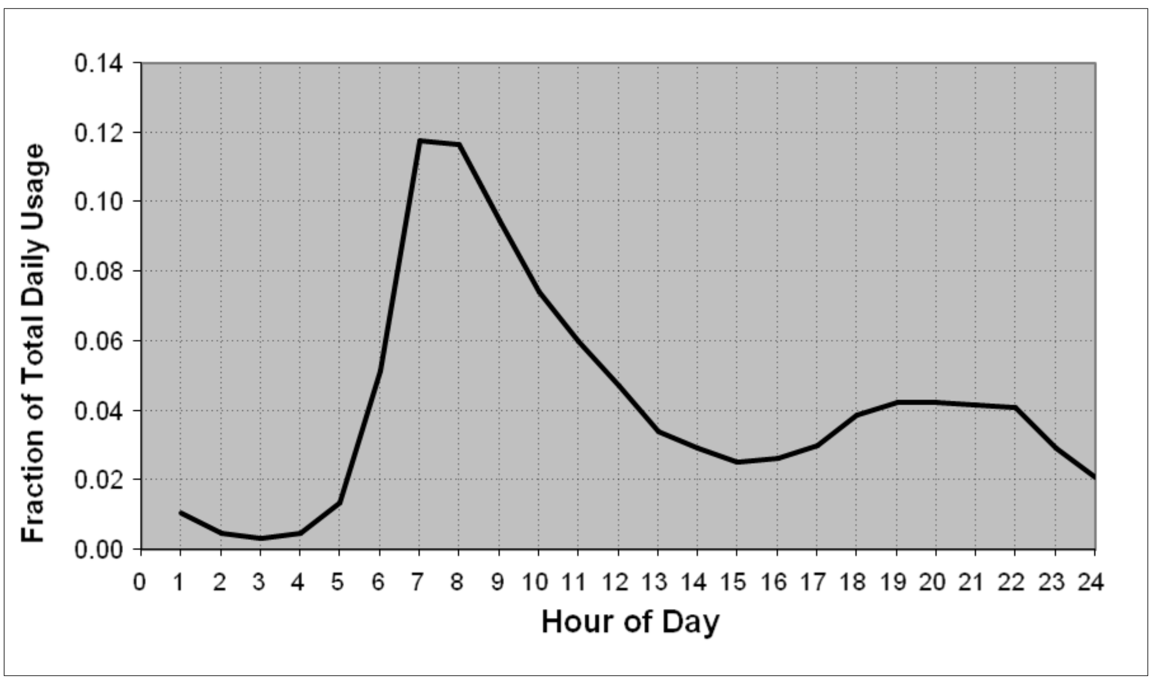


Figure 9. Shower hot water use profile

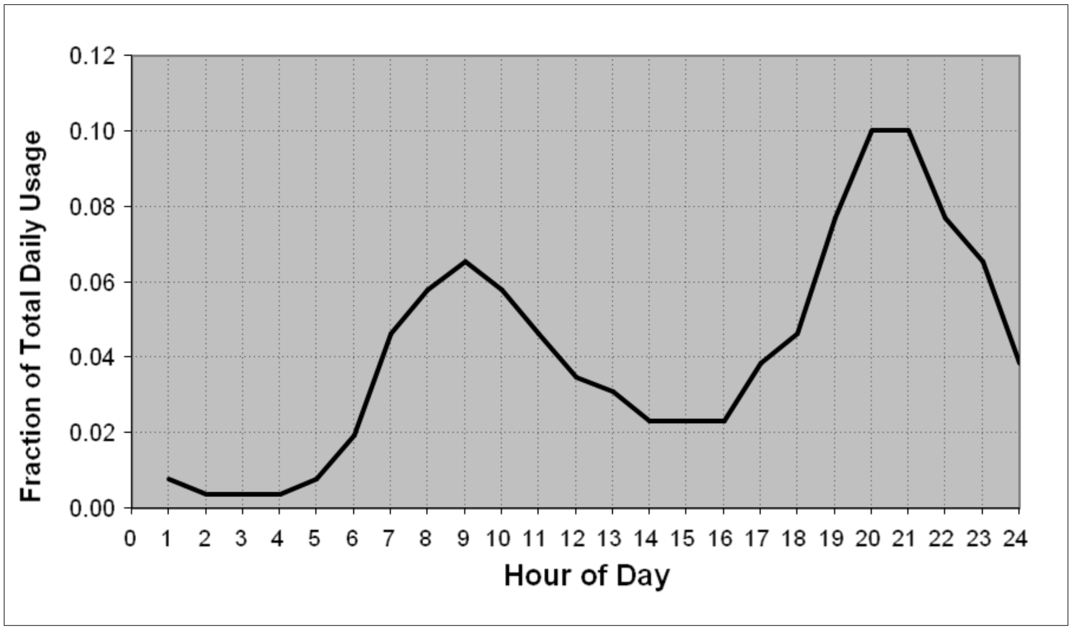


Figure 10. Bath hot water use profile

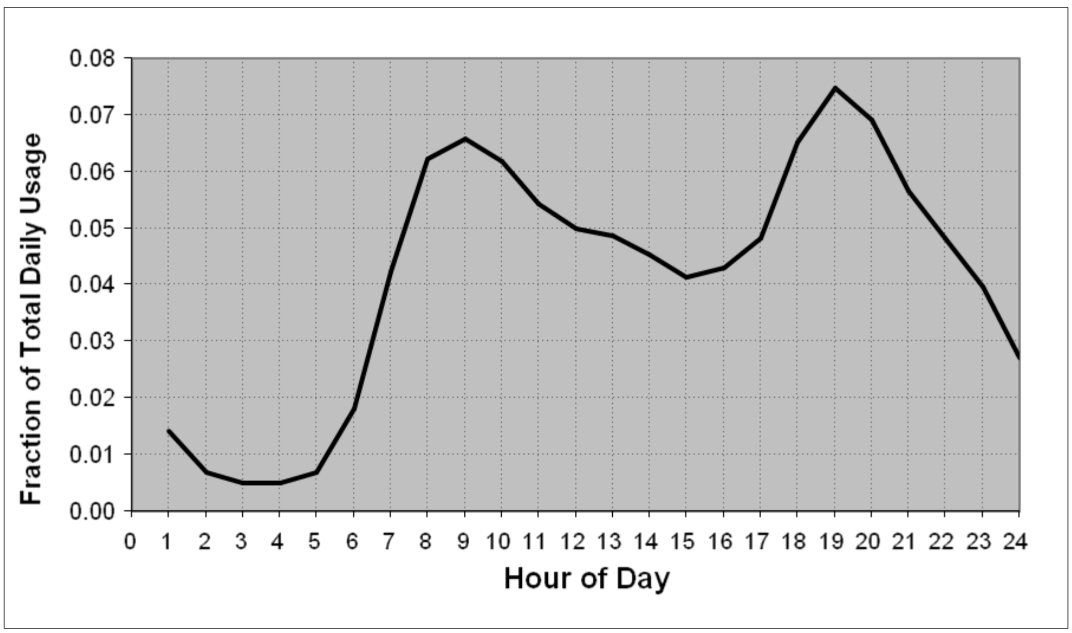


Figure 11. Sink hot water use profile

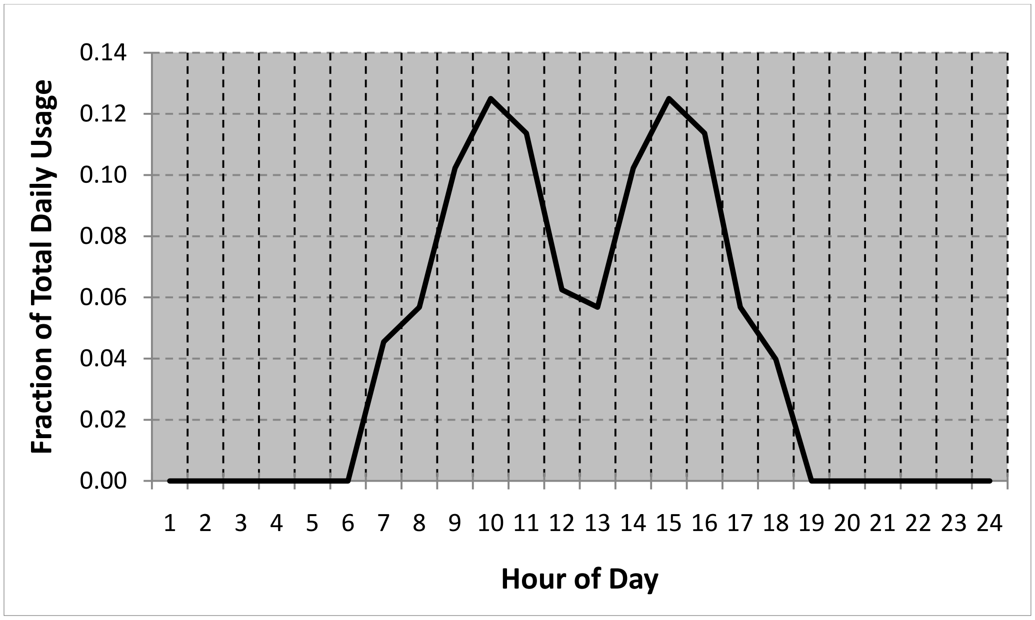


Figure 12. Central restroom sink hot water use profile

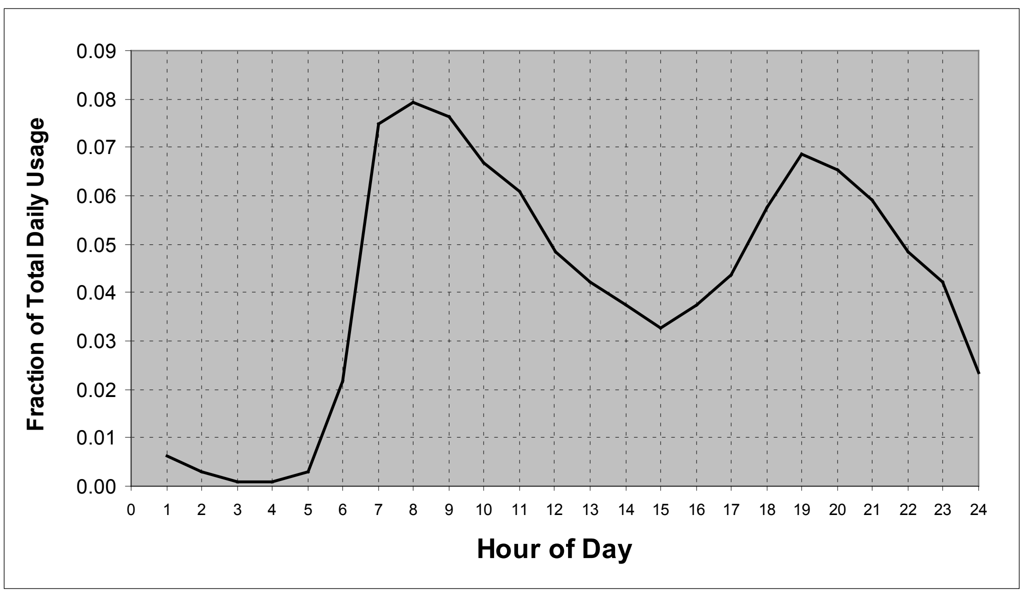


Figure 13. Combined DHW use profile

For the central restroom in a multi-family building, the daily use depends on the number of full-time employees and the number of guests who come to see 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 shall be assumed, each using the restroom three times per day, and 21 visitors, of whom one in three uses restroom facilities (Gleick et al. 2003).

Based on these numbers, Figure 12, and values from Table 9, 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 3526 gal/year.

Weekend/weekday multipliers for daily hot water use were derived from data collected in the 1200 house Aquacraft study (AWWA 1999). 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 and multi-family homes with in-unit clothes washers are summarized in Table 45. This is an optional level of detail for DHW analysis, and is not required if the simulation tool the analyst uses does not allow variable daily hot water use.

Table 45. 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

