2014 Building America House Simulation Protocols

E. Wilson, C. Engebrecht Metzger,
S. Horowitz, and R. Hendron
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5500-60988
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Definitions

A/C	air-conditioning
ACH_{50}	Air changes per hour at 50 Pa pressurization or depressurization
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
BPM	brushless permanent magnet (motor type)
CEC	California Energy Commission
CFA	conditioned floor area
cfm	cubic feet per minute
COU	coefficient of utilization
DEG	Davis Energy Group
DHW	domestic hot water
DOE	U.S. Department of Energy
DOE-2	building energy analysis program
DSE	distribution system efficiency
DUF	dryer usage factor
EER	energy efficiency ratio
EF	energy factor
ER	efficacy ratio
FFA	finished floor area
HP	heat pump
HSP	House Simulation Protocols
HSPF	heating seasonal performance factor
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
IHG	internal heat gain
LBNL	Lawrence Berkeley National Laboratory
LED	light-emitting diode
MAT	monthly average temperature
MEL	miscellaneous electric load
NCTH	New Construction Test Home
NREL	National Renewable Energy Laboratory
NREMD	National Residential Efficiency Measures Database
OA	outdoor air
PSC	permanent split capacitor (motor type)
RESNET	Residential Energy Services Network
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
STEM	short term monitoring test
TMY3	Typical Meteorological Year, version 3
TRNSYS	The Transient Energy System Simulation Tool is software designed to simulate the transient performance of thermal energy systems
XPS	extruded polystyrene

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Executive Summary

The Building America House Simulation Protocols document provides specifications to facilitate accurate and consistent analysis of new and existing, single-family and multifamily, buildings. The specifications include the definition of a consistent reference building for new construction, assumptions and methods for analyzing retrofits of existing buildings, and a set of standard operating conditions defining average occupant use levels and operating schedules for the purposes of an asset (as opposed to operational) evaluation. The HSP also documents the justification and references to literature that informed these specifications.

The House Simulation Protocols document is divided into five sections:

- **Section 1 – Introduction** provides background information on the Building America program and the purpose of the HSP. There is also a brief discussion of analysis tools.
- **Section 2 – New Construction** provides information about design assumptions and analysis methods for new construction. In new construction, the project house (also known as prototype, or New Construction Test Home) is compared to a reference building that represents a "typical" code-built house in 2010.
- **Section 3 – Existing Homes** provides similar information for the analysis of existing homes, including design assumptions and analysis methods for comparing pre-retrofit to post-retrofit homes. This section also uses as many aspects of the real house as possible to provide default values for components of an existing house with unknown performance characteristics.
- **Section 4 – Standard Operating Conditions** defines how the building is operated by the simulated occupants for the analysis of new and existing homes. Standard user profiles, which represent an average of many occupants rather than actual profiles for an average or typical set of occupants, were developed based on review of the available literature.
- **Section 5 – Report Energy Use and Energy Savings** provides a standardized template and examples for reporting the results of Building America analysis in a consistent format.

1 Introduction

1.1 Background

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 to improve 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. This process results in innovations that can be used cost effectively in production-scale housing and retrofit programs.

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.

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 to measure progress toward the program's goals. The House Simulation Protocols (HSP) document provides guidance to program partners and managers so they can compare energy savings for new construction and retrofit projects. The HSP provides the program with analysis methods that are proven to be effective and reliable in investigating the energy use of advanced energy systems and of entire houses.

1.2 History

This 2014 document is an updated version of the Building America House Simulation Protocols last published in October 2010 (Hendron and Engebrecht 2010). This version incorporates the changes published in the 2012 addendum to the BA HSP (Metzger et al. 2012), feedback from BA research teams, organizational improvements, and some additional updates. Significant updates since the 2012 addendum include updated site-to-source multipliers, economic parameters, water heater setpoint (from 130ºF to 125ºF), as well as a new Quick Reference summary table for the new construction B10 Benchmark (Table 1).

1.3 Analysis Tools

A key decision in any building energy analysis is determining which tool or program to use 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 BA program.

The BA teams are also encouraged to use other simulation tools when appropriate for specialized building simulation analysis (new technologies, some multifamily projects, etc.), provided the tool has met the requirements of the Building Energy Simulation Test and Diagnostic Method in accordance with the software certification sections of the Residential Energy Services Network (RESNET) (2006). Regardless of the tool selected, teams should present complete analysis results in their final project summaries.

2 New Construction

To track progress toward aggressive multiyear, whole-house energy savings goals of 30%–50% for new homes, NREL developed the concept of a new construction reference building that represents the typical code-built house at the time of the contract recompetition. Since 2010, this reference building has been called the "B10 Benchmark" (or "Benchmark" in this document) because this reference building is generally consistent with the 2009 International Energy Conservation Code (ICC 2009), hereafter referred to as "IECC," with additional definitions that enable the analyst to evaluate all residential end uses consistent with typical homes built in 2010. In 2013, the 2009 IECC is still the most widely used energy code in the United States, and is consistent with DOE's benchmark for other programs, including the Better Buildings initiative.

The goal is to essentially maintain the energy performance of the Benchmark construction throughout the contract period of the BA Teams. However, minor updates (such as those in the 2014 version) to the HSP are beneficial when more accurate information becomes available through new research or to provide additional clarification. These types of changes do not affect the overall reference point-in-time of the building.

A series of user profiles, intended to be an average over many homes rather than the behavior of an individual set of typical 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 low-rise multifamily 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 multiyear energy savings goals established by BA.

- **New Construction Test Home (NCTH)**. A research home or prototype home built as part of a community-scale project that includes advanced systems and design features built as part of the BA program.

Table 1 summarizes the B10 Benchmark specifications in a quick reference format.

Table 1. New Construction B10 Benchmark Specifications – Quick Reference

	Category	IECC Zones	Option	Ref.
Bldg	Orientation	All	North	p. 8
	Neighbors	All	None	p. 10
Operation	Heating set point	All	71°F	p. 48
	Cooling set point	All	76°F	p. 48
	Humidity set point	All	No dehumidifier	p. 49
	Natural vent.	All	See p. 49	p. 49
	Int. shading	All	0.7 multiplier on SHGC[a], year-round	p. 49
	Occupancy	All	$N_{occupants} = 0.59 \times N_{br} + 0.87$	p. 62
	Hot water use	All	Sinks, showers, and baths: $30 + 10 \times N_{br}$ gal/day @ 110°F Clothes, dish washer: $4.61 + 1.53 \times N_{br}$ gal/day @125°F	Table 11
Walls	Wall construction	1,2,3,4	R-13 fiberglass batt, Gr-1, 2 × 4, 16 in. o.c.	Table 2
		4C,5,6	R-13 fiberglass batt, Gr-1, 2 × 4, 16 in. o.c., R-5 XPS[b]	
		7,8	R-21 fiberglass batt, Gr-1, 2 × 6, 24 in. o.c.	
	Exterior finish	All	Vinyl, light colored	Table 5
Ceilings/Roofs	Unfinished attic	1,2,3	Ceiling R-30 cellulose, vented: 1 ft^2 per 300 ft^2 ceiling area	Table 2
		4,4C,5	Ceiling R-38 cellulose, vented: 1 ft^2 per 300 ft^2 ceiling area	
		6,7,8	Ceiling R-49 cellulose, vented: 1 ft^2 per 300 ft^2 ceiling area	
	Finished roof	1,2,3	R-30C fiberglass batt, 2 × 10	Table 2
		4,4C,5	R-38C fiberglass batt, 2 × 12	
		6,7,8	R-30 + R-19 fiberglass batt	
	Roof material	All	Asphalt shingles, medium	Table 5
	Radiant barrier	All	None	p. 7
Foundation/Floors	Slab	1,2,3	Uninsulated	Table 2
		4,4C,5	2-ft R-10 perimeter, R-5 gap	
		6,7,8	4-ft R-10 perimeter, R-5 gap	
	Finished Basement	1,2,3	Uninsulated	Table 2
		4,4C,5	Wall 8-ft R-10 XPS, furring strips, ½-in. drywall	
		6,7,8	Wall 8-ft R-15 XPS, furring strips, ½-in. drywall	
	Unfinished Basement	1,2,3	Uninsulated	Table 2
		4,4C,5	Whole Wall, R-10 XPS, furring strips, ½-in. drywall	
		6,7,8	Whole Wall, R-15 XPS, furring strips, ½-in. drywall	
	Crawlspace	1,2	Uninsulated, unvented	Table 2
		3	Wall R-5 XPS, unvented	
		4,4C,5,6,7,8	Wall R-10 XPS, unvented	
	Interzonal floor (e.g., above garage)	1,2	R-13 fiberglass batt	Table 2
		3,4	R-19 fiberglass batt	
		4C,5,6	R-30 fiberglass batt	
		7,8	R-38 fiberglass batt	
	Carpet	All	80% carpet (R-2)	p. 11

	Category	IECC Zones	Option	Ref.
Thermal Mass	Floor	All	Wood surface	p. 9
	Exterior wall	All	½-in. drywall	
	Partition wall	All	½-in. drywall	
	Ceiling	All	½-in. drywall	
	Furniture	All	8 lb/ft^2 conditioned floor area	p. 64
Windows and Doors	Window areas	All	15.0% F25 B25 L25 R25	p. 8
	Windows	1,2,3	Double-pane, low-gain low-e, nonmetal frame, air fill (U = 0.37, SHGC = 0.30)	Table 4
		4,4C,5, 6,7,8	Double-pane, medium-gain low-e, nonmetal frame, argon fill (U = 0.35, SHGC = 0.44)	
	Eaves	All	2 ft	p. 7
	Overhangs	All	None	p. 10
Airflow	Air leakage	All	7 ACH_{50}, 0.5 shelter coefficient	p. 16
	Mech. vent.	All	Exhaust, ASHRAE Standard 62.2-2010; 0.30 W/cfm	p. 17
Major Appliances	Refrigerator	All	434 (kWh/yr)	Table 25
	Cooking range	All	Electric, 250 + 83 × N_{br} (kWh/yr)	
	Dishwasher	All	87.6 + 29.2 × N_{br}	
	Clothes washer	All	38.8 + 12.9 × N_{br}	
	Clothes dryer	All	Electric, 538.2 + 179.4 × N_{br} (kWh/yr)	
Misc.	MELs	All	1185.4 + 180.2 × N_{br}+ 0.3188 × FFA[c] (kWh/yr)	Table 25
	Large, uncommon loads	All	See Table 26	Table 26
Lighting	Int. hard-wired	All	0.8 (FFA × 0.542 + 334) kWh/yr	p.18
	Interior plug-in	All	0.2 (FFA × 0.542 + 334) kWh/yr	
	Garage	All	Garage Area × 0.08 + 8 kWh/yr	
	Exterior	All	FFA × 0.145 kWh/yr	
Space Conditioning	*Gas available on site*	All	Heating: Gas, 78% AFUE[d] furnace Cooling: SEER 13 Central air conditioner	Table 6
	*Gas **not** available on site*	All	Heating/Cooling: 7.7 HSPF[e]/13 SEER[f] air source heat pump	
	Air handler	All	0.364 W/cfm	p. 11
	Ducts	All	15% leakage, R-8	Table 7
	Ceiling fan	All	Included in MELs (77.3 + 0.0403 × FFA kWh/yr)	Table 27
	Dehumidifier	All	None	p. 11
Water Heating	*Gas available on site*	All	Gas,EF[g] = 0.67 – 0.0019 × Volume (gal)	Table 8
	*Gas **not** available on site*	All	Electric, EF = 0.97 – 0.00132 × Volume (gal)	
	Location	Use BA zones→	*Hot-Humid, Hot-Dry*: Attached garage, else in conditioned space *All other*: Unconditioned basement, else in conditioned space	Table 10
	Distribution	All	Uninsulated, TrunkBranch, copper	Table 13
	Water heater set point	All	125°F	p. 49

[a] Solar heat gain coefficient [b] Extruded polystyrene [c] Finished floor area [d] Annual fuel utilization efficiency
[e] Heating season performance factor [f] Seasonal energy efficiency ratio [g] Energy factor

2.1 New Construction B10 Benchmark Specifications

The following sections summarize the Benchmark definition. NREL and other BA partners have also developed a series of tools, including spreadsheets with detailed hourly energy use and load profiles, to help analysts quickly and consistently apply the Benchmark. These tools are available on the BA website (www1.eere.energy.gov/buildings/residential/ba_house_simulation.html). BEopt can also automatically simulate the Benchmark when the specifications for an NCTH are entered.

The Benchmark may be applied to either a single-family or a multifamily 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 either:

1. A residence that shares one or more walls with another unit, or
2. A residence in a building of two or three units stacked vertically.

This definition includes, but is not limited to, duplexes, row houses, townhomes, two-flats, and three-flats.

A **multifamily** building has at least five housing units, each of which must share a floor or a ceiling with another unit. Also, a given multifamily building may have no more than three full above-grade stories; otherwise, it is considered a commercial building, which is outside the scope of this document. These definitions are based on those provided by the EIA Residential Energy Consumption Survey (DOE 2005) database (modified so that row houses are considered single-family attached even if there are more than four units).

2.1.1 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 exceptions:
    - Unfinished attics shall be insulated at the attic floor and have a ventilation area of 1 ft^2 per 300 ft^2 ceiling area.
    - Finished attics shall be considered part of the living space, and shall have the same thermal boundary as the NCTH.
    - Basements and crawlspaces in climate zones 3 through 8 shall be unvented and insulated at the walls, regardless of the NCTH design.
- The Benchmark shall not have a radiant barrier.
- Surfaces adjacent to neighboring units (attached walls, floors, and ceilings) shall be modeled as adiabatic for both the Benchmark and the NCTH.

- The same foundation type (slab, crawlspace, or basement) as the NCTH
- Basement and crawlspace wall construction shall be 8" concrete.
- 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 (A_F), 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). If the simulation tool cannot model windows in basement walls, the windows shall be added to the above-grade window area.

$$A_{F,\,Liv} = 0.15 \times A_{ExWa,\,Liv} \qquad (1)$$
$$A_{F,\,Bsm} = 0.15 \times A_{ExWa,Bsm}$$
$$A_{F,\,Liv} = 0.30 \times A_{ExWa,\,Liv} \qquad (2)$$
$$A_{F,\,Bsm} = 0.30 \times A_{ExWa,Bsm}$$

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 façade 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, and the orientation of the Benchmark is fixed so that the front of the building faces

north. If the required area cannot fit on a particular façade because of geometry constraints (e.g., attached garage), the area on that façade shall be reduced.

- 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 2 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 walls can be found in Table 2. 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).

Table 2. Insulation R-Values

(excerpted from ICC 2009 unless otherwise noted)

Climate Zone	Ceiling R-Value	Frame Wall R-Value	Floor[a] R-Value	Basement Wall R-Value	Crawlspace Wall R-Value	Slab R-Value, Depth
1	30	13	13	0	0	0
2	30	13	13	0	0	0
3	30	13	19	0[b]	5	0
4 except Marine	38	13	19	10	10	10, 2 ft
5 and Marine 4	38	13+5[c]	30	10	10	10, 2 ft
6	49	13+5[c]	30	15	10	10, 4 ft
7 and 8	49	21[d]	38	15	10	10, 4 ft

[a] Floor R-value applies to cantilevered floors and floors above garage space.
[b] Basement wall insulation is required in dry regions of Region 3 (as defined in Section 301 in the 2009 IECC), but is not included in the Benchmark for ease of implementation and because basements in this region are uncommon.
[c] "13+5" means R-13 cavity insulation combined with R-5 continuous insulating sheathing on the exterior of the wall.
[d] R-21 is accomplished with an R-21 fiberglass batt in a 2×6 stud cavity; all other walls use 2×4 studs

The above-grade exterior walls shall be light-frame 2 × 4 or 2 × 6 wood construction. The framing factors in Table 3 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 2. The simulation tool shall account for reduced insulation depth at roof edges where appropriate.
- 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 2.
- R-values of walls in an insulated basement or unvented crawlspace are specified in Table 2. 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 2. This R-value is for rigid foam insulation and does not include the slab itself or ground effects.