The mains water temperature for a typical house varies significantly depending on the location and time of year. Equation 29, based on TMY3 data for the location of the Test House, shall be used to determine the daily mains water temperature for all models:

$$T_{mains} = (T_{amb,avg} + offset) + ratio \times (T_{amb,max}/2) \times \sin(0.986 \times (day\# - 15 - lag) - 90) \qquad (29)$$

where

T_{mains} = mains (supply) temperature to DHW tank (°F)
$T_{amb,avg}$ = annual average ambient air temperature (°F)
$T_{amb,max}$ = 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# = day of the year (1–365)
offset = 6°F
ratio = $0.4 + 0.01\,(T_{amb,avg} - 44)$
lag = $35 - 1.0\,(T_{amb,avg} - 44)$.

This equation is based on analysis by Burch and Christensen (2007) using data for multiple locations, as compiled by Abrams and Shedd (1996), 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.

For the constant terms in the ratio and lag factors to represent 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 the minimum ambient temperature 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 29 shall be calculated using Equation 30.

$$\text{day\#} = 30 \times \text{month\#} - 15$$

where

$$\text{month\#} = \text{month of the year (1–12)}$$

An example using Equations 29 and 30 to determine the monthly mains temperature profile for Chicago, Illinois, is shown in Figure 14.

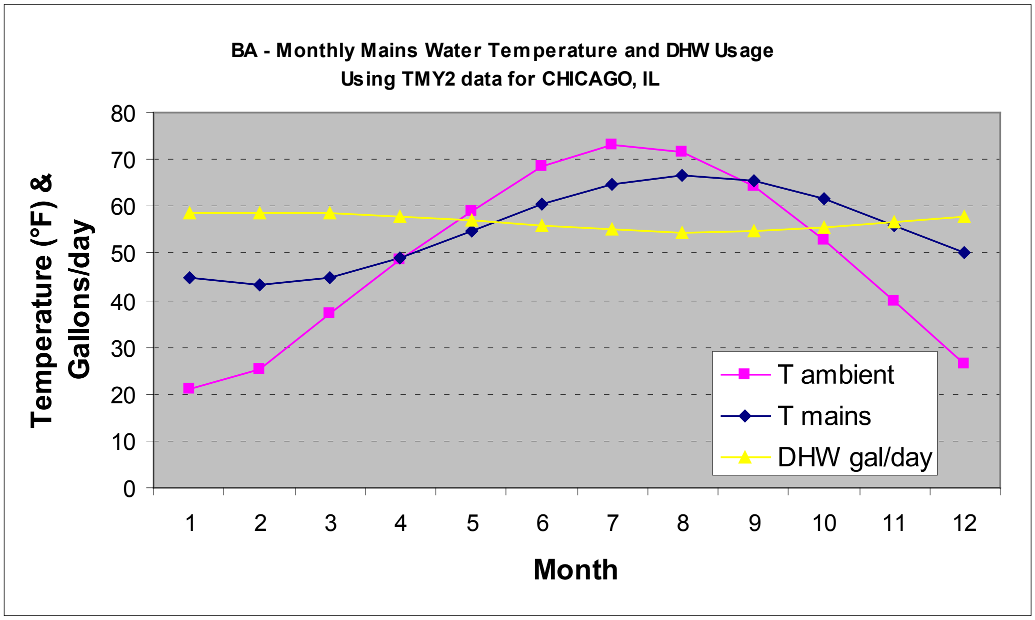


Figure 14. Mains temperature profile for Chicago

Lighting

Operating conditions for lighting are closely tied to the lighting design, and are addressed in the discussions of lighting analysis in the New Construction and Existing Homes sections.

Appliances and Miscellaneous Electric Loads

The hourly, normalized load shape for combined residential equipment use is shown in Figure 15, and is based on 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 (such as refrigerator and transformer loads) are nearly constant and some (such as the range and dishwasher) are highly dependent on time of day, we have also developed a series of normalized hourly profiles for major appliances and MELs (see Figures 16 to 23). Numerical values associated with these profiles can be found in the BA Analysis Spreadsheet. 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 5 to Figure 8). If detailed MELs analysis is not included in the simulation, the hourly profile for "Other MELs" may be used for the entire MELs load.

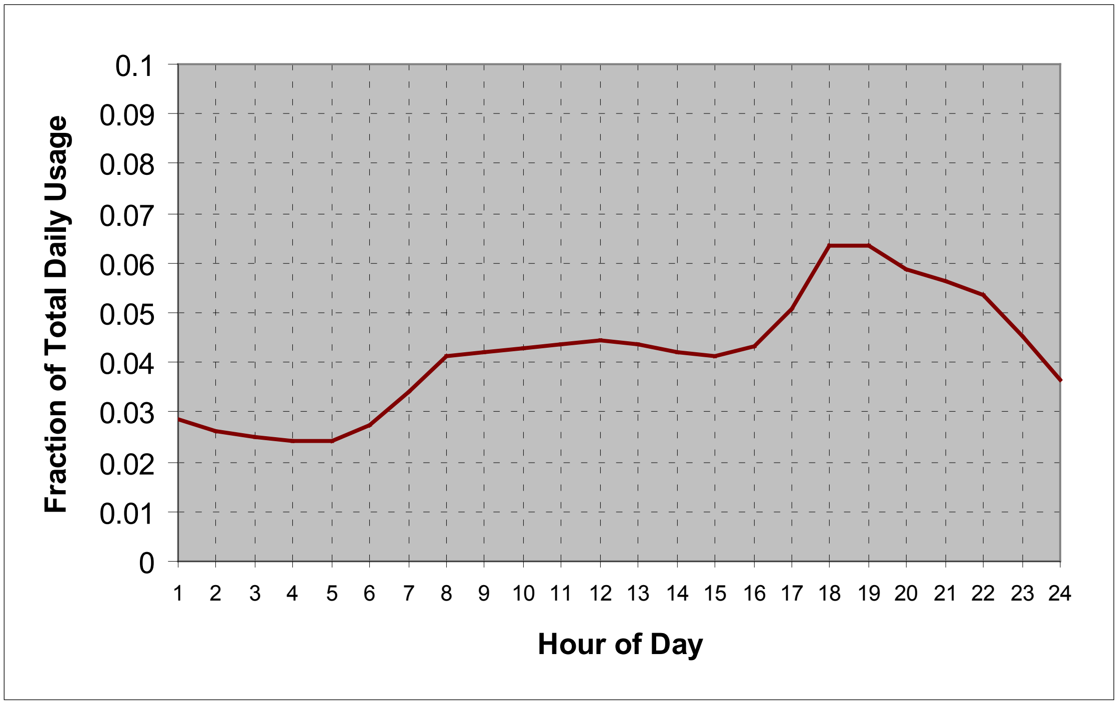


Figure 15. Total combined residential equipment profile
(Pratt et al. 1989)

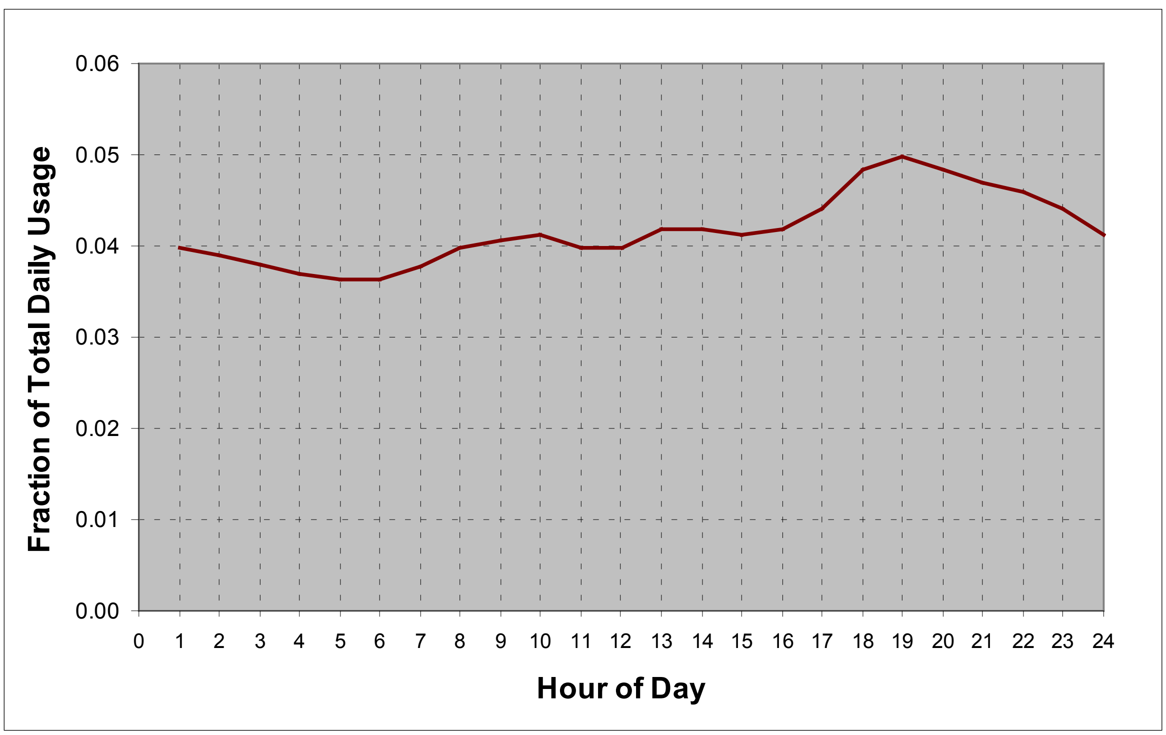


Figure 16. Refrigerator normalized energy use profile
(Pratt et al. 1989)