Table 3. Benchmark Framing Factors

Enclosure Element	Frame Spacing (in. on center)	Framing Fraction (% area)
2 × 4 walls (above grade)	16	25%[b]
2 × 6 walls (above grade)	24	22%[b]
2 × 4 walls (below grade)[a]	16	18%
Floors/basement ceiling	16	13%
Ceilings below unconditioned space	24	7%
Roof, when insulated at roof	24	7%

[a] Below-grade wood framing is not part of the Benchmark, but is included here for completeness
[b] ASHRAE Handbook – Fundamentals (I-P Edition), p.27.3 (ASHRAE 2009)

The assembly U-value and SHGC for vertical fenestration, including windows and sliding glass doors, shall be determined using Table 4. Values in Table 4 were determined using the 2009 IECC (ICC 2009) in combination with values that reflect common window options on the market. 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 4.

Table 4. Fenestration Assembly Characteristics

Climate Zone	Vertical Fenestration U-Value (U_F) (Btu/h·ft^2·°F)	Vertical Fenestration SHGC
1 to 3	0.37	0.30
4 to 8	0.35	0.44

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 and emissivity of the Benchmark exterior wall finish and roof material are shown in Table 5.

Table 5. Exterior Wall Finish and Roof Material Properties

Category	Option	Absorptivity	Emissivity
Exterior Wall Finish	Vinyl, light	0.30	0.90
Roof Material	Asphalt shingles, medium colored	0.85	0.91

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.

2.1.2 Space Conditioning Equipment

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

For all homes, including multifamily buildings with centralized space conditioning systems, the Benchmark building shall use individual space conditioning systems in each unit, with the equipment type and efficiency specified in Table 6, and depending on whether natural gas is available at the project site.

Heating and cooling equipment (including the air handler) shall be sized using the procedures published by the Air Conditioning Contractors of America. (ACCA 2006; ACCA 1995)

Table 6. Benchmark Space Conditioning Equipment Efficiencies

	Function	Benchmark Space Conditioning Device
Dual-fuel *(natural gas available on site)*	Heating Cooling	78% AFUE gas furnace 13 SEER air conditioner
All-electric *(natural gas **not** available on site)*	Heating and cooling	7.7 HSPF/13 SEER air source heat pump

The Benchmark air handler shall have power consumption equal to 0.500 W/cfm.

The Benchmark shall not have a whole-house fan.

Regardless of whether the NCTH actively controls relative humidity, the Benchmark shall not include dehumidification.

2.1.3 Distribution System

The Benchmark shall include an air distribution system with the properties listed in Table 7. The location of the ductwork in the Benchmark is based on the type of foundation used for the NCTH. The Benchmark duct return register values stem from field experience from IBACOS and CARB Building America Teams. If the simulation tool does not permit the input of duct specifications to the level of detail used in Table 7, 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 7 and the procedures in the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 152 (ASHRAE 2004). The ASHRAE Standard 152 Spreadsheet developed by Lawrence Berkeley National Laboratory (LBNL) can assist with this calculation.

Table 7. 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[a]	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)
Number of ducted return registers	All	Single-family detached: $N_{returns}$ = 1 + $N_{stories}$[b] Multifamily/attached: $N_{returns}$ = 0	
Supply/return duct insulation (inside thermal enclosure)[c]	All	None	
Supply/return duct insulation (all other locations)	All	R-8	
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[d]	37% OA[d]
	Basement or crawlspace	0% OA	0% OA
	Multifamily	100% OA	100% OA
Supply duct location	Slab-on-grade or raised floor	100% attic[d]	65% attic[d], 35% conditioned space
	Crawlspace	100% crawlspace	65% crawlspace, 35% above-grade conditioned space
	Basement	100% basement	65% basement, 35% above-grade conditioned space
	Multifamily	100% conditioned space	100% conditioned space
Return duct and air handler location	Slab-on-grade or raised floor	100% attic[e]	100% attic[e]
	Crawlspace	100% crawlspace	100% crawlspace
	Basement	100% basement	100% basement
	Multifamily	100% conditioned space	100% conditioned space

[a] Finished floor area (ft^2)
[b] For purposes of specifying the Benchmark duct system, the number of stories is defined as each level of living space in the home, including basements (finished and unfinished) and finished attics.
[c] Thermal enclosure 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 the thermal envelope and ducts within that space have R-6 insulation.
[d] If the NCTH does not have an attic, the leakage is assumed to be in conditioned space and the leakage imbalance shall be made up of 0% outside air.
[e] If the NCTH does not have an attic,this percentage of duct leakage is assumed to be in conditioned space.

2.1.4 Domestic Hot Water

The Benchmark water heater's volume, energy factor (EF), and burner capacity are specified in Table 8. If natural gas is available on the project site, the Benchmark will have a gas water heater; otherwise, the Benchmark will have an electric resistance water heater. The water heater tank location is specified in Table 9. For a multifamily building with a central hot water system, the Benchmark shall have an individual domestic hot water (DHW) tank in each unit. Storage and burner capacities are determined using the guidelines recommended in the *HVAC Applications Handbook* (ASHRAE 2007); these are based on the minimum capacity permitted by the U.S. Department of Housing and Urban Development and the Federal Housing Administration (HUD 1982). EF is consistent with the federal standard (0.67 – 0.0019 × V for gas; 0.97 – 0.00132 × V for electric) for the corresponding storage capacity (DOE 2001a). For gas water heaters, the Benchmark recovery efficiency is 0.76 (AHRI 2013).

Table 8. Benchmark DHW Storage and Burner Capacity

(ASHRAE 2007 and NREL 2013)

	# Bedrooms	**1**	**2**		**3**		**4**		**5**	**6**
	# Bathrooms	**All**	**≤ 1.5**	**≥ 2**	**≤ 1.5**	**≥ 2**	**≤ 2.5**	**≥ 3**	**All**	**All**
Dual-fuel *(natural gas available on site)*	Storage (gal)	30	30	30	30	40	40	50	50	50
	Burner (kBtu/h)	36	36	36	36	36	38	38	48	50
	EF	0.61	0.61	0.61	0.61	0.59	0.59	0.58	0.58	0.58
All-electric* *(natural gas **not** available on site)*	Storage (gal)	30	30	40	40	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
	EF	0.93	0.93	0.92	0.92	0.90	0.90	0.88	0.88	0.86

*The Benchmark has an electric water heater only if natural gas is not available at the project site.

Table 9. Determination of Benchmark Water Heater Location

(Source: Lstiburek 1999)

BA Climate Zone (PNNL and ORNL 2007)	Benchmark Water Heater Location
Hot-Humid, Hot-Dry	Attached garage if one exists, otherwise in conditioned space
Marine, Mixed-Humid, Cold, Very Cold	Unconditioned basement if one exists, otherwise in conditioned space

An example set of DHW specifications based on a typical three-bedroom, two-bathroom NCTH is shown in Table 10. 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 10. Example Characteristics of a Benchmark DHW System in a Hot-Humid Climate

(based on an NCTH with three bedrooms and two bathrooms)

Storage capacity (V) (gal)	40
EF	0.59
Recovery efficiency	0.76
Burner capacity	36,000 Btu/h
Fuel type	Natural gas
Tank location	Attached garage

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 multifamily housing with a common laundry room. The average daily water consumption by end use is shown in Table 11. Table 12 shows example characteristics of Benchmark DHW events and constraints. 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 Residential Energy Consumption Survey (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 multifamily housing (NRC 2002). The equation for the office/public sink is based on engineering judgment.

Table 11. DHW Consumption by End Use

End Use	End Use Water Temperature	Water Use	Sensible Heat Gain	Latent Heat Gain
Clothes washer	Water heater set point	$2.35 + 0.78 \times N_{br}$ gal/day (hot only)	0[a]	0[a]
Common laundry	Water heater set point	2.47 gal/day/housing unit (hot only)	0[a]	0[a]
Dishwasher	Water heater set point	$2.26 + 0.75 \times N_{br}$ gal/day (hot only)	0[a]	0[a]
Shower	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[b]
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)

[a] Sensible and latent heat gains from appliances are included in Section 2.1.8.
[b] Negligible compared to showers and sinks.

Table 12. Example Characteristics of Benchmark DHW Events and Constraints

(based on a NCTH with three bedrooms)

Characteristics	Sink	Shower	Bath	CW	DW
Average duration (min)	0.62	7.8	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	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)

Hot water distribution system design can have a significant impact on wait times for hot water, interior heat gains from pipes, and total water heating energy. NREL and Davis Energy Group (DEG) analyzed a wide range of distribution system types, and developed a set of equations to assist with the calculation of whole-house energy savings for improved distribution systems. The basic characteristics of the Benchmark distribution system are summarized in Table 13. Treatment of other distribution system types is discussed in Section 2.2.

Table 13. Benchmark DHW Distribution System Characteristics

Branching configuration	Trunk and branch
Material	Copper
Pipe insulation	None
Pipe diameters and layout	Based on 2010 ft^2 house from DEG (2006b) ¾-in. trunk, ½-in. branches. See Maguire et al. (2011) diagram
Pipe length (for costing only)	Total length (ft) = 366 + 0.1322 × (FFA – 2432) + 86 × (N_{bath} - 2.85) (derived from data in DEG [2006a])
Number of bathrooms	N_{br}/2+½
Recirculation loop	None
Location	Inside conditioned space

The daily internal heat gain (IHG) 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.

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

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.)

2.1.5 Air Infiltration

The rated air leakage for a single-family home (detached or attached) Benchmark shall be seven air changes per hour at 50 Pa:

$$ACH_{50} = 7.0 \quad (5)$$

All spaces within the thermal boundary should be included in volume calculations. This includes conditioned/unvented crawlspaces, cathedralized attics, and conditioned or semi-conditioned basements.

The Benchmark building has a shelter coefficient of 0.50, which can be described as "heavily shielded, many large obstructions within one building height."

For a multifamily building, the ACH_{50} values for the Benchmark are specified in Table 14 (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 ACH_{50} values do consider how the unit's location (ground or top floor) affects the infiltration.

Table 14. Multifamily Common Space and Residential Unit ACH_{50} Values for Benchmark

Room Type	ACH_{50}
Central laundry	2.9
Office	6.0
Indoor corridors	1.2
Workout room	2.9
Central restroom	2.9
Multipurpose room	4.1
Residential unit	7(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)

2.1.6 Mechanical Ventilation

Whole-house mechanical ventilation in the Benchmark and NCTH shall be consistent with the rate recommended by ASHRAE Standard 62.2-2010 (ASHRAE 2010b), accomplished using a single point exhaust ventilation system, unless justification for a lower rate can be provided (i.e., moisture concerns in humid climates). 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 0.30 W/cfm.

In addition to whole-house ventilation, the Benchmark shall include a kitchen range hood exhaust fan, spot ventilation fan in each bathroom, and exhaust from the clothes dryer. The flow rates, power draws, and run times of each exhaust fan are specified in Table 15. Interactive effects between these spot exhaust ventilation fans and natural infiltration shall be included in the analysis.

Table 15. Benchmark Ventilation Specifications

Ventilation Type	Flow Rate (cfm)	Power (W/cfm)	Time
Kitchen spot exhaust	100	0.30	6:00 p.m.–7:00 p.m.
Bathroom spot exhaust	50 per bathroom	0.30	7:00 a.m.–8:00 a.m.
Whole-house ventilation	Per ASHRAE 62.2-2010	0.30	All-day
Clothes dryer exhaust	100	*	11:00 a.m.–12:00 p.m.

* Clothes dryer fan power is already included in clothes dryer appliance energy. The authors realize the inconsistancy between the profile of the electricity use (spread out over a day) and ventilation (1 hour discrete event) of the clothes dryer.

For multifamily 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 16.

Table 16. Multifamily 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
Multipurpose room	0.06
Central restroom	50 cfm per urinal/water closet

2.1.7 Lighting

For the Benchmark lighting budget, 66% of all lamps are incandescent, 21% are compact fluorescent lamps (CFLs), and the remaining 13% are T-8 linear fluorescent (KEMA 2009).

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 multifamily 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 6–9. These equations were derived from detailed calculations using Option 2 for a cross-section of residential floor plans using typical fixtures and lamps.

$$\text{Interior hard-wired lighting} = 0.8*(FFA \times 0.542 + 334)\ \text{kWh/yr}, \quad (6)$$

$$\text{Interior plug-in lighting} = 0.2*(FFA \times 0.542 + 334)\ \text{kWh/yr}, \quad (7)$$

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

$$\text{Exterior lighting} = FFA \times 0.145\ \text{kWh/yr} \quad (9)$$

A percentage of this lighting energy use is associated with each month (Table 17). The total kWh/yr found in Equations 6–9 are multiplied by each of these numbers to find the kilowatt-hours used for a given month.

Table 17. 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.

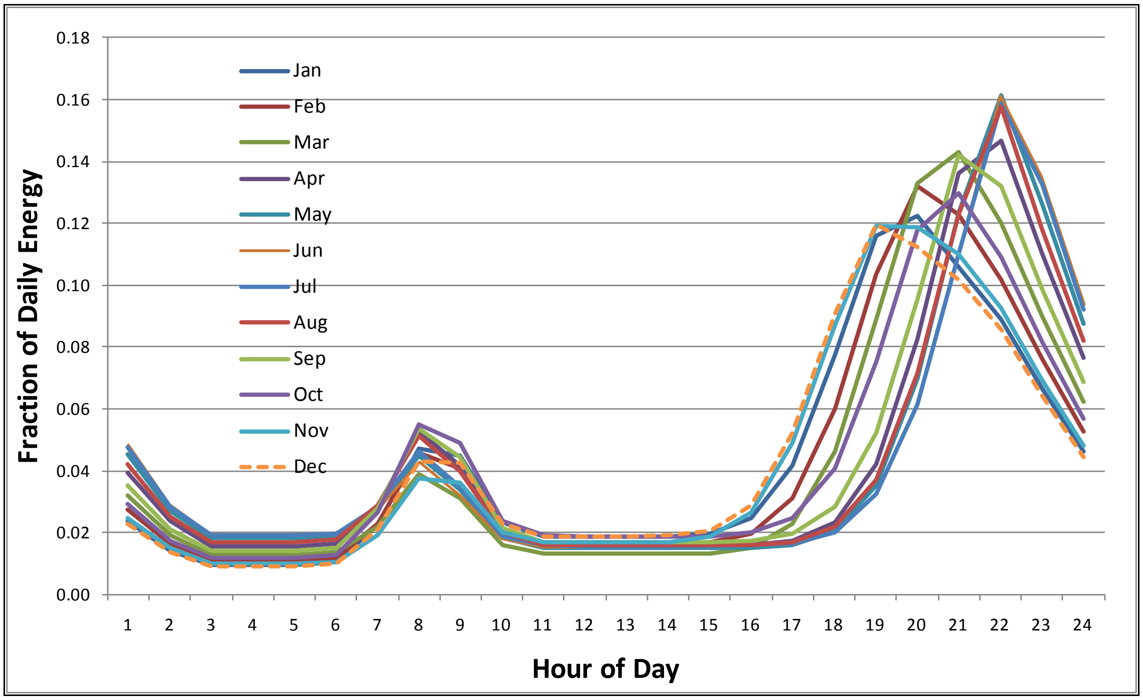


Figure 1. Normalized hourly lighting profile for a given month using Option 1

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 10–12. 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. Default lamp efficacies are provided in Table 18, but actual average efficacy of installed lamps should be used if available, especially for LED lamps, for which a wide range of efficacies are available.