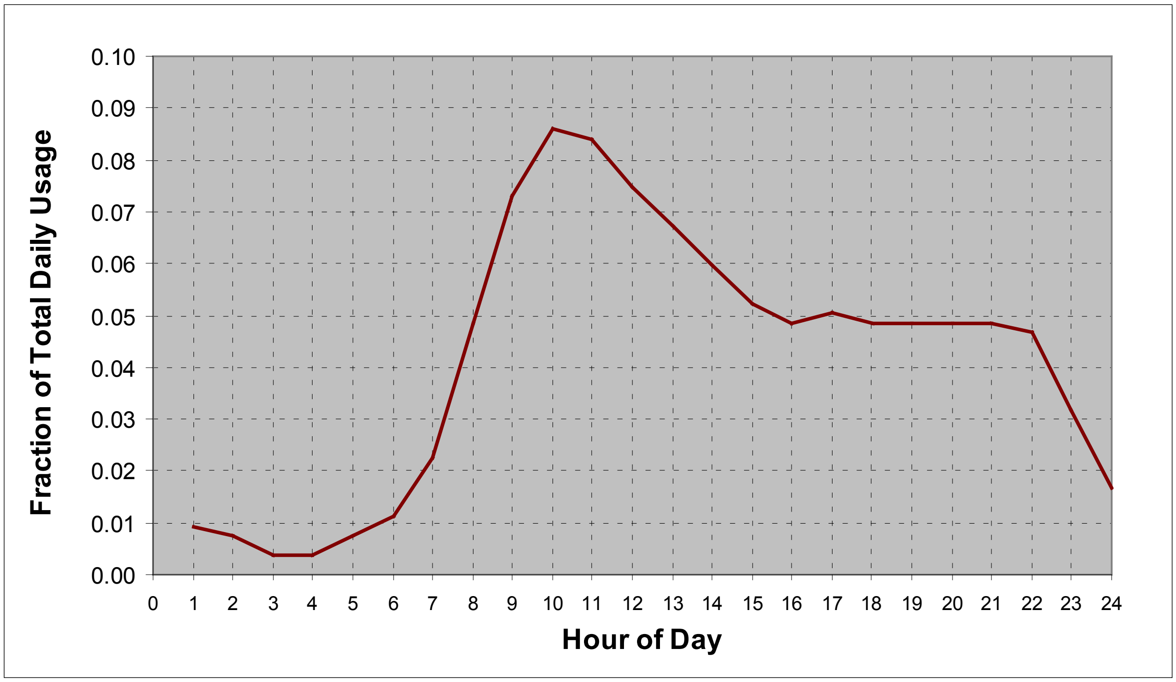


Figure 17. Clothes washer normalized machine energy use profile
(Pratt et al. 1989)

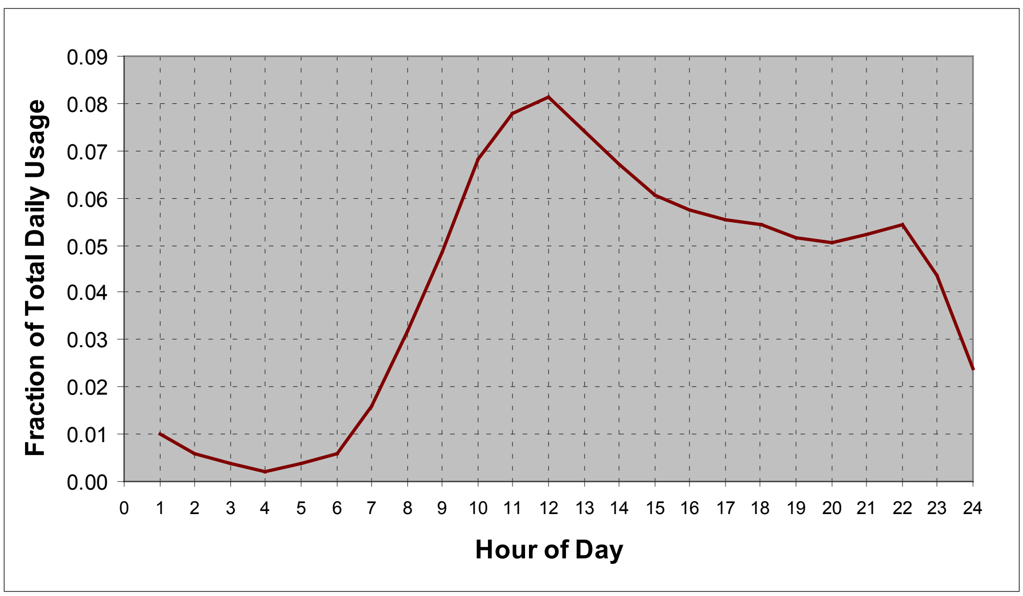


Figure 18. Clothes dryer normalized energy use profile
(Pratt et al. 1989)

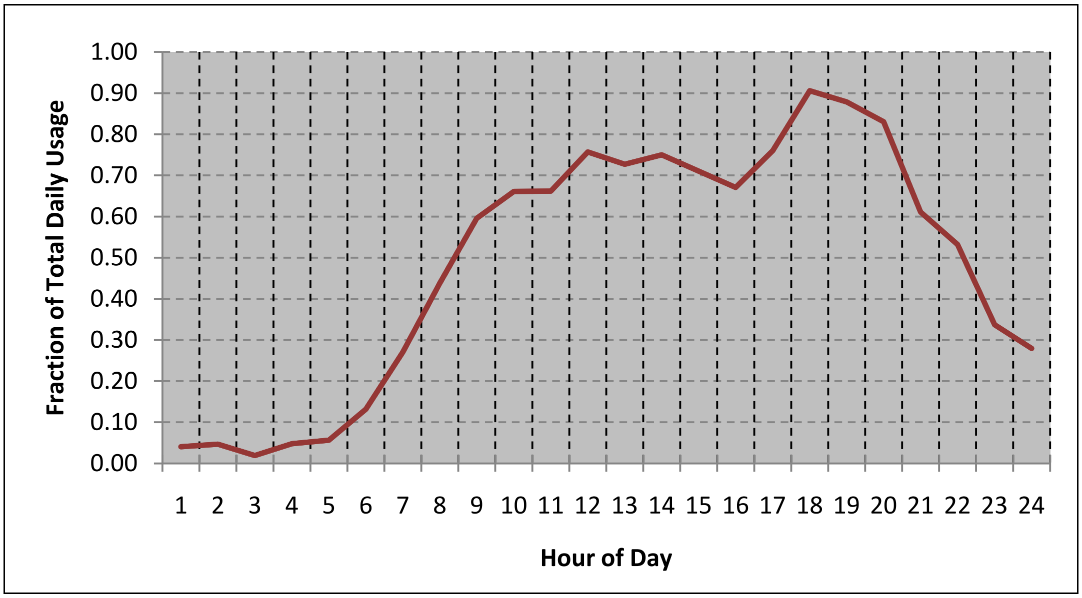


Figure 19. Common laundry clothes washer normalized energy use profile
(Toronto 1999)

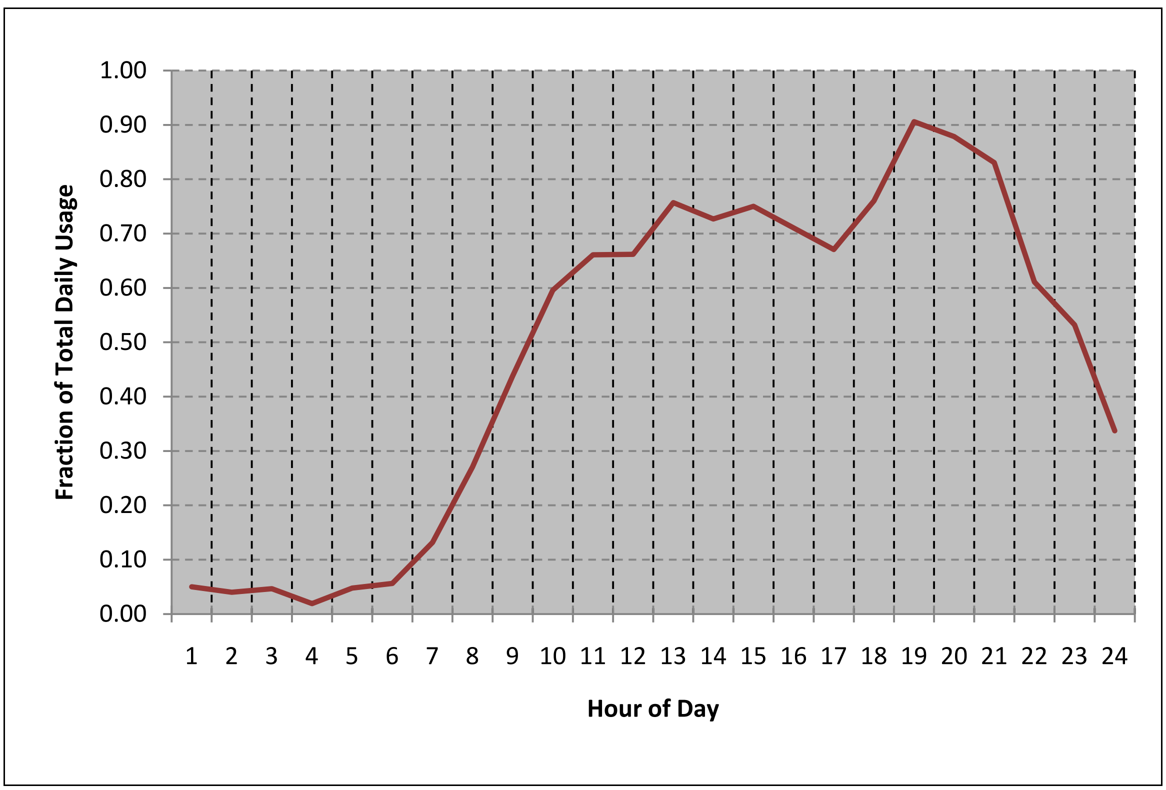


Figure 20. Common laundry clothes dryer normalized energy use profile
(shifted one hour relative to clothes washer)

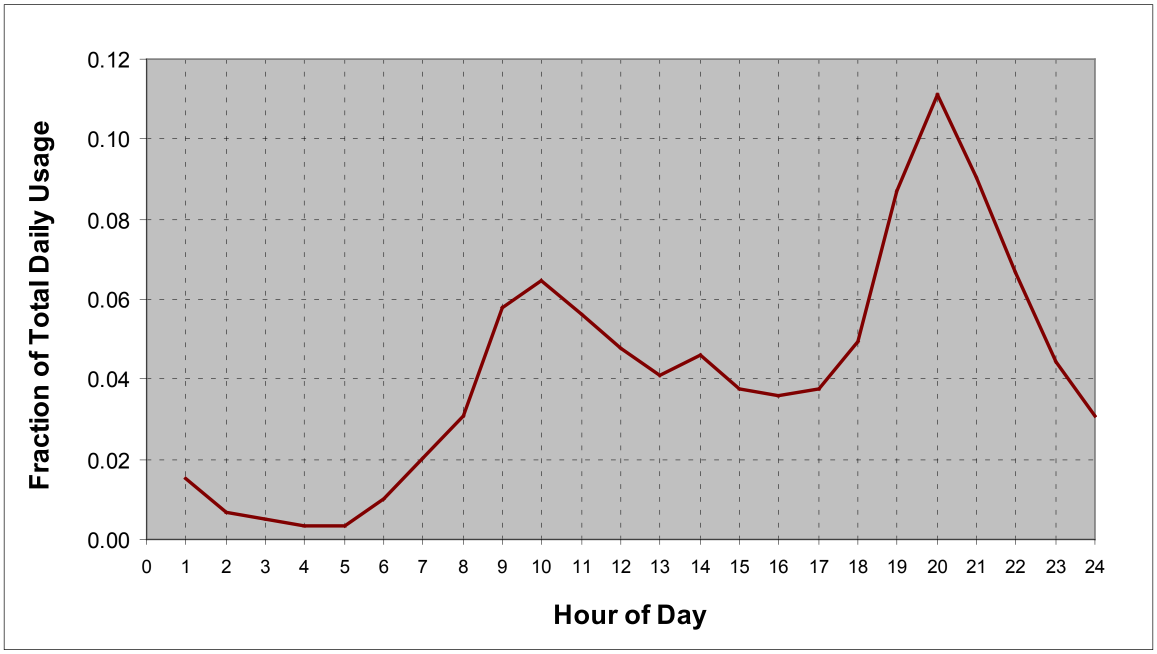


Figure 21. Dishwasher normalized energy use profile
(Pratt et al. 1989)