Table 18. Default Efficacy by Lamp Type

Lamp Type	Default Efficacy (lm/W)	Efficacy Ratio (ER)
Incandescent	**15**	**1.00**
Linear fluorescent, T5	104	0.14
Linear fluorescent, T8 (default)	**88**	**0.17**
Linear fluorescent, T12	82	0.18
Compact fluorescent (CFL)	**55**	**0.27**
Miscellaneousfluorescent	85	0.18
High pressure sodium	90	0.17
Metal halide	75	0.20
Light-emitting diode (LED)	**50**	**0.30**

Bold values indicate default values for use in Equations 10–12.

$$\text{NCTH interior hard wired lighting (kWh/yr)} = L_{HW} \times \{[(F_{Inc,HW}+0.34) + (F_{CFL,HW}-0.21) \times ER_{CFL} + F_{LED,HW} \times ER_{LED} + (F_{LF,HW} -0.13) \times ER_{LF}] \times SAF \times 0.9 + 0.1\} \quad (10)$$

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 CFL

$F_{LED,HW}$ = 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

ER_{CFL} = efficacy ratio (incandescent to CFL), Table 18

ER_{LED} = efficacy ratio (incandescent to LED) , Table 18

ER_{LF} = efficacy ratio (incandescent to linear fluorescent), Table 18

SAF = Smart replacement algorithm factor:
$1.1 \times F_{Inc}^4 - 1.9 \times F_{Inc}^3 + 1.5 \times F_{Inc}^2 - 0.7 \times F_{Inc} + 1$

$$\text{NCTH garage lighting (kWh/yr)} = L_{GAR} \times \{[(F_{Inc,GAR}+0.34) + (F_{CFL,GAR}-0.21) \times ER_{CFL} + F_{LED,GAR} \times ER_{LED} + (F_{LF,GAR} -0.13) \times ER_{LF}] \times 0.9 + 0.1\} \quad (11)$$

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 CFL

$F_{LED,GAR}$ = fraction of lamps in the garage that are LED

$F_{LF,GAR}$ = fraction of lamps in the garage that are linear fluorescent

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

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 CFL

$F_{LED,OUT}$ = 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 average efficacies, fraction of hard-wired lighting per room type, and primary fixture type (Table 19 and Table 20), recommended room lighting levels (Table 21 and Table 22), operating hours per day per room (Table 24). All other parameters are user inputs that are used by both the Benchmark and the NCTH.

Table 19. Fixed Values for Benchmark 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

Table 20. Fixed Values for Benchmark Option 2—Multifamily Common Spaces

Multifamily Common Space	Average Efficacy (lm/W)	Fraction Hard-Wired	Primary Fixture Type
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

Table 21. Single- and Multifamily 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 22. Multifamily Common Space Illumination

(Source: IESNA Lighting Handbook (Rea et al. 2000), Security Lighting for People, Property & Spaces)

Area Type	Lighting Requirements (fc)
Common laundry	30
Common office	30
Indoor corridor	15
Workout room	15
Equipment room	30
Central restroom	15
Multipurpose room	15

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 website. Profiles generated using the spreadsheet are normalized, and must be combined with annual lighting energy values, which are calculated separately.

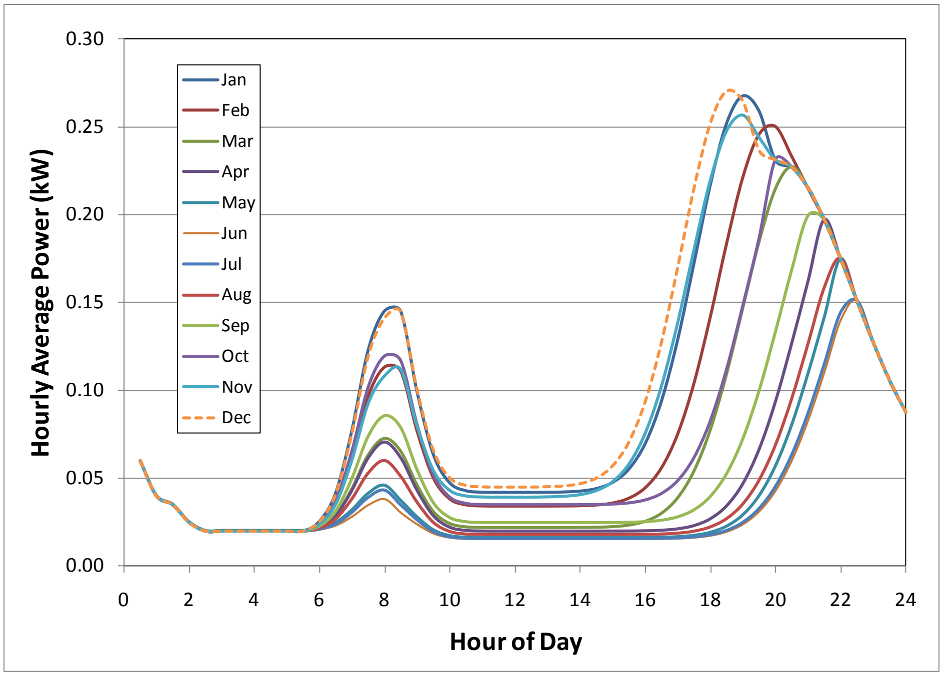


Figure 2. Interior and garage lighting profile (International Falls, Minnesota)

In Option 2, the plug-in lighting for the NCTH (or housing unit) is determined by the difference between the required footcandles (fc) (Table 21 and Table 22) for a given room type and the total installed hard-wired footcandles for that room.

To use Option 2, details such as lamp type (e.g., incandescent versus CFL) 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 21 and Table 22 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). 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. Note: All footcandle levels are measured at a 3-ft work plane for most indoor spaces and on the ground for hallways.

Outdoor lighting has 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.

The illumination at the horizontal plane can be determined by Equation 13. This calculation is required for all indoor spaces, and is automated in the BA Analysis Spreadsheet.

$$\text{Horizontal Illuminance (fc)} = (\text{lumens/lamp}) \times N_{La} \times COU \times LLF/(\text{FFA of room}) \quad (13)$$

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 23 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.

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 (Table 18). These defaults may be modified for the NCTH with sufficient justification.

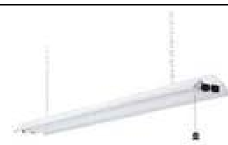
For Either Option:

The lighting plans for the NCTH and Benchmark shall use the hours of operation listed in Table 24, 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 23. Coefficient of Utilization (COU) by Fixture Type

Fixture Type	Picture of Fixture Type	Default COU
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
LED		0.75

(Source: iStockphoto.com)

Fixture Type	Picture of Fixture Type	Default COU
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 23 provided by Lithonia (www.lithonia.com) unless otherwise noted. Used by permission.

Table 24. Average Lighting Operating Hours for Room Types

(Source: Navigant Consulting 2002, after applying a takeback for average efficacy improvements)

Room Type	Operation (Hours/Day/Room)		Room Type	Operation (Hours/Day/Room)	
	Single-Family	Multifamily		Single-Family	Multifamily
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

For common areas in multifamily 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 multipurpose room is the same as for an office.

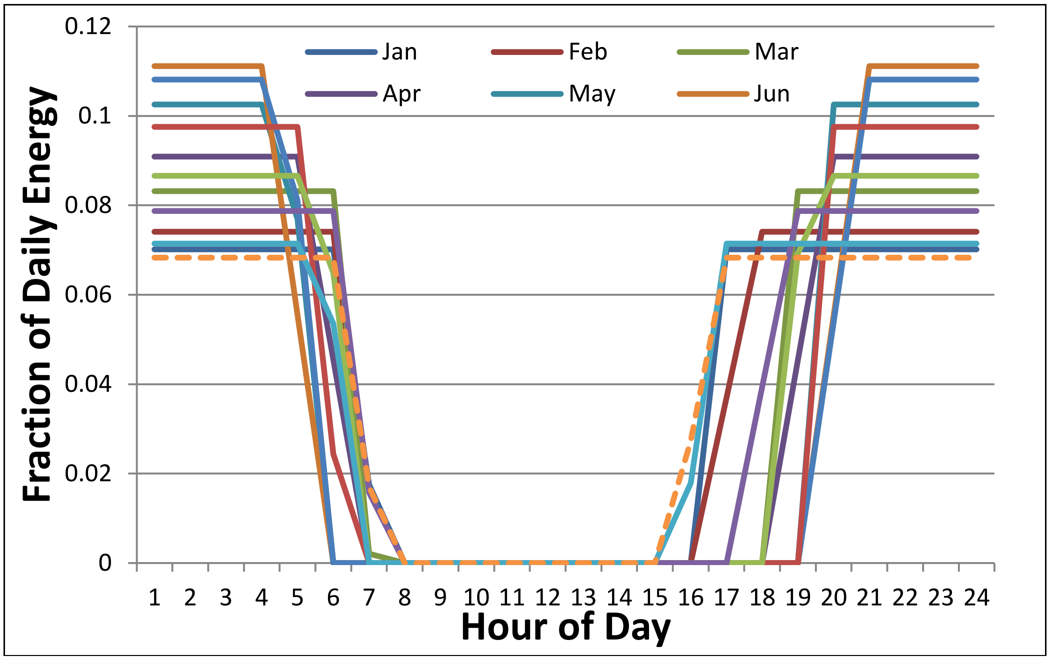


Figure 3. Normalized hourly profile for outdoor areas in multifamily housing

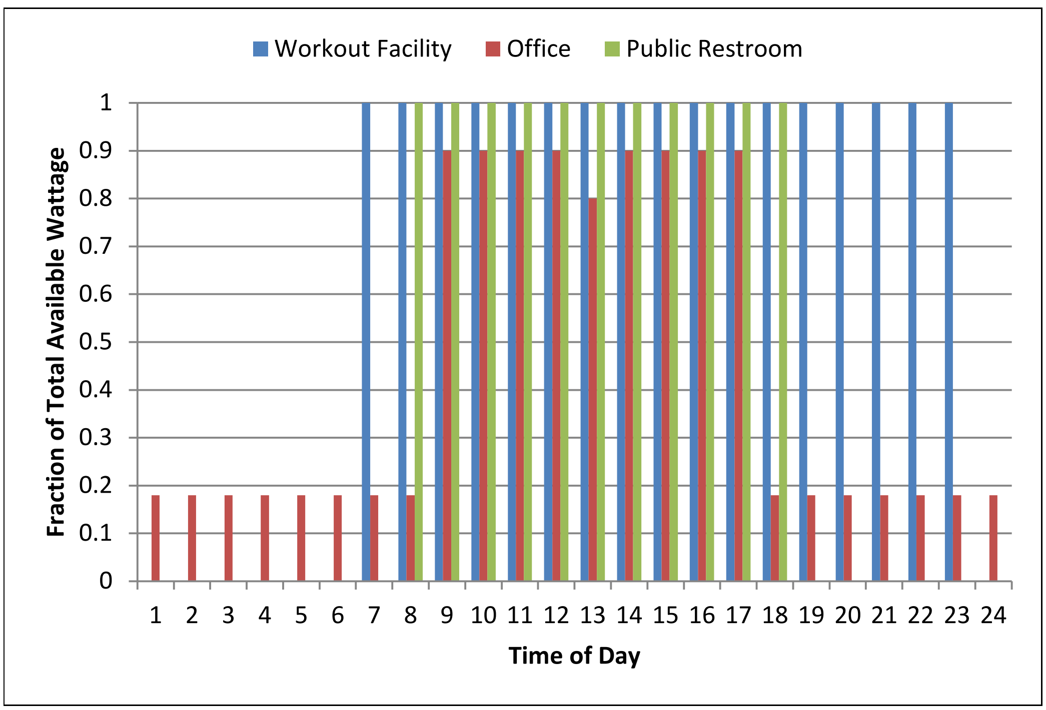


Figure 4. Multifamily common area usage fractions

2.1.8 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 25 (Jiang et al. 2008 and Sachs 2005 for multifamily). 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 multifamily building with a common laundry room). The Benchmark building has an electric cooking range and electric clothes dryer, regardless of appliance fuel types in the NCTH.

Table 25. Annual Appliance Loads and MELs for the Benchmark[1]

Appliance	Electricity (kWh/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
Dishwasher (8 place settings)	$87.6 + 29.2 \times N_{br}$	0.60	0.15
Range (electric)[a]	$250 + 83 \times N_{br}$	0.40	0.30
Miscellaneous electric loads[d]	$1185.4 + 180.2 \times N_{br} + 0.3188 \times FFA$	0.93	0.02
Large uncommon loads	see Table 26		
Multifamily Common Space MELs			
Office	3.2[b] × FFA	1.00	0.00
Workout room	9.8[b] × FFA	1.00	0.00
Corridor/restroom/mechanical	0		
Elevator	1,900	1.00	0.00
Multipurpose Room MELs			
Television	673[c]	1.00	0.00
Refrigerator	434	1.00	0.00
Dishwasher	52[b]	0.60	0.15
Range (electric)	62.4[b]	0.40	0.30
Microwave	78[b]	1.00	0.00

[a] Assuming 74% EF cooktop, 11% EF oven
[b] Assuming 1 h/wk use (data from appliance usage list from PSNH 2013)
[c] Assuming on during office hours (data from appliance usage list from PSNH 2013)
[d] Includes ceiling fans. If NCTH ceiling fans are accounted for separately, the MELs equation can be adjusted by subtracting 77.3 + 0.0403 × FFA.

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

[1] End-use loads in this table include only energy used within the machine. Associated DHW use is treated separately (see Section 2.1.4). 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.

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 refrigerators and freezers, which are assumed to be constant regardless of the number of bedrooms (see Table 26). The general relationship between appliance loads, number of bedrooms, and house size was derived empirically from the 2001 Residential Energy Consumption Survey (DOE 2001b).

Table 26. Large Uncommon Electric and Gas Loads in the Benchmark

Appliance	Average Units/ Household	Electricity (kWh/yr)	Natural Gas (therms/yr)	Sensible Load Fraction	Latent Load Fraction
Extra refrigerator	0.221	243.6		0.50	–
Freezer	0.342	319.8		0.50	–
Pool heater, gas	0.014		$3.00 \times F_{scale}$*	-	–
Pool heater, electric	0.004	$8.3 \times F_{scale}$		–	–
Pool pump	0.070	$158.5 \times F_{scale}$		–	–
Hot tub/spa heater, gas	0.011		$0.87 \times F_{scale}$	–	–
Hot tub/spa heater, electric	0.048	$49.0 \times F_{scale}$		–	–
Hot tub/spa pump	0.059	$59.5 \times F_{scale}$		–	–
Well pump	0.127	$50.8 \times F_{scale}$		–	–
Gas fireplace	0.032		$1.95 \times F_{scale}$	0.50	0.10
Gas grill	0.029		$0.87 \times F_{scale}$	–	–
Gas lighting	0.012		$0.22 \times F_{scale}$	–	–

*Where the scaling factor, $F_{scale} = (0.5 + 0.25\ N_{br}/3 + 0.25\ FFA/1920)$

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 27.

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. If NCTH ceiling fans are accounted for separately, the MELs equation in Table 25 can be adjusted by subtracting 77.3 + 0.0403 × FFA. 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 27. Example of Benchmark Annual Consumption for MELs

(based on an NCTH with three bedrooms and 1,920 ft^2)

Miscellaneous Electric Load	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Hard-Wired			
Ceiling fan	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
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
Boom box/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
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

Miscellaneous Electric Load	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Kitchen (continued)			
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
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

Miscellaneous Electric Load	Average Units/ Household	Energy/Unit (kWh/yr)	Energy/Household (kWh/yr)
Other (continued)			
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
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
Total MEL			**3373**

2.1.9 Site Generation

There is usually no on-site electricity generation in a 2010 vintage house. Therefore, all electricity for the Benchmark is purchased from the local utility.

2.2 Modeling the New Construction Test Home

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 ACH_{50} 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 multifamily 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 nonzero 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 8.5 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 NCTH has a hot water distribution system different from the Benchmark (see Table 13), 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.[2] These calculations are automated in the BA Analysis Spreadsheet. For any distribution system type not listed, other than centralized DHW in multifamily 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 12) 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 2003b), 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 15:

$$\text{Clothes washer cycles per year} = (392) \times (½+N_{br}/6) \times 12.5\ \text{lb}/W_{test} \quad (15)$$

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 16:

[2] When using the referenced equations, note that internal heat gain and recovery load should be restricted to non-negative values.

Clothes dryer cycles per year = DUF × clothes washer cycles per year (16)

where

DUF = 0.84.

The dishwasher annual operating cycles are similarly calculated, using Equation 17:

Dishwasher cycles per year = (215) × (½ + N_{br}/6) (17)

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). 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 28) 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 28. Useful Cooking Energy Output for Gas and Electric Ranges

Cooking Applicance	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.

3 Existing Homes

This section provides a 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 standard 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.

3.1 Analysis Tools Specific to Existing Buildings

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:

- Occupant behavior is extremely difficult to determine accurately during the 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).

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 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.

3.1.1 Modeling the Pre-Retrofit Case

3.1.1.1 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 (STEM) test 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, 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 29.
- R-values for cavity insulation in closed rafter roofs from Table 30.
- R-values for cavity insulation in floors over unconditioned space from Table 31.
- Insulation thickness in all other locations shall be measured. Nominal R-value for the measured thickness shall be determined using the National Residential Efficiency Measures Database (NREMD) (NREL 2013) or BEopt, which uses the NREMD. For reference, ranges of nominal R-value per inch values are shown in Table 32 (values depend on thickness, density, and application method).

Table 29. 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

Table 30. Default R-Values for Cathedral Ceilings/Cathedralized Attic Cavity Insulation

Roof Construction Type	Year of Construction 1990+	1980–1989	1950–1979	Pre-1950	Pre-1920
2 × 6	13	9	7	0	0
2 × 10	19	15	11	0	0

Table 31. 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

Table 32. Default R-Values for Common Insulation Types

(NREL 2013, DOE 2003a; REM/Rate Version 12.41)

Insulation Material	Nominal R-Value/in.
High density fiberglass batt	3.7–4.3/in.
Low density fiberglass batt	3.1/in.*
Loose fill fiberglass	2.4–2.8/ in.
Cellulose (blown, wet or dry)	3.2–4.3/in.
Expanded polystyrene (EPS)	4.8–5.0/in.
Extruded polystyrene (XPS)	5.0/in.
Open-cell polyurethane spray foam	3.6/in.
Closed-cell polyurethane spray foam	6.5–6.6/in.
Rigid polyisocyanurate	6.0/in.

*R-19 batts that are 6.25 in. thick and compressed to 5.5 in. to fit in a 2 × 6 cavity shall be derated to R-17.

- Installation quality of non-foam (e.g., fiberglass batt or loose-fill/blown cellulose, fiberglass, or mineral wool) wall insulation can be determined by thermographic inspection, following RESNET guidelines (RESNET 2012). If thermographic inspection is not completed, the installation quality is assumed to be Grade III (RESNET 2006). Wall assembly R-value shall be derated based on RESNET installation grade. Parallel path calculations shall include an air gap as follows:
    - Grade I: 0% of the cavity area is an air gap
    - Grade II: 2% of the cavity area is an air gap
    - Grade III: 5% of the cavity area is an air gap
- The default framing factors in Table 3 may be used for houses using wood construction.
- All vertical fenestration, including windows and sliding glass doors, shall be modeled using a BEopt option matching observed glazing type and frame type, or by looking up U-values and SHGCs from Tables 4 and 10, respectively, in Chapter 15 of ASHRAE Fundamentals (ASHRAE 2009), and using those as model inputs.
- Default solar absorptivity equal to 0.60 for opaque areas of exterior walls and from Table 33 for opaque areas of roofs.
- Default total infrared emittance of exterior walls and roofs equal to 0.90.

Table 33. 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

3.1.2 Space Conditioning 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 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 manufacturer's published data must be used, or default values if published performance data are not available.

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), values in Table 34 and Table 35 may be used. Typical values for AFUE were obtained from ASHRAE (2012), EPRI (1987), and the Technical Support Documents for the National Appliance Energy Conservation Act appliance standards (DOE 2007). Typical values for SEER, EER, and HSPF were obtained from the engineering analysis of appliance standards for air conditioners and heat pumps (DOE 2002a, DOE 2002b), 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 34. Default Air-Conditioning and Heat Pump Efficiencies

Type of Air-Conditioning or Heat Pump Equipment	Base SEER	Base EER	Base HSPF
Split central air conditioner, two-speed reciprocating compressor, electronically commutated air handler motor (brushless permanent magnet [BPM]), thermostatic expansion valve, fan coil	14	10.5	
Split central air conditioner, single-speed scroll compressor, BPM air handler motor, cased coil	12	10.8	
Split central air conditioner, single-speed reciprocating compressor, permanent split capacitor (PSC) air handler motor, cased coil (after 1991)	10	9.3	
Split central air conditioner, single-speed reciprocating compressor, PSC air handler motor, cased coil (1981–1991)	8	7.7	
Split central air conditioner, single-speed reciprocating compressor, PSC air handler motor, cased coil (before 1981)	6.5	6.4	
Split heat pump, single-speed scroll compressor, BPM air handler motor, thermostatic expansion valve	14	10.5	8.0
Split heat pump, single-speed reciprocating compressor, PSC air handler motor (after 1991)	10	9.3	7.1
Split heat pump, single-speed reciprocating compressor, PSC air handler motor (1981–1991)	8	7.7	6.6
Split heat pump, single-speed reciprocating compressor, PSC air handler motor (before 1981)	6.5	6.4	6.0
Packaged central air conditioner, single-speed reciprocating compressor, PSC air handler motor	10	9.1	
Packaged heat pump, single-speed reciprocating compressor, PSC air handler motor	10	9.1	6.8
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor, < 20,000 Btu/h (after 1991)		9.75	
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor, ≥ 20,000 Btu/h (after 1991)		8.5	
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor (1981–1991)		7.5	
Room air conditioner, louvered sides, cooling only, single-speed compressor, PSC fan motor (before 1981)		6.5	
Room electric heat pump, louvered sides, single-speed compressor, PSC fan motor, < 20,000 Btu/h		9	7.1
Room electric heat pump, louvered sides, single-speed compressor, PSC fan motor, ≥ 20,000 Btu/h		8.5	6.8
Direct evaporative cooling		25	

Table 35. Default Furnace and Boiler System Efficiencies

Type of Space Heating Equipment	Base AFUE[a]
Condensing gas[b] furnace	90
Gas furnace, direct vent or induced draft combustion, electronic ignition, in conditioned space	80
Gas furnace, natural draft combustion, vent damper, electronic ignition, in conditioned space	78
Gas furnace, natural draft combustion, standing pilot light, in conditioned space	75
Gas furnace, natural draft combustion, standing pilot light, no vent damper, in unconditioned space	64
Gas hot water boiler, natural draft combustion, standing pilot light, vent damper	80
Gas steam boiler	75[c]
Condensing gas boiler or condensing tank/tankless combo system	90
Gas hot water/fan coil combo system	80
Gas boiler/tankless coil combo system	80
Gas space heater, fan type	73
Gas space heater, gravity type	60
Oil furnace, flame retention burner, vent dampers, in conditioned space	81
Oil furnace, conventional burner, no vent dampers, in conditioned space	71
Oil hot water boiler, induced draft combustion, vent damper	80
Oil steam boiler	82
Electric resistance furnace or boiler, conditioned space	100
Electric resistance furnace or boiler, unconditioned space	98
Electric resistance baseboard heating	100
Electric space heater	100

[a] Combined Appliance AFUE or combo systems. AFUE values for gas furnaces from 2012 ASHRAE HVAC Systems and Equipment (I-P Edition), Chapter 33, Table 1.
[b] Gas refers to either natural gas or propane
[c] Source: 1987 National Appliance Energy Conservation Act

Preliminary data on gas furnaces (Brand et al. 2013) show no relationship between equipment age and efficiency degradation. Air conditioners and heat pumps are known to degrade because of poor installation quality, lack of maintenance, and/or age; however, there is not enough data to establish a relationship between equipment age and performance degradation. Analysts should attempt to adjust equipment efficiency (SEER, EER, and HSPF) based on any available data.

Parker et al. (1997) provides a basis for adjusting air conditioner performance based on reduced evaporator airflow rate.

Auxiliary electricity use for furnaces and boilers, including draft fans and controls, shall be measured directly if possible. If accurate measurements cannot be made, the default values of auxiliary electricity use in Table 36 may be used.

Table 36. Default Heating System Auxiliary Electricity Consumption

(Source: DOE 2007)

Type of Heating Equipment	Induced Draft Fan Power (W)
Gas furnace, natural draft	0
Gas furnace, induced draft	75
Gas furnace, condensing	90
Oil furnace, condensing and non-condensing	220
Gas hot water boiler, condensing and non-condensing	76
Oil hot water boiler, condensing and non-condensing	220

A cooling system shall be included in the Pre-Retrofit Case model only 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.

3.1.3 Distribution System

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, 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 (2004).

For houses with hydronic space heating or cooling systems, if the distribution losses are not modeled explicitly, a distribution efficiency of 95% can be assumed and applied to the appliance efficiency, representing a small amount of energy loss through the pipes.

3.1.4 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. If recovery efficiency and standby losses are required for modeling (e.g., to use for TRNSYS inputs), they can be measured using the procedures described by LBNL (Szydlowski and Cleary 1988). If EF cannot be determined by making direct measurements or examining the published performance data, the default specifications in Table 37 may be used. These defaults were largely derived from technical support documents for the Federal appliance standard for water heaters (DOE 2000a). Preliminary data on water heaters (Goetzler et al. 2012) show no relationship between equipment age and efficiency degradation.

Table 37. Default DHW EFs, Based on Known Equipment Characteristics

Type of Water Heating Equipment	Base EF
Gas[a] water heater, 40-gal tank, pilot light, natural draft combustion, poorly insulated, no heat traps, no flue baffling	0.45
Gas water heater, 40-gal tank, pilot light, natural draft combustion, 1-in. insulation, no heat traps, standard flue baffling	0.54
Gas water heater, 40-gal tank, intermittent ignition, induced draft combustion, 3 in. insulation, heat traps, enhanced flue baffling, flue/vent dampers	0.64
Gas water heater, 40-gal tank, ENERGY STAR® rating	0.67
Gas tankless water heater[b]	0.76
Oil water heater, 32-gal tank, intermittent ignition, induced draft combustion, poorly insulated, no heat traps, poor heat recovery from flue	0.53
Oil water heater, 32-gal tank, interrupted ignition, induced draft combustion, 3-in. insulation, heat traps, enhanced flue baffling	0.61
Electric water heater, 50-gal tank, poorly insulated, no heat traps	0.79
Electric water heater, 50-gal tank, 1.5-in. insulation, heat traps	0.87
Electric water heater, 50-gal tank, 3-in. insulation, heat traps	0.90
Electric tankless water heater[b]	0.91

[a] Gas refers to either natural gas or propane
[b] Tankless water heaters are derated by 8% due to thermal losses that aren't reflected in the standard DOE rating procedure.

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 and Erickson 2004). Five major end uses have been identified for DHW: showers, sinks, baths, dishwasher, and clothes washer (see Table 38). 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 38. 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	Use analysis spreadsheet	0[a]	0[a]
Common laundry	Water heater set point	Use analysis spreadsheet	0[a]	0[a]
Dishwasher	Water heater set point	Use analysis spreadsheet	0[a]	0[a]
Shower	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[b]
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)

[a] Sensible and latent heat gains from appliances are included in Section titled, 2.1.8.
[b] Negligible compared to showers and sinks.

If no EnergyGuide label is available, the default EF values for dishwashers (see Table 39) or modified energy factor for clothes washers (see Table 40) shall be used for the Pre-Retrofit Case.

Table 39. Default Dishwasher Characteristics

Equipment Characteristics	EF (load/kWh)
Power dry optional, multitier spray device, load size and soil level controls	0.6
Power dry optional, multitier 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 40. 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 multifamily housing shall comply with the guidelines in the New Homes section.

3.1.5 Air Infiltration

The ACH_{50} 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 ACH_{50}, an annual average natural infiltration rate may be used based on the guidelines in ASHRAE (1988), Section 5, and ASHRAE (1993), Section 4.

3.1.6 Mechanical Ventilation

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, supplemented with measured flow rates, if available.

3.1.7 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 Section 2.1.7. When using the simplified approach (Option 1), the Pre-Retrofit lighting energy shall be calculated using Equations 6–12, 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. If the home is unoccupied at the time of the pre-retrofit lighting audit, the pre-retrofit model should include additional plug-in lighting to meet IESNA illumination levels (Rea et al. 2000). If the home is occupied at the time of the lighting audit, no additional lighting is necessary; actual installed lighting levels should be used for the analysis. The BA Analysis Spreadsheet shall be used to calculate lighting energy for the Pre-Retrofit case when using Option 2.

3.1.8 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 and Cleary 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 are not available for certain major appliances (e.g., ovens and clothes dryers), the default EFs in Table 41 through Table 45 shall be used. These defaults were derived from historical appliance efficiency studies (DOE 2004a; 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 28) 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 41. 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 42. 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 43. 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 44. 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: nonreflective pans, rounded coil elements **Oven: not self-cleaning, standard door seals, standard vent rate, standard insulation**	Cooktop: 73.7% Oven: 10.9%

Table 45. Default Internal Loads From Appliances and MELs 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	0.74	0.02

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. Improvements to the large, uncommon electric and gas loads (listed in Table 26) can be modeled in BEopt, starting with version 2.1.

The fraction of end-use energy converted into internal sensible and latent loads is shown in Table 45. 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 and MELs in common areas of multifamily housing, the same guidelines described for new homes shall be used.

3.1.9 Site Generation

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

3.2 Modeling the Post-Retrofit Case

The retrofits in the Post-Retrofit Case shall be modeled either as-designed or as-implemented, 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 ACH_{50} 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 ACH_{50}, 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 annual simulations, but is often the only information that is publicly available about a cooling system.

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 2004b), 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 18:

$$\text{Clothes washer cycles per year} = (392) \times (½ + N_{br}/6) \times 12.5\ \text{lb}/W_{test} \quad (18)$$

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 19:

$$\text{Clothes dryer cycles per year} = \text{DUF} \times \text{Clothes washer cycles per year} \quad (19)$$

where

DUF = 0.84.

The dishwasher annual operating cycles are similarly calculated, using Equation 20:

$$\text{Dishwasher cycles per year} = (215) \times (½ + N_{br}/6) \quad (20)$$

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). Annual average and monthly average hot water uses are calculated.

Energy savings for a new range or oven may be credited only 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 28) divided by the EF, 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 Case 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 Section 2.1.7. 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. A reduction from Pre-Retrofit illumination levels is allowed as long as the Post-Retrofit level meets IESNA guidelines (Rea et al. 2000). 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.

4 Standard Operating Conditions

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

For technologies such as ceiling fans that are designed to save energy by enabling a change in operating conditions, the NCTH may use operating conditions that differ from those required for the Benchmark building. A published reference that proves those specific operating conditions can be changed and maintain occupant comfort, must be included in the analysis section of the related reports for the team to implement those changes in BEopt. The Benchmark shall always use the operating conditions outlined below.

4.1 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.

4.2 Space Conditioning

Thermostat set points based on the optimum seasonal temperature for human comfort as defined in ASHRAE Standard 55-2010 (ASHRAE 2010a).

Set point for cooling: 76°F with no setup period

Set point for heating: 71°F with no setback period

Takeback, setup and setback are not included in the analysis of thermostat set points because more analytical data are needed in this area (Greening et al. 2000).

Heating and cooling shall occur only during certain months of the year in accordance with the guidelines presented below. 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 typical meteorological year (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 MAT < 66°F.

The cooling system shall be enabled for a month in which MAT ≥ 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 ≤ 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.

Dehumidification shall be simulated in homes that have dehumidifiers (NCTH, Pre-Retrofit, or Post-Retrofit, but not Benchmark). Set point for dehumidification: 60% relative humidity (no lower limit).

4.2.1 Natural Ventilation for Cooling

The Benchmark natural ventilation schedule shall be set to reflect windows being opened occasionally. In situations where it is a Monday, Wednesday, or Friday and there is a cooling load, windows will be opened if the cooling capacity of 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 natural ventilation rate 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 below the temperature specified in Table 46, or if the air change rate exceeds 20 air changes per hour.

Table 46. Natural Ventilation Seasonal Temperature Limits

Season	Windows Close if Indoor Temperature Drops Below:
Heating only	75°F (1°F *below* cooling set point)
Cooling only	72°F (1°F *above* heating set point)
Both heating and cooling enabled	72°F (1°F *above* heating set point)

4.2.2 Operation of Shading Devices

Solar gains through windows shall be modified by a constant interior shading multiplier of 0.7, meaning that all solar gains are reduced by 30% through use of blinds, shades, or curtains.

4.3 Domestic Hot Water

The hot water set point shall be 125°F, and the mixed temperature for showers, sinks, and baths shall be 110°F. This set point is based on field data (Lutz and Melody 2012) and the 2010 federal rulemaking for residential water heaters (DOE 2010).

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.