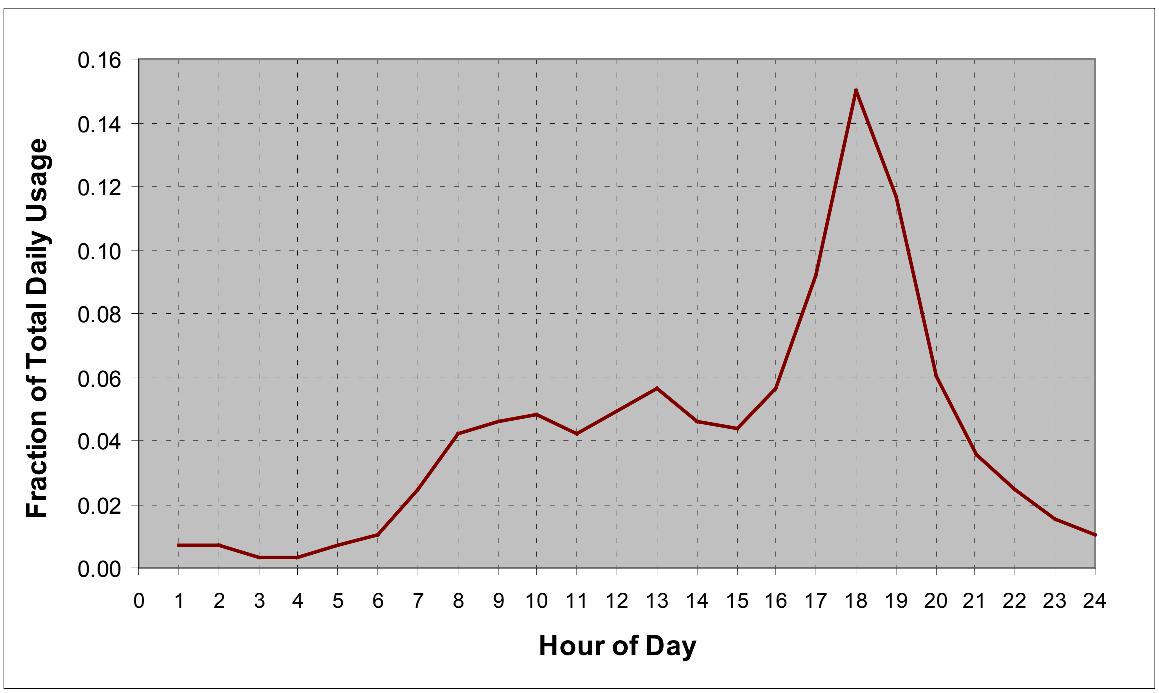


Figure 22. Range/oven normalized energy use profile
(Pratt et al. 1989)

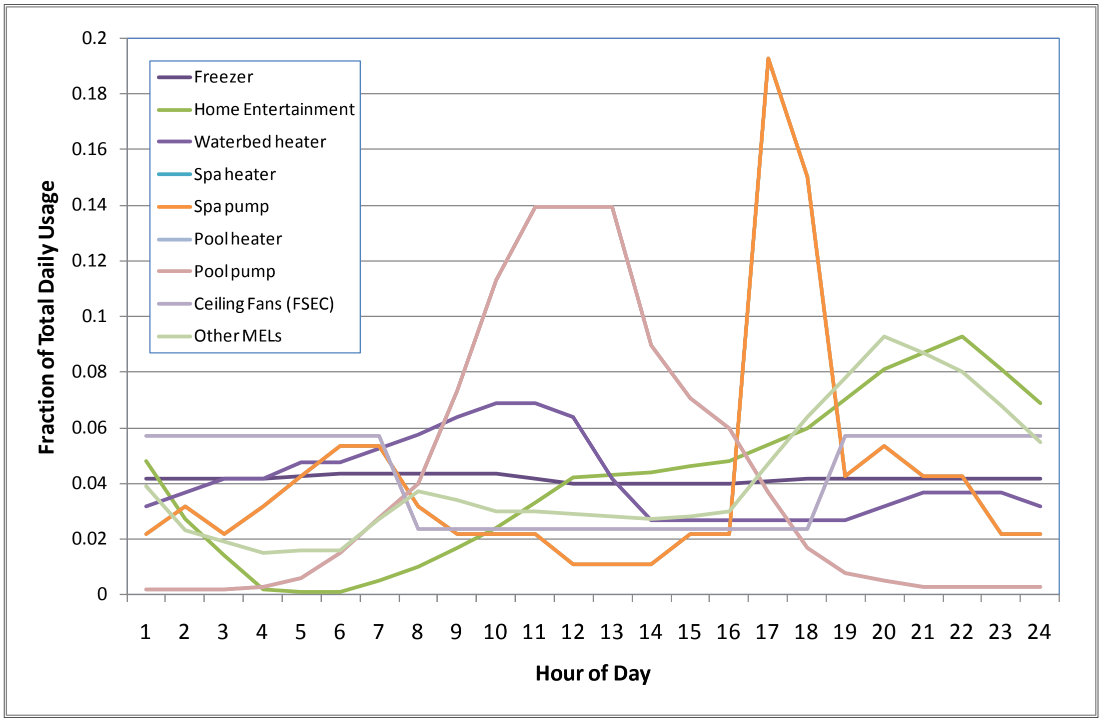


Figure 23. MELs normalized energy use profile
(Mills 2008)

All hourly end-use profiles were taken from the End-Use Load and Consumer Assessment Program study, except the profile for ceiling fans (Parker et al. 2010), and MELs (Mills et al. 2008). 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 Test House. Seasonal multipliers shall be applied for certain major appliances and MELs. These multipliers, which were derived based on defaults from the Home Energy Saver software (Mills et al. 2008), are graphed in Figure 24. The numerical data are provided in the BA Analysis Spreadsheet. If MELs are not addressed individually in the simulation, the "Other MELs" seasonal multipliers may be used for the entire MELs energy load.

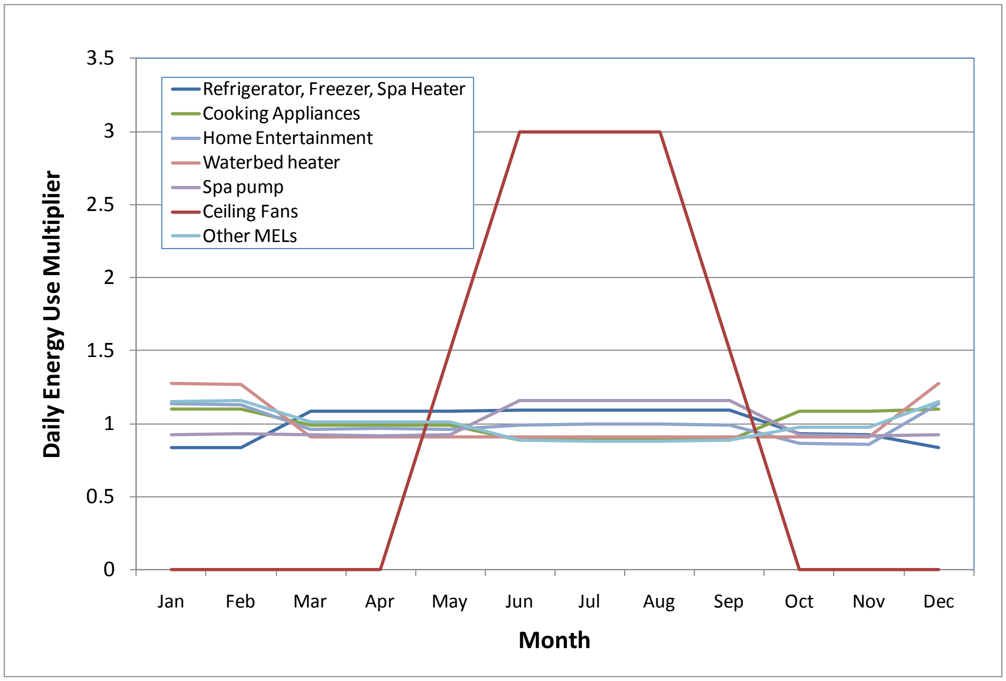


Figure 24. Seasonal multipliers for appliances and MELs

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 each house being modeled; therefore, they are not considered operating conditions for the purposes of Building America performance analysis.

Annual cycles for clothes washers, dryers, and dishwashers shall be calculated using the Building America Analysis Spreadsheet posted on the BA Web site.

Occupancy

The number of occupants in single-family and multi-family dwellings during non-vacation periods shall be estimated based on the number of bedrooms using Equations 31 and 32, respectively.

$$\text{Number of occupants} = 0.59 \times N_{br} + 0.87 \quad (31)$$

$$\text{Number of occupants} = 0.92 \times N_{br} + 0.63 \quad (32)$$

where

N_{br} = number of bedrooms

During vacation periods, the number of occupants shall be zero.

Sensible and latent gains shall be accounted for separately, and different loads shall be applied in different space types when possible (see Table 46). The occupant heat gains are based on ASHRAE (2009). The average hourly occupancy profile is shown in Figure 25, and an example set of detailed hourly occupancy curves is shown in Figure 26.

Table 46. Peak Sensible and Latent Heat Gain From Occupants
(ASHRAE 2009)

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	

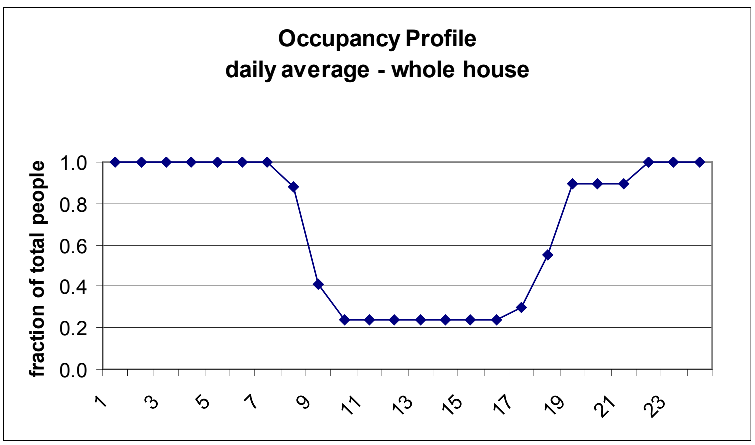


Figure 25. Average hourly load profile from occupants for all day types and family types
(16.5 h/day/person total)

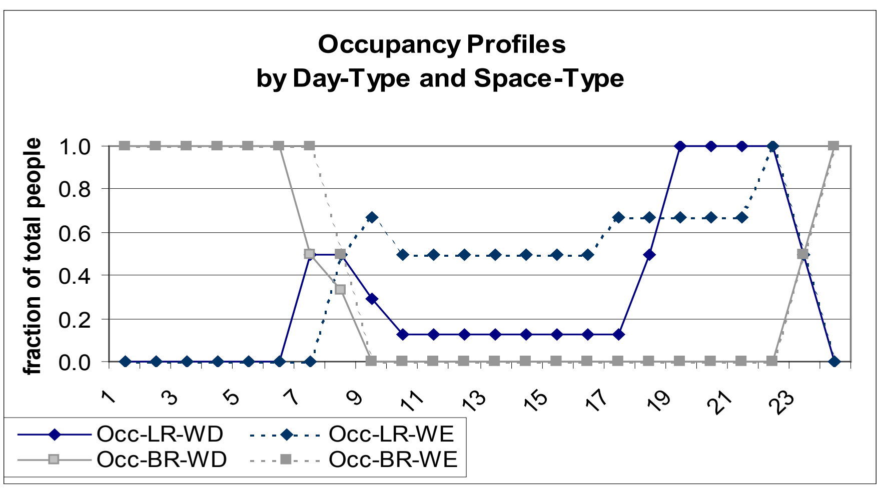


Figure 26. Detailed hourly load profiles resulting from occupants being in different parts of the house on weekdays (WD) and weekends (WE)

For common areas in multi-family buildings, an example occupancy profile is shown in Figure 27. 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.

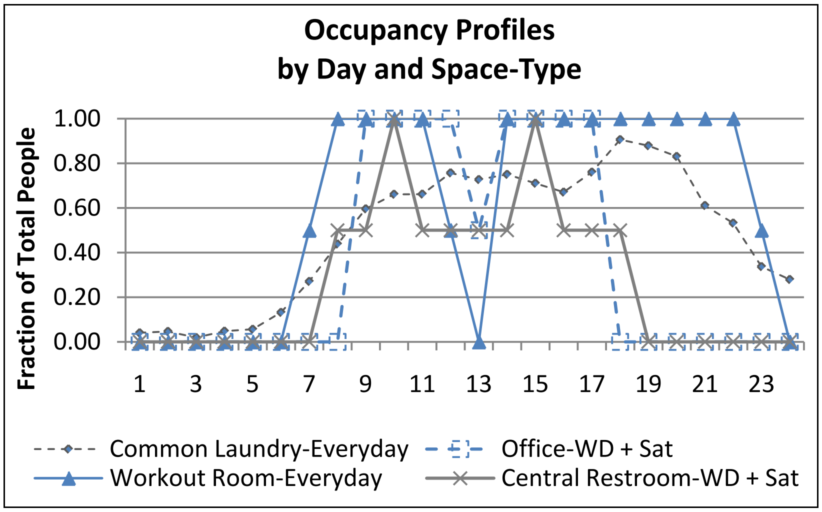


Figure 27. Detailed hourly load profiles resulting from occupants being in different common spaces on specific days of the week

Example occupancy profiles for different day and room types are available in spreadsheet format on the BA Web site. These profiles, which were developed by NREL, are based on the basic occupancy schedule in Figure 25, combined with engineering judgment.

Internal Mass

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.

Reporting Energy Use and Energy Savings

Reporting energy use and energy savings in a consistent format is an important component of BA analysis. The following tables shall be supplied with the analysis report for every BA Test House. Analysis based on alternate approaches (actual operating conditions, energy-conscious occupants, equivalent comfort, etc.) may also be valuable to supplement the primary energy savings calculation.