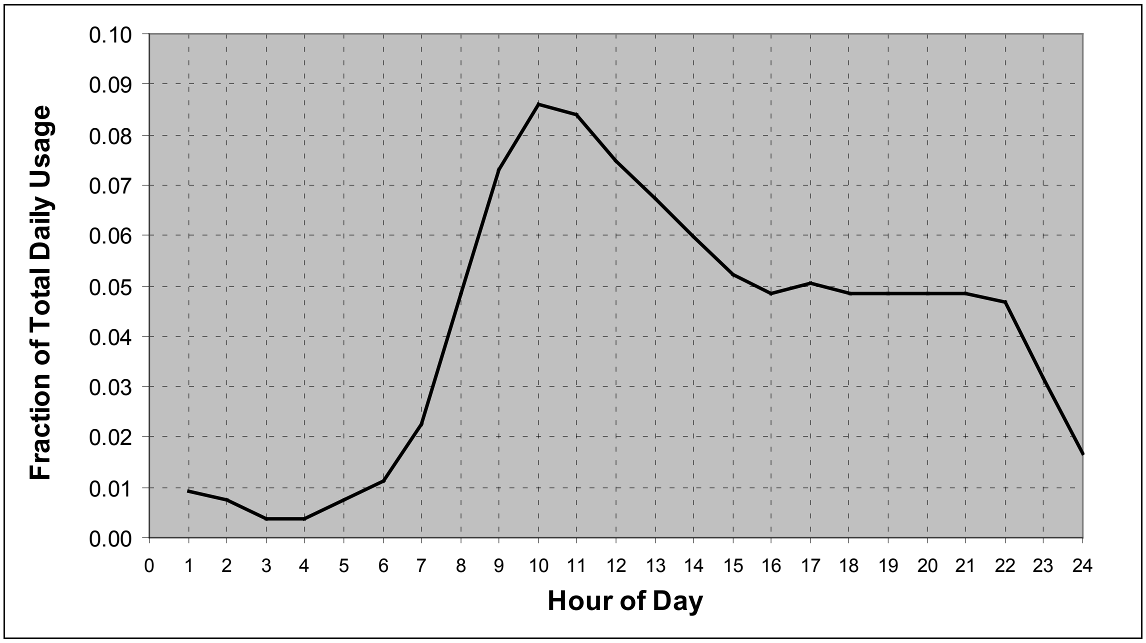


Figure 5. Clothes washer hot water use profile

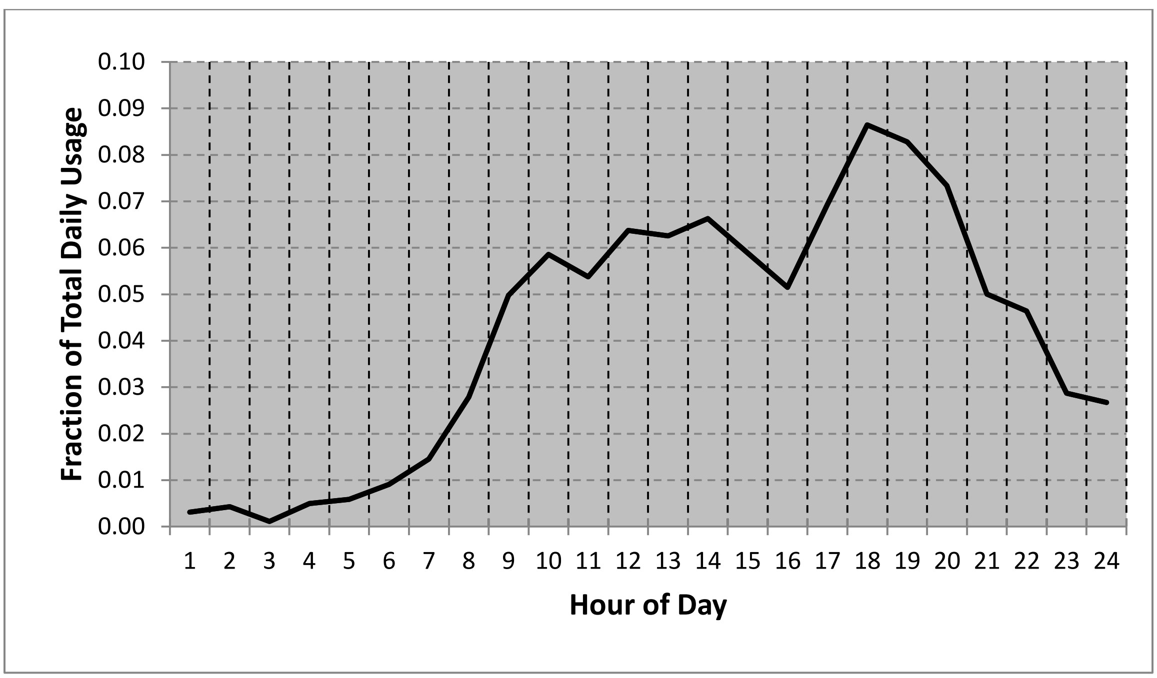


Figure 6. Multifamily common laundry hot water use profile: weekday

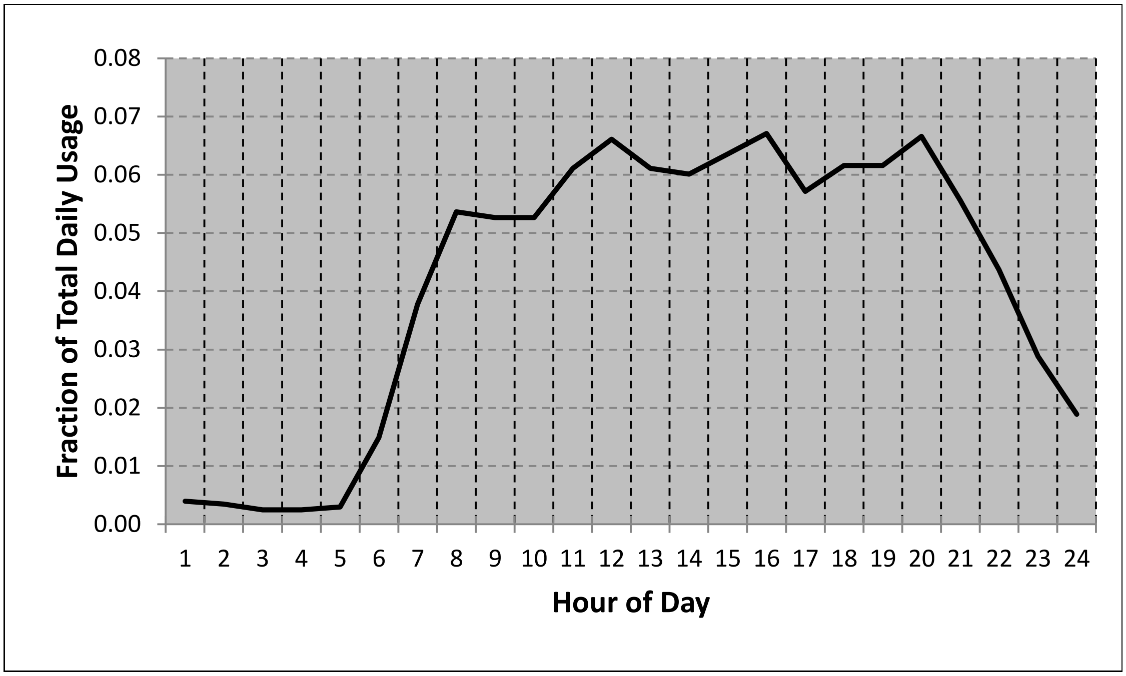


Figure 7. Multifamily common laundry hot water use profile: weekend

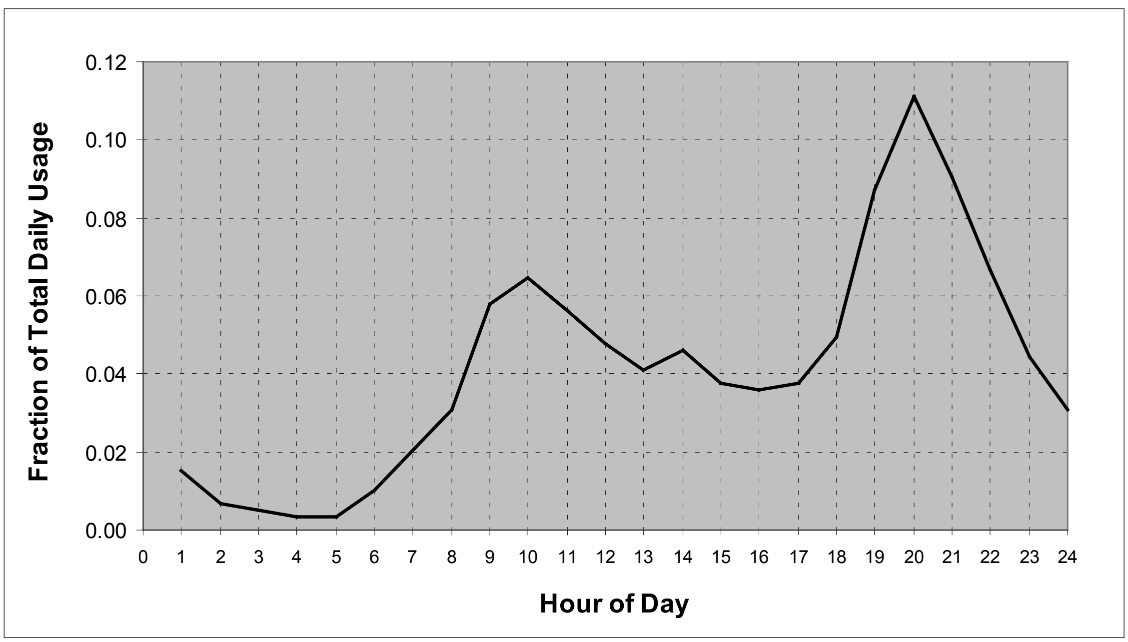


Figure 8. Dishwasher hot water use profile

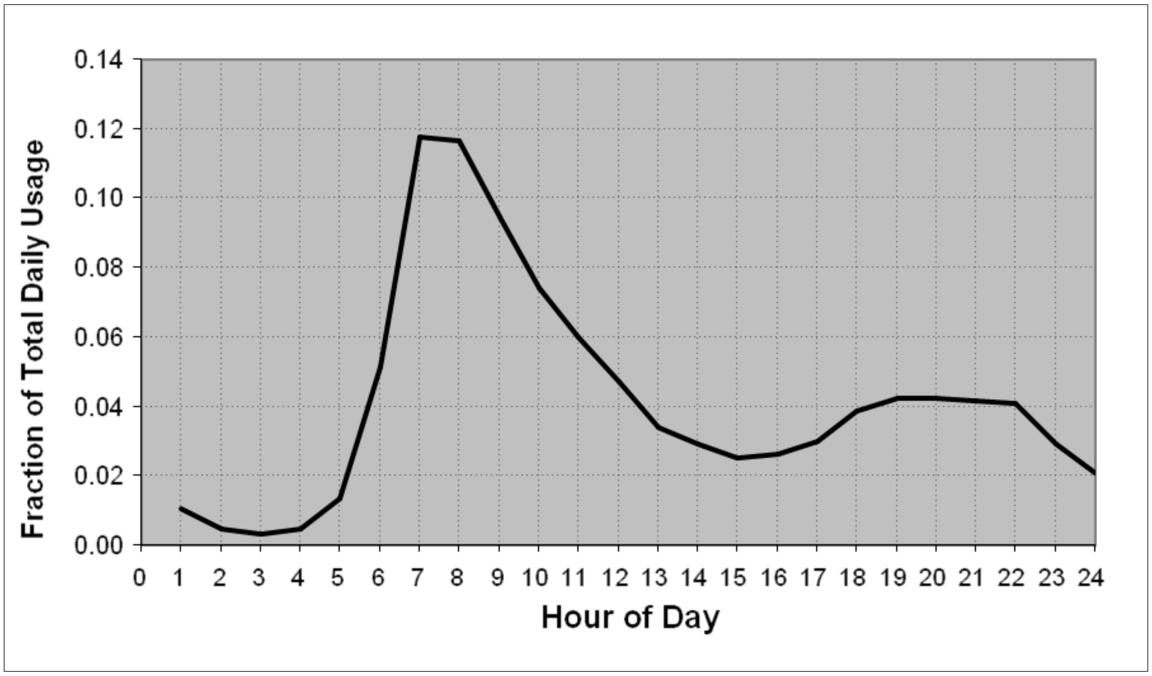


Figure 9. Shower hot water use profile

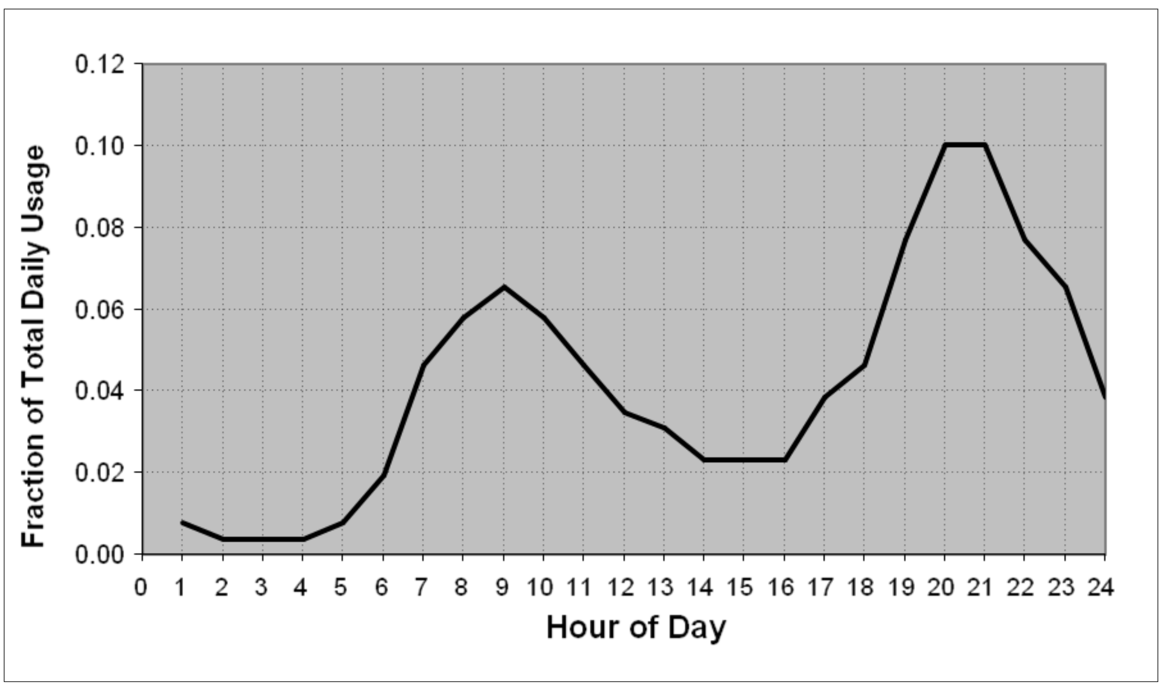


Figure 10. Bath hot water use profile

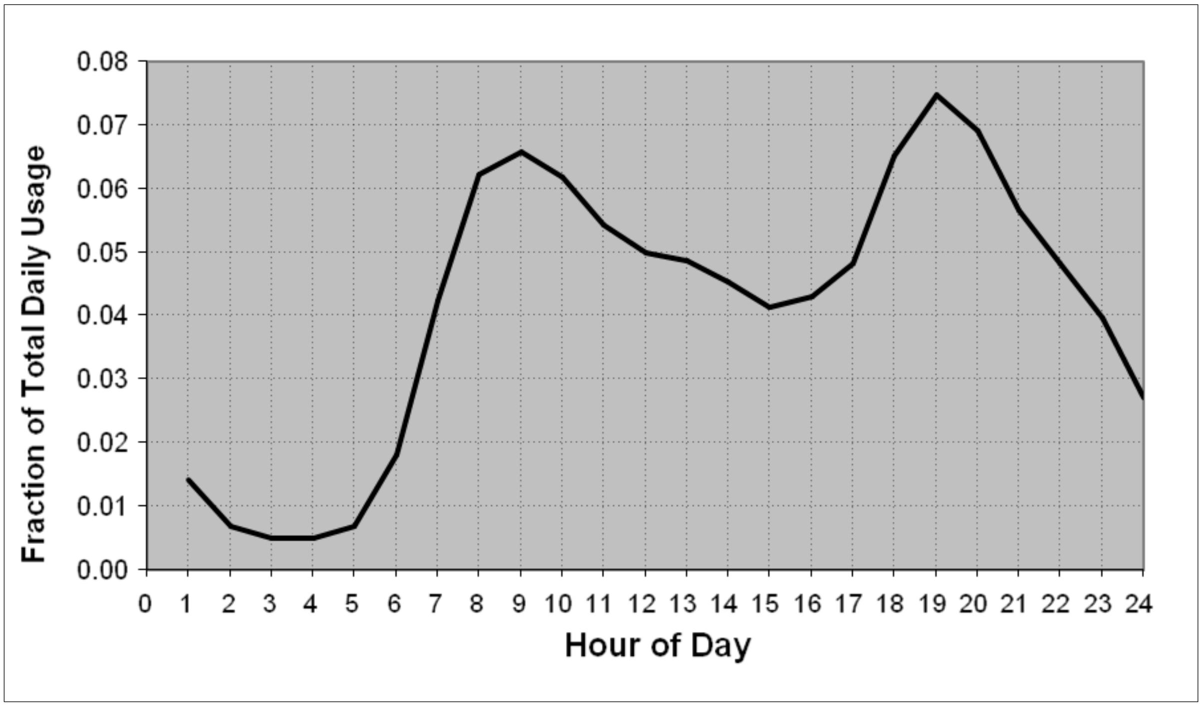


Figure 11. Sink hot water use profile

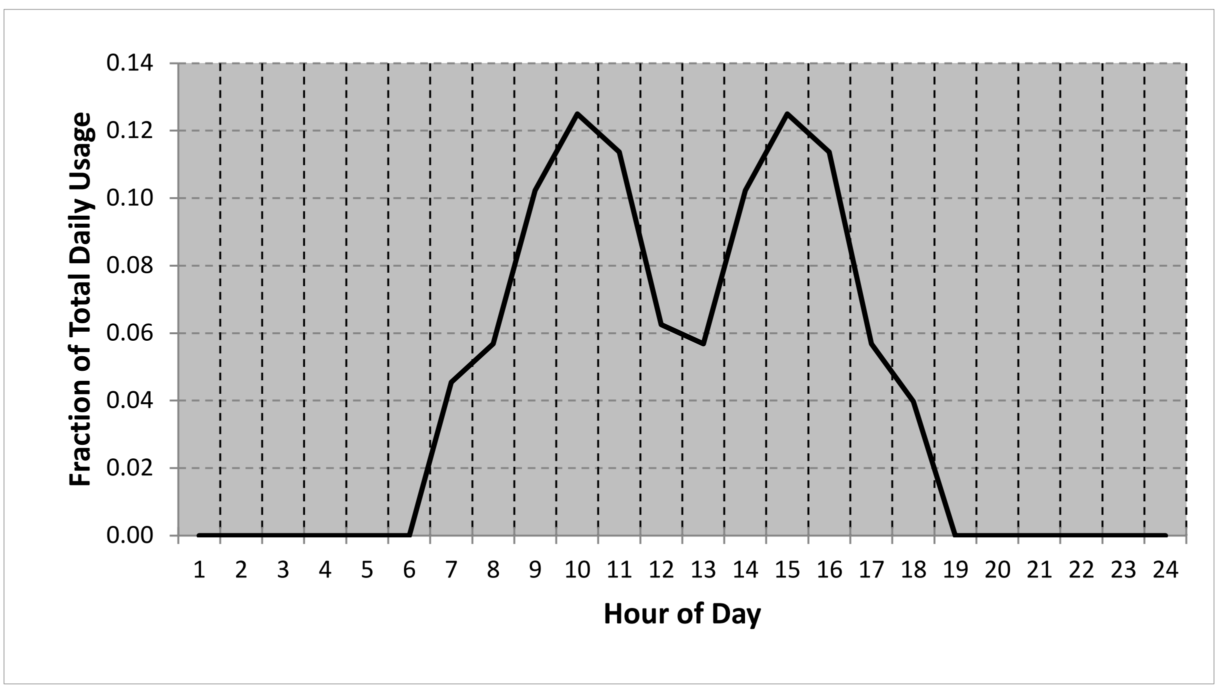


Figure 12. Central restroom sink hot water use profile

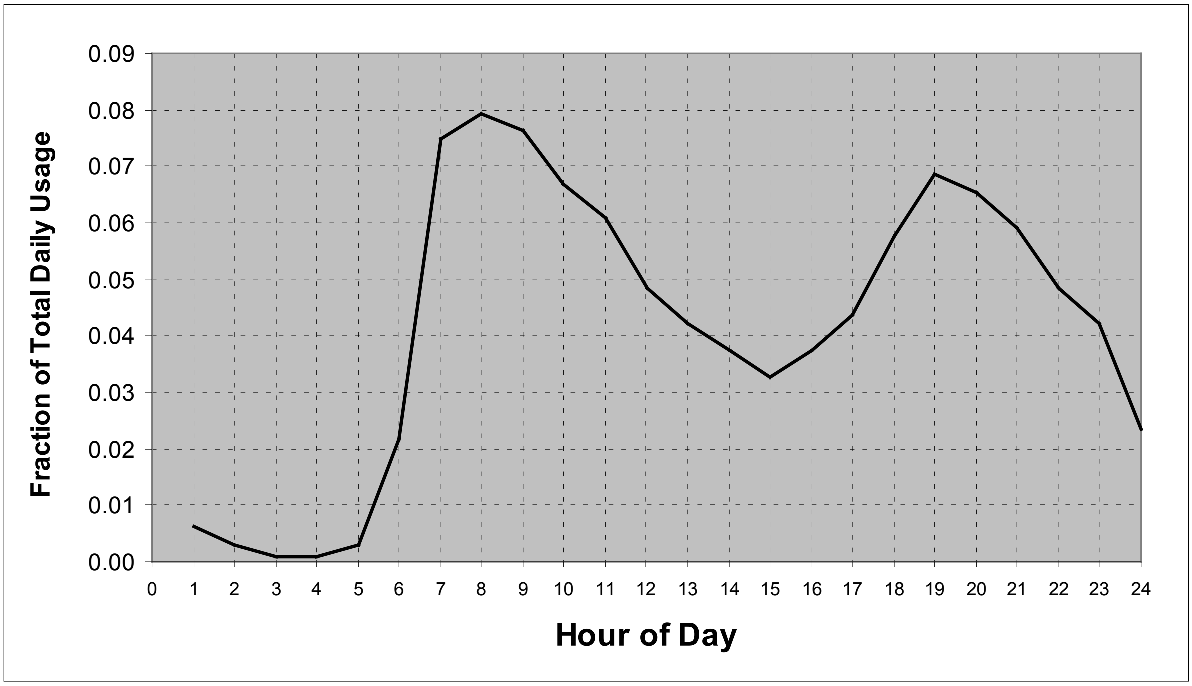


Figure 13. Combined DHW use profile

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).

For the central restroom in a multifamily 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 11, 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 multifamily homes with in-unit clothes washers are summarized in Table 47. 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 47. 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 21, based on TMY3 data for the location of the Test House, shall be used to determine the daily mains water temperature for all models:

$$T_{mains} = (T_{amb,avg} + \text{offset}) + \text{ratio} \times (T_{amb,max}/2) \times \sin(0.986 \times (\text{day\#} - 15 - \text{lag}) - 90) \quad (21)$$

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 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 21 shall be calculated using Equation 22.

$$\text{day\#} = 30 \times \text{month\#} - 15 \quad (22)$$

where

month# = month of the year (1–12)

An example using Equations 21 and 22 to determine the monthly mains temperature profile for Chicago, Illinois, is shown in Figure 14.

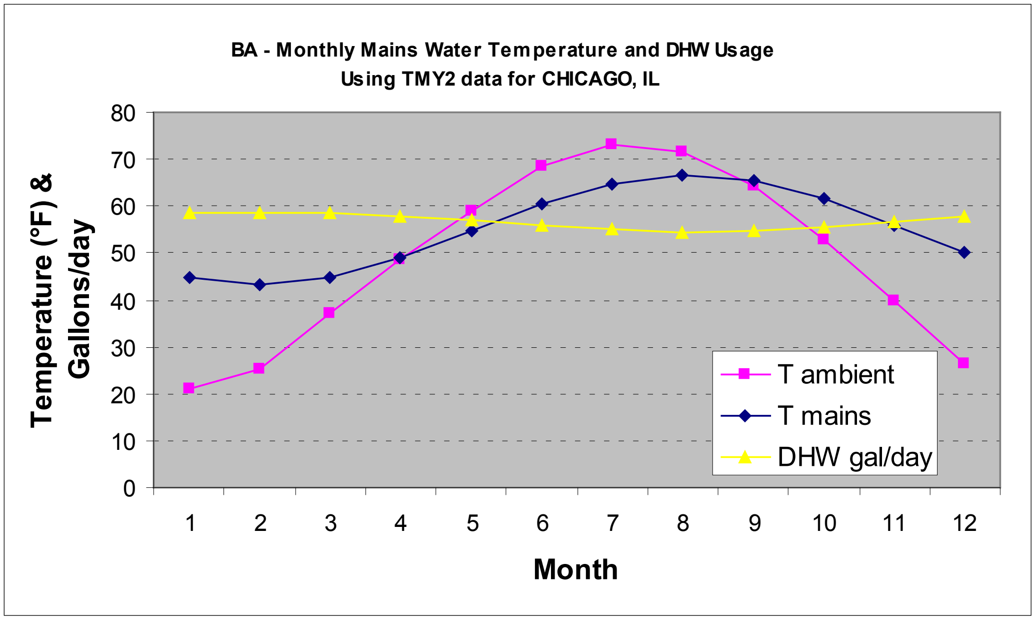


Figure 14. Mains temperature profile for Chicago

4.4 Lighting

Operating conditions for lighting are closely tied to the lighting design, and are addressed in Sections 2.1.7 and 3.1.7.

4.5 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 electricity 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 Figure 16 to Figure 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.

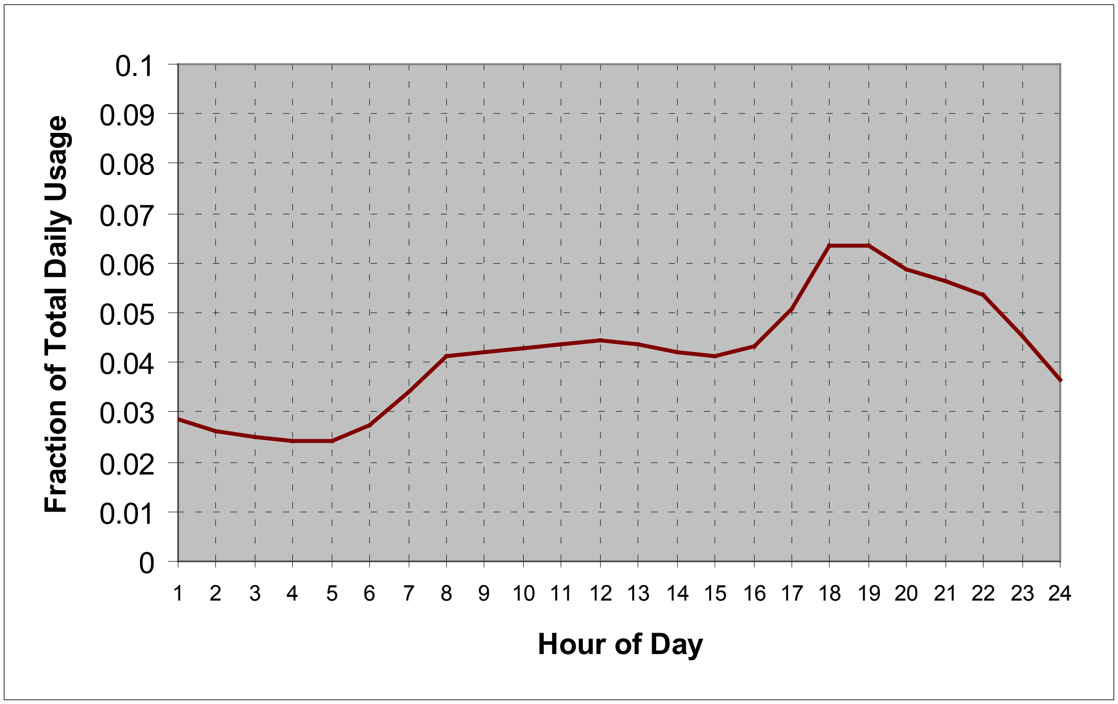


Figure 15. Total combined residential equipment profile

(Pratt et al. 1989)

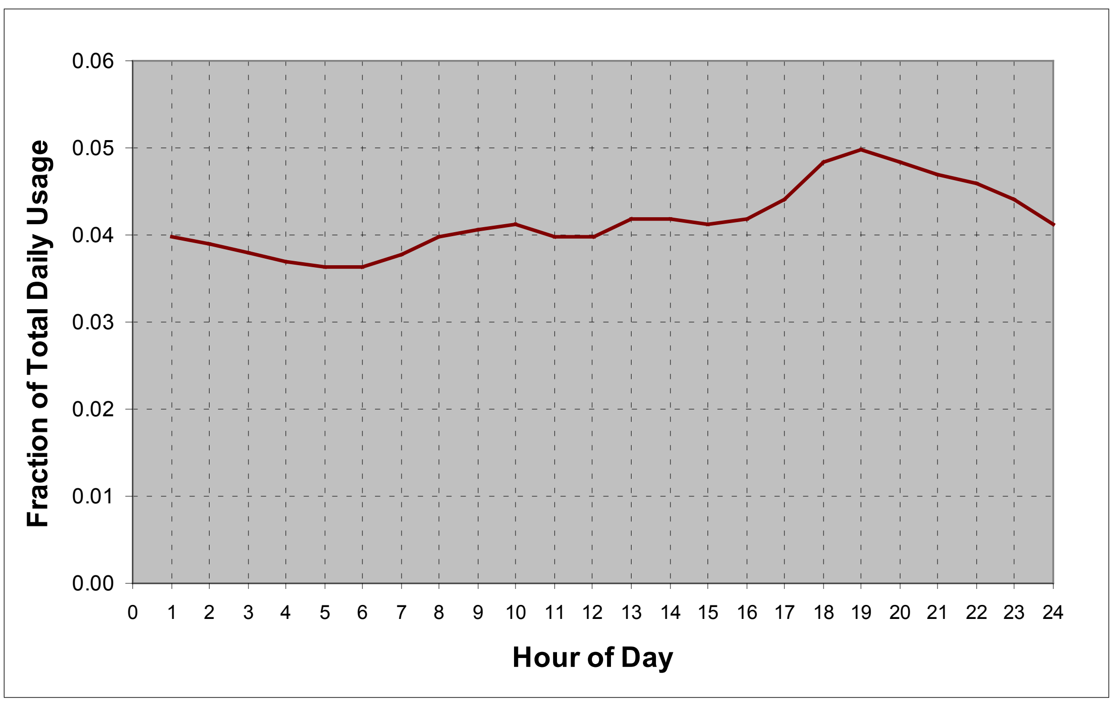


Figure 16. Refrigerator normalized energy use profile

(Pratt et al. 1989)

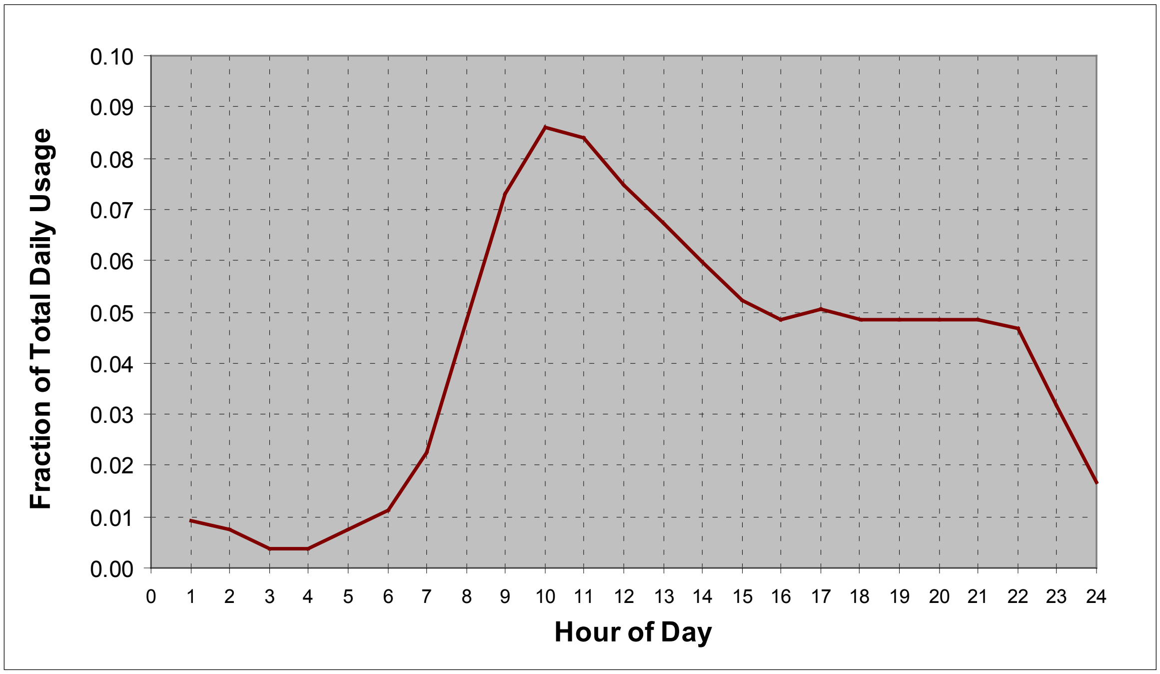


Figure 17. Clothes washer normalized machine energy use profile

(Pratt et al. 1989)

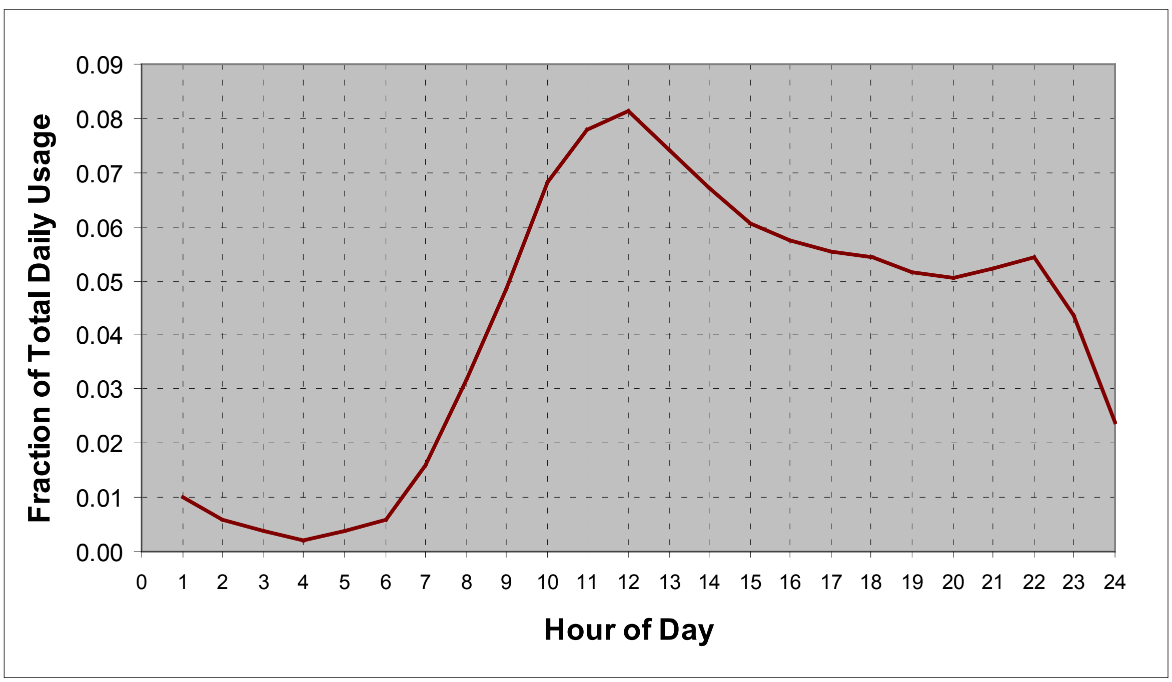


Figure 18. Clothes dryer normalized energy use profile

(Pratt et al. 1989)

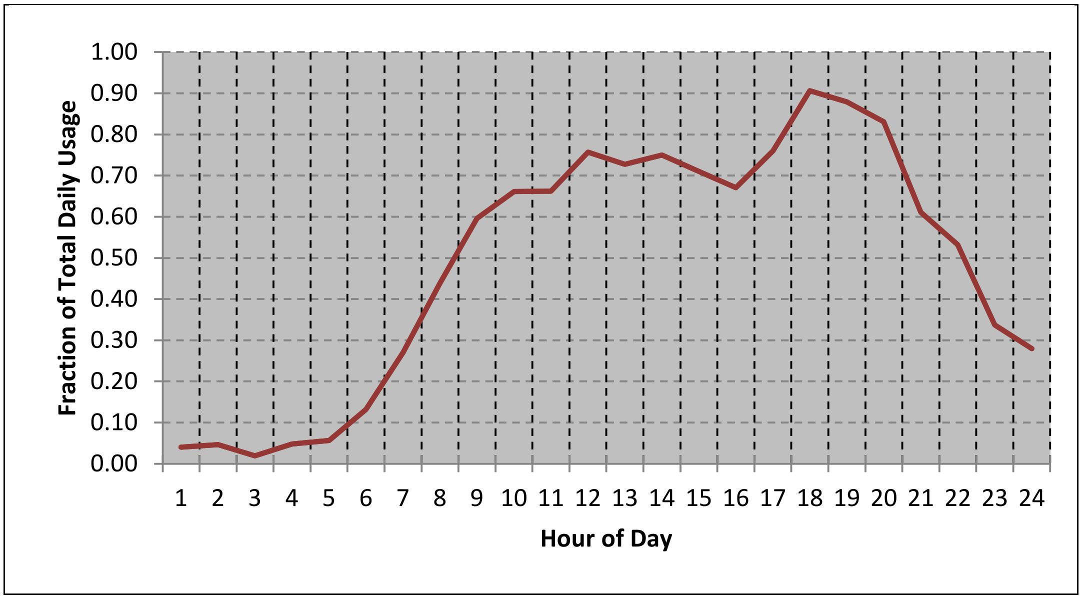


Figure 19. Common laundry clothes washer normalized energy use profile

(Toronto 1999)

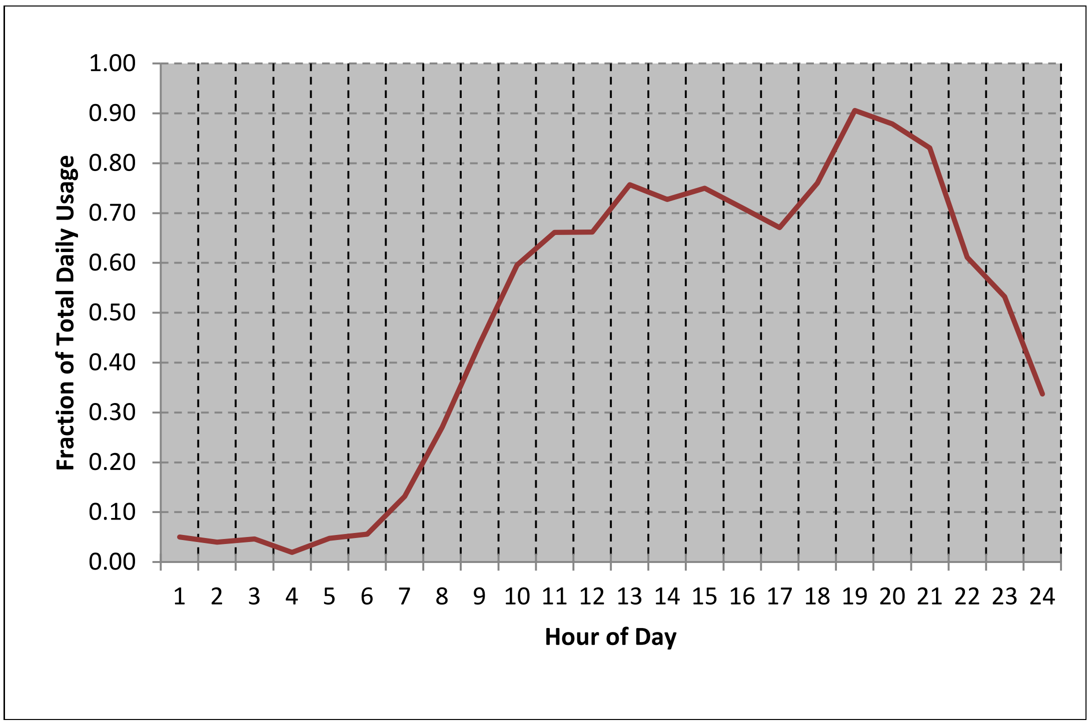


Figure 20. Common laundry clothes dryer normalized energy use profile

(shifted one hour relative to clothes washer)

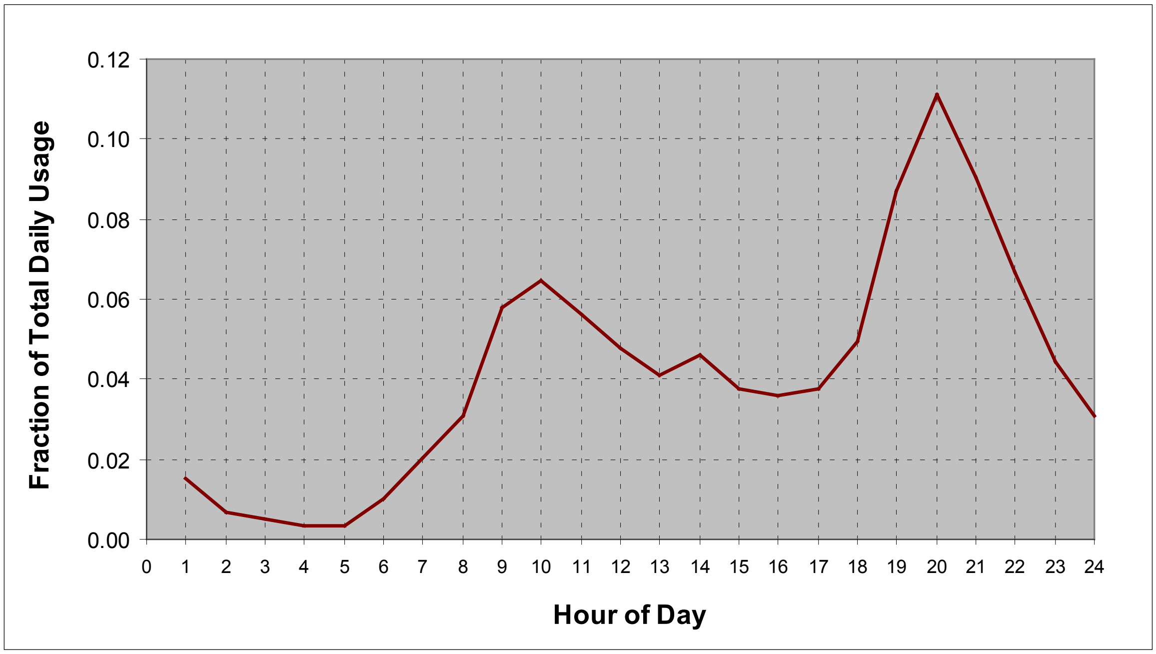


Figure 21. Dishwasher normalized energy use profile

(Pratt et al. 1989)

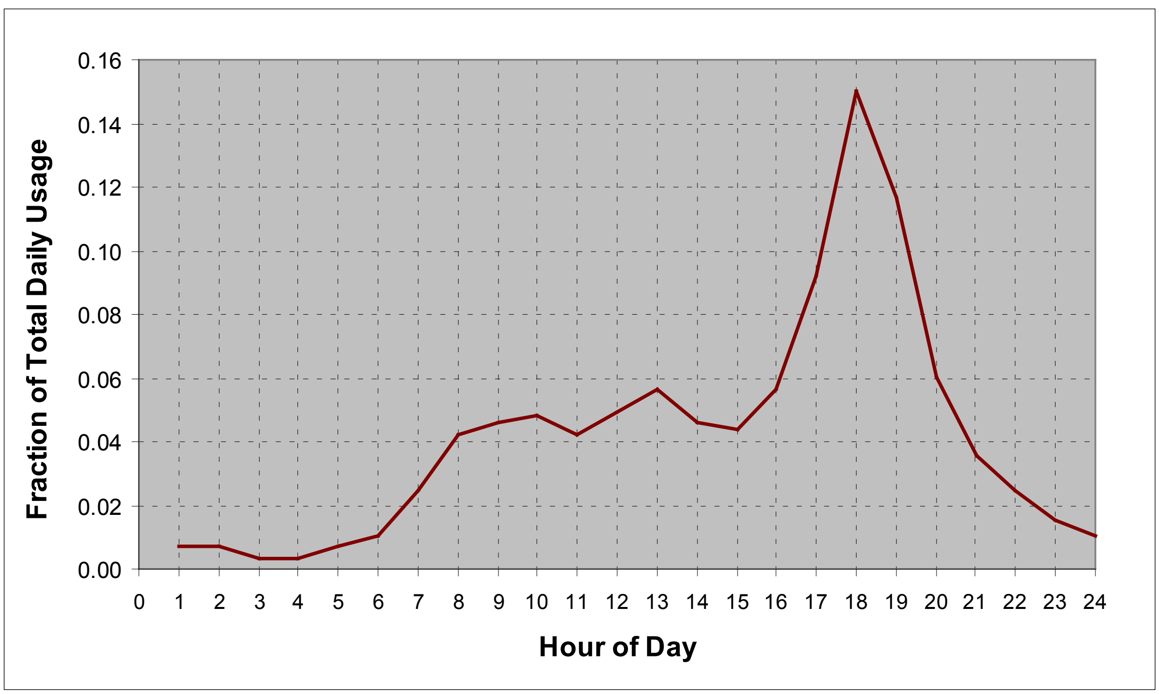


Figure 22. Range/oven normalized energy use profile

(Pratt et al. 1989)

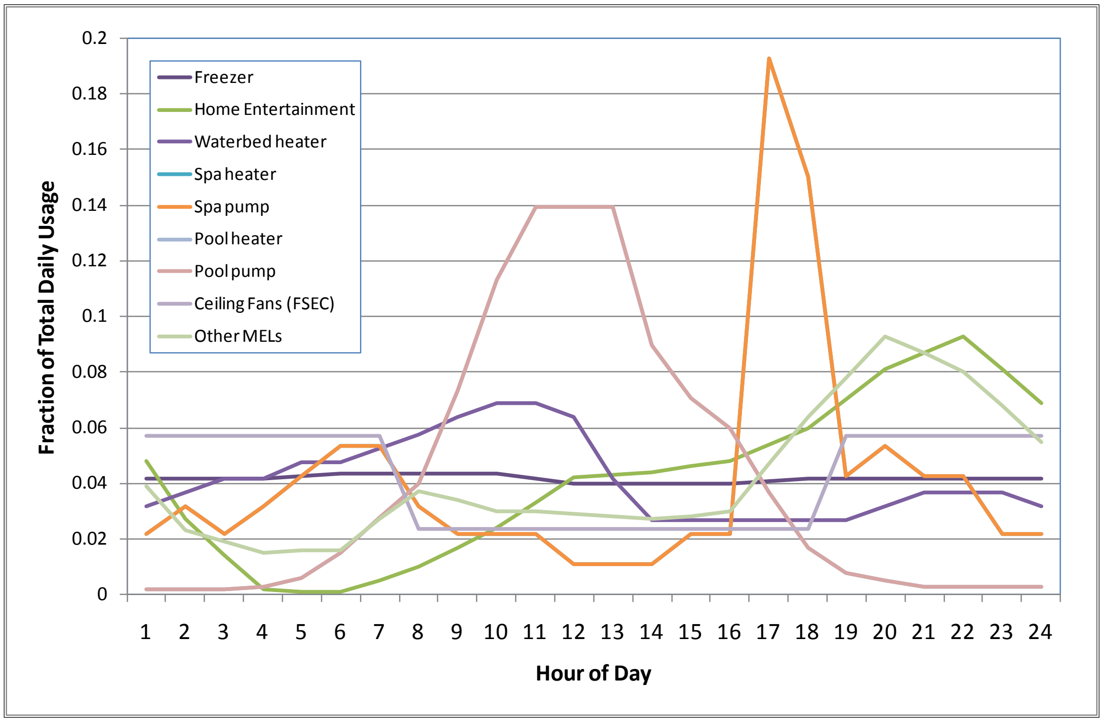


Figure 23. MELs normalized energy use profile

(Mills 2008)

All hourly end-use profiles were taken from Pratt et al. (1989), except the profile for ceiling fans (Parker et al. 2010), and MELs (Mills 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 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.