New Construction

Table 47 shows an example of a site energy consumption report for a hypothetical NCTH, along with the Benchmark, Builder Standard Practice, and Regional Standard Practice. The latter two reference cases represent the house the builder would have built in the absence of Building America, and a house built to the minimum requirements of the local energy code, respectively.

Similar analytical results based on source energy are presented in Table 48, along with percent energy savings for each end use. End uses are described in more detail in Table 49.

Table 47. Summary of Site Energy Consumption by End Use Using BA Research Benchmark

	Annual Site Energy							
	BA Benchmark		Region Standard		Builder Standard		BA NCTH	
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 and 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 48. 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		
	BA Benchmark	Regional	Builder	NCTH	BA Benchmark	Regional	Builder	BA Benchmark	Regional	Builder
End use	(MBtu/yr)	(MBtu/yr)	(MBtu/yr)	(MBtu/yr)	Base	Base	Base	Base	Base	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 and 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 49. 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 and 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 NCTH 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 48 show the NCTH 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 33, using the site-to-source multipliers in Table 50.

$$\text{Source MBtu} = \text{kWh} \times 3.412 \times M_e / 1000 + \text{therms} \times M_g/10 + \text{MBtu} \times M_o \qquad (33)$$

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 50).

Table 50. Source EFs for Energy Delivered to Buildings
(Deru and Torcellini 2007)

Energy Source	Source EF
Electricity	3.365
Natural gas	1.092
Fuel oil/kerosene	1.158
Gasoline	1.187
LPG	1.151

To determine whether the target energy saving has been met, a house size multiplier shall be applied to all Benchmark source energy consumption calculations. The adjusted Benchmark Source energy (Equation 34) assumes that a typical house size is 2400 ft^2 with three bedrooms.

$$\text{Adjusted Benchmark Source MBtu} = (M_{size}) \times \text{Source MBtu} \qquad (34)$$

where

M_{size} = $(N_{br}/3)^{0.034} \times (2400/\text{floor area})^{0.167}$

Table 51 reports energy savings for individual energy efficiency measures applied to the NCTH, 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 (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 NCTH.

The NCTH model is created by changing the characteristics of each component that is not the same in the two houses. In the interest of quality control and of assessing each measure's value, the incremental changes are added progressively and one at a time. Each improvement is analyzed by simulating the new combination of measures and comparing the energy performance to the previous combination of measures.

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

When available, actual energy tariffs for the NCTH 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 NCTH compared with those of homes currently being sold by the builder partner.

Reporting of peak hourly energy consumption is also encouraged for every NCTH. Peak energy is based on the hour with the greatest gas or electric energy consumption during the course of one year, as determined by the hourly simulation.

Table 51. Example Measure Savings Report for New Construction

					National Average		Builder Standard (Local Costs)			
	Site Energy		Source Energy		Energy Cost		Energy Cost		Measure	Package
Increment	(kWh)	(therms)	(MBtu)	Savings (%)	($/yr)	Savings (%)	($/yr)	Savings (%)	Value ($/yr)	Savings ($/yr)
BA Benchmark	29950	0	306.9		$ 2,995		$ 2,950			
Regional standard practice	29712	0	304.4	1%	$ 2,971	1%	$ 2,927			
Builder standard 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 ++ includes basement 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, appliances, and 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

Existing Homes

Table 52 shows an example of a site energy consumption report for a hypothetical project, before and after the retrofits are performed. Similar information based on source energy is presented in Table 53, along with percent energy savings for each end use.

Table 52. Example Summary of Site Energy Consumption by End Use for an Existing Homes Project

	Annual Site Energy			
	Pre-Retrofit		Post-Retrofit	
End use	(kWh)	(therms)	(kWh)	(therms)
Space heating	11225	0	4397	0
Space cooling	2732	0	902	0
DHW	4837	0	1351	0
Lighting	3110		1204	
Appliances and MELs	7646	0	7436	0
OA ventilation	400		400	
Total Usage	**29950**	**0**	**15690**	**0**
Site generation	0		7402	
Net Energy Use	**29950**	**0**	**8289**	**0**

The "Percent of End Use" column in Table 53 shows the Post-Retrofit energy savings for each end use as a fraction of the energy use in the Pre-Retrofit Case. The "Percent of Total" columns show the contribution of each end use toward an overall energy reduction goal.

Source energy is determined using the same methodology described for new construction.

Table 53. Example Summary of Source Energy Consumption by End Use for an Existing Homes Project

End Use	Estimated Annual Source Energy		Source Energy Savings	
	Pre-Retrofit (MBtu/yr)	Post-Retrofit (MBtu/yr)	Percent of End-Use	Percent of Total
Space heating	115	45	61%	23%
Space cooling	28	9	67%	6%
DHW	50	14	72%	12%
Lighting	32	12	61%	6%
Appliances and MELs	78	76	3%	1%
OA ventilation	4	4	0%	0%
Total Usage	**307**	**161**	**48%**	**48%**
Site generation	0	-76		25%
Net Energy Use	**307**	**85**	**72%**	**72%**

Table 54 reports energy savings for individual energy efficiency measures applied to the Pre-Retrofit Case in terms of site energy, source energy, and energy cost. "Source Energy Savings

%" are determined by comparing the source energy for each measure increment to the source energy for the Pre-Retrofit Case (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 Post-Retrofit Case.

When available, actual energy tariffs for the house shall be used to determine whole-building energy costs. Peak hourly energy consumption should also be reported Pre- and Post-Retrofit for every project. Peak energy is based on the hour with the greatest gas or electric energy consumption during the course of one year, as determined by the hourly simulation.

Table 54. Example Measure Savings Report for an Existing Homes Project[5]

	Site Energy		Source Energy		National Average Energy Cost		Economics (Local Costs)			
							Energy Cost		Measure	Package
Increment	(kWh)	(therms)	(MBtu)	Savings (%)	($/yr)	Savings (%)	($/yr)	Savings (%)	Value ($/yr)	Savings ($/yr)
Pre-Retrofit	29950	0	306.9		$ 2,995		$ 2,950			
+ improved walls	27779	0	284.6	7%	$ 2,778	7%	$ 2,736	7%	$ 190.4	$ 190
++ Low-E windows	25810	0	264.5	14%	$ 2,581	14%	$ 2,542	13%	$ 193.9	$ 384
++ Smaller A/C (5 -> 4 tons)	25420	0	260.5	15%	$ 2,542	15%	$ 2,504	14%	$ 38.4	$ 423
++ Including basement wall insulation	25170	0	257.9	16%	$ 2,517	16%	$ 2,479	15%	$ 24.6	$ 447
++ Ground source heat pump (+ DHW)	19331	0	198.1	35%	$ 1,933	35%	$ 1,904	35%	$ 575.1	$ 1,023
++ Solar DHW	17718	0	181.5	41%	$ 1,772	41%	$ 1,745	40%	$ 158.9	$ 1,181
++ Lighting, appliances, and plug (post-retrofit)	15690	0	160.8	48%	$ 1,569	48%	$ 1,545	47%	$ 199.8	$ 1,381

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