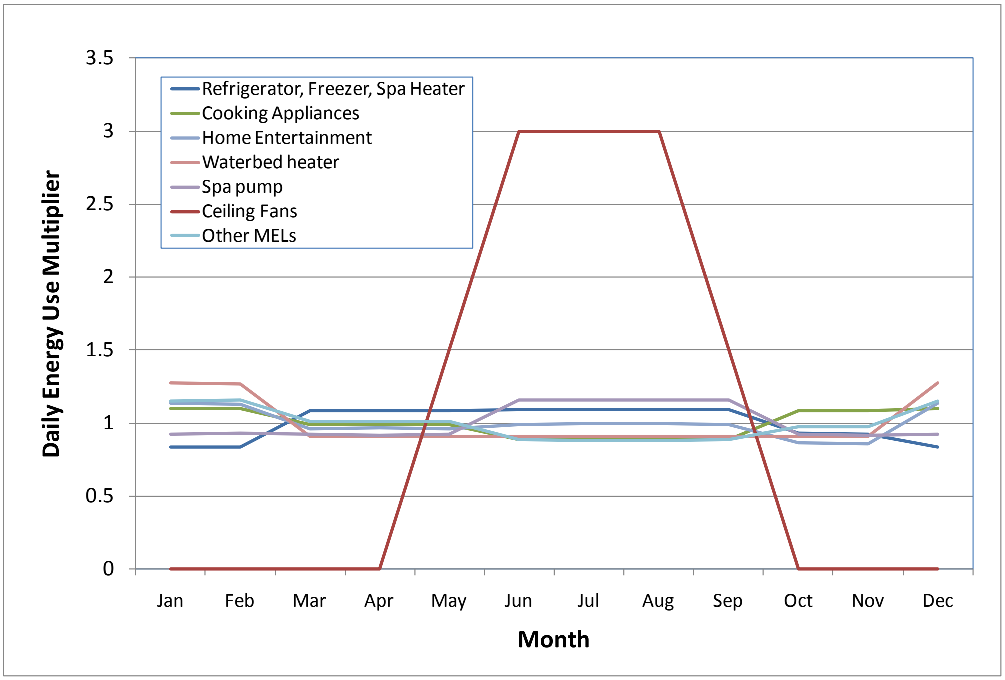


Figure 24. Seasonal multipliers for appliances and MELs

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

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

4.6 Occupancy

The number of occupants in single-family and multifamily dwellings during nonvacation periods shall be estimated based on the number of bedrooms using Equations 23 and 24, respectively.

$$\text{Number of occupants} = 0.59 \times N_{br} + 0.87 \quad (23)$$

$$\text{Number of occupants} = 0.92 \times N_{br} + 0.63 \quad (24)$$

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 48). 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 48. Peak Sensible and Latent Heat Gain From Occupants

(ASHRAE 2009)

Zone Type	Internal Load (Btu/person/h)	
	Sensible Load	Latent Load
Single-zone model	220	164
Multiple-zone model		
Living area	230	190
Bedroom area	210	140
Common laundry	250	200
Office	250	200
Workout room	710	1090
Central restroom	245	155

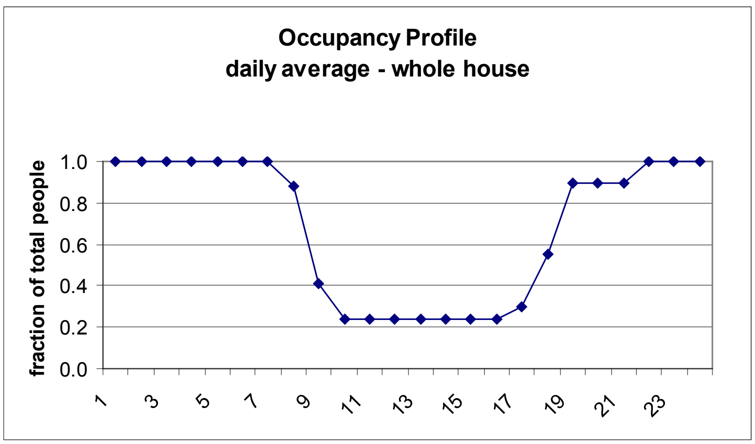


Figure 25. Average hourly load profile from occupants for all day types and family types

(16.5 h/day/person total)

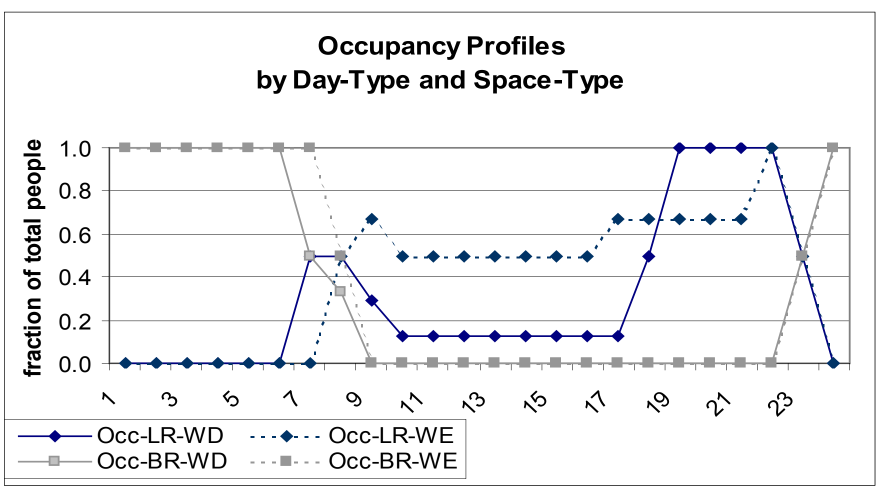


Figure 26. Detailed hourly load profiles resulting from occupants being in different parts of the house on weekdays (WD) and weekends (WE)

For common areas in multifamily 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.

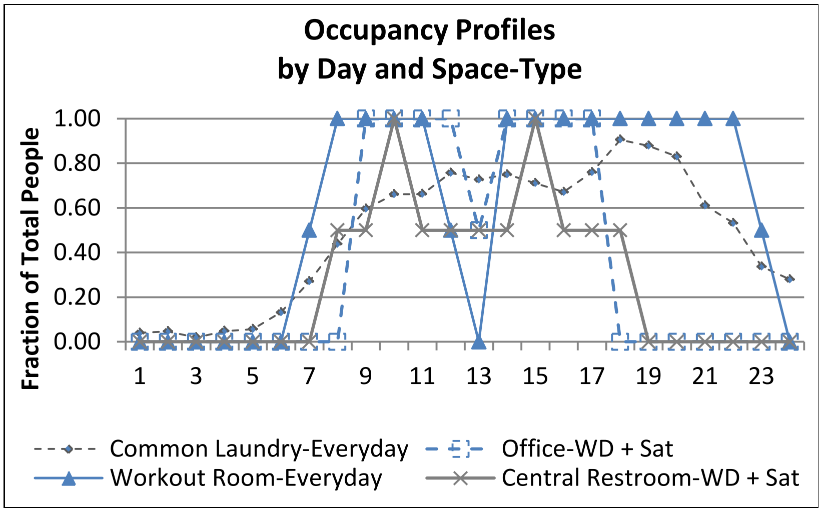


Figure 27. Detailed hourly load profiles resulting from occupants being in different common spaces on specific days of the week

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

4.7 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.

5 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.

5.1 New Construction

Table 49 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 BA, 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 50, along with percent energy savings for each end use. End uses are described in more detail in Table 51.

Table 49. Example Summary of Site Energy Consumption by End Use

	Annual Site Energy							
End Use	BA Benchmark		Region Standard		Builder Standard		BA NCTH	
	(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 50. Example Summary of Source Energy Consumption by End Use

End Use	Estimated Annual Source Energy				Source Energy Savings					
					Percent of End Use			Percent of Total		
	BA Benchmark (MBtu/yr)	Regional (MBtu/yr)	Builder (MBtu/yr)	NCTH (MBtu/yr)	BA Benchmark Base	Regional Base	Builder Base	BA Benchmark Base	Regional Base	Builder 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 51. End Use Category Definitions

End Use	Potential Electricity Usage	Potential Gas Usage
Space heating	Supply fan during space heating, HP[a], 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[b], 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 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 electricity generation	None

[a] Heat pump
[b] Air-conditioning

For attached and multifamily 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 50 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.

The **site-to-source energy conversion** shall be performed using Equation 25, using national site-to-source multipliers from Table J2-A in ASHRAE Standard 105-2013 (ASHRAE 2013). Multipliers for electricity, natural gas, fuel oil, and propane are shown in Table 52.

$$\text{Source MBtu} = \text{kWh} \times 3.412 \times M_e / 1000 + \text{therms} \times M_g/10 + \text{MBtu} \times M_o \qquad (25)$$

where:

M_e = site-to-source multiplier for electricity (see Table 52)

M_g = site-to-source multiplier for natural gas (see Table 52)

M_o = site to source multiplier for all other fuels (see Table 52).

Table 52. Site-to-Source Energy Multipliers for Energy Delivered to Buildings

(ASHRAE 2013)

Energy Source	Site-to-Source Energy Multiplier
Electricity	3.15
Natural gas	1.09
Fuel oil/kerosene	1.19
Propane gas	1.15

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 26) assumes that a typical house size is 2400 ft^2 with three bedrooms.

$$\text{Adjusted Benchmark Source MBtu} = (M_{size}) \times \text{Source MBtu} \qquad (26)$$

where

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

Table 53 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.

Table 53. Example Measure Savings Report for New Construction

Increment	Site Energy		Source Energy		National Average Energy Cost		Builder Standard (Local Costs)			
							Energy Cost		Measure	Package
	(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

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 ratio. Measures with the highest benefit-to-cost 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 1 year, as determined by the hourly simulation.

5.2 Existing Homes

Table 54 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 55, along with percent energy savings for each end use.

Table 54. Example Summary of Site Energy by End Use for an Existing Homes Project

End Use	Annual Site Energy			
	Pre-Retrofit		Post-Retrofit	
	(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**

Table 55. Example Summary of Source Energy 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%**

The “Percent of End Use” column in Table 51 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 56 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 56. Example Measure Savings Report for an Existing Homes Project

Increment	Site Energy		Source Energy		National Average Energy Cost		Economics (Local Costs)			
							Energy Cost		Measure	Package
	(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 HP (+ 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

5.3 Economic Parameters and Financing

The economic assumptions for Building America cash flow analysis are documented in Table 57 and are consistent with the default values in BEopt.

Table 57. Cash Flow Assumptions

Group	Construction Type	Category	Value
Economics	All	Project analysis period	30 years
		Inflation rate	2.4%[3]
		Discount rate	3.0%
Mortgage/loan	New	Mortgage period	30 years
		Interest rate	4.0%[4]
		Down payment	0.0%
	Existing, loan	Loan period	5 years
		Interest rate	6.5%[5]
		Down payment	0.0%
	Existing, cash	Down payment	100%
	All	Marginal income tax rate, federal	28%

The analyst should use OpenEI to find whatever utility rate is the closest to the actual rate the homeowner pays. This is applicable to all analyses, including for the Benchmark, NCTH, and pre- and post-retrofits.

5.4 Benchmark Component Costs

Table 58 shows the default values for the Benchmark home and their associated costs. These costs can be selected automatically in the BEopt software, by choosing “B10 Benchmark” as the reference building in Building America mode.

There are two possible reasons a category is listed, but no cost is listed:

1. The option (for example, natural ventilation/opening windows) has no associated cost.
2. It appears in BEopt, and is therefore part of this list, but is not part of the Benchmark building (for example, electric baseboards).

These costs are currently consistent with the National Residential Efficiency Measures Database (NREL 2013). Because this database is dynamic and changes as more relevant data become available, these values may change over time. However, the units will likely remain consistent.

[3] Three-year average, July 2010–July 2013 (www.dlt.ri.gov/lmi/business/cpi.htm)
[4] Three-year average, September 2010–August 2013 (www.freddiemac.com/pmms/pmms30.htm)
[5] Estimated three-year average of home equity loan rates, September 2010–September 2013 (www.bankrate.com/funnel/graph/)

Table 58. Cost Assumptions

Group	Category	Option	BA Zone(s)	Cost	Cost Units	2nd Cost	2nd Cost Units
Building	Orientation	North	All	0	$		
	Neighbors	North	All	0	$		
Operation	Heating set point	71°F	All	0	$		
	Cooling set point	76°F	All	0	$		
	Humidity set point	60% relative humidity	All	0	$		
	MELs	1	All	0	$		
	Miscellaneous gas loads	1	All	0	$		
	Natural ventilation	Benchmark	All	0	$		
	Interior shading	Benchmark	All	0	$		
Walls	Wood Stud	R-13 fiberglass batt, Gr-1, 2 × 4, 16 in. o.c.	1,2,3,4	3.4	$/ft² net exterior wall		
		R-21 fiberglass batt, Gr-1, 2 × 6, 24 in. o.c.	7,8	3.5	$/ft² net exterior wall		
		R-13 fiberglass batt, Gr-1, 2 × 4, 16 in. o.c., R-5 XPS	4C,5,6	4.4	$/ft² net exterior wall		
	Double wood stud	None	All	0	$		
	Concrete masonry unit	None	All	0	$		
	Structurally insulated panel	None	All	0	$		
	Insulating concrete form	None	All	0	$		
	Other	None	All	0	$		
	Exterior finish	Vinyl, Light	All	2.67	$/ft² Exterior Wall		
	Interzonal (e.g., between attached garage and conditioned space) walls	R-13 fiberglass batt, Gr 1, 2 × 4, 16 in. o.c.	1,2,3,4	2.6	$/ft² wall		
		R-21 fiberglass batt, Gr 1, 2 × 6, 24 in. o.c.	7,8	2.7	$/ft² wall		
		R-13 fiberglass batt, Gr 1, 2 × 4, 16 in. o.c., R-5 XPS	4C,5,6	3.6	$/ft² wall		

Group	Category	Option	BA Zone(s)	Cost	Cost Units	2nd Cost	2nd Cost Units
Ceilings/ Roofs	Unfinished attic	Ceiling R-30 cellulose, vented	1,2,3	0.95	$/ft^2 ceiling		
		Ceiling R-38 cellulose, vented	4,4C,5	1.1	$/ft^2 ceiling		
		Ceiling R-49 cellulose, vented	6,7,8	1.2	$/ft^2 ceiling		
	Finished roof	R-30C fiberglass batt, 2 × 10	1,2,3	2.1	$/ft^2 roof		
		R-38C fiberglass batt, 2 × 12	4,4C,5	2.7	$/ft^2 roof		
		R-30 + R-19 fiberglass batt	6,7,8	3.2	$/ft^2 roof		
	Roof material	Asphalt shingles, medium	All	1.78	$/ft^2 roof		
	Radiant barrier	None	All	0	$		
Foundation/ Floors	Slab	Uninsulated	1,2,3				
		2-ft R-10 perimeter, R-5 gap	4,4C,5	1.9	$/ft^2 slab ins. (perimeter)	1.2	$/ft^2 gap insulation
		4-ft R-10 perimeter, R-5 gap	6,7,8	1.9	$/ft^2 slab ins. (perimeter)	1.2	$/ft^2 gap insulation
	Finished Basement	Uninsulated	1,2,3				
		Wall 8-ft R-10 XPS, furring strips, 0.5 in. gypsum board[6]	4,4C,5	2.7	$/ft^2 wall		
		Wall 8-ft R-15 XPS, furring strips, 0.5-in. gypsum board	6,7,8	3.3	$/ft^2 wall		
	Unfinished Basement	Uninsulated	1,2,3				
		Whole Wall, R-10 XPS, furring strips, 0.5-in. gypsum board	4,4C,5	2.7	$/ft^2 basement wall		
		Whole Wall, R-15 XPS, furring strips, 0.5-in. gypsum board	6,7,8	3.3	$/ft^2 Basement Wall		
	Crawlspace	Uninsulated, unvented	1,2				
		Wall R-5 XPS, unvented	3	0.84	$/ft^2 floor	0.97	$/ft^2 wall
		Wall R-10 XPS, unvented	4,4C,5,6, 7,8	0.84	$/ft^2 floor	1.5	$/ft^2 wall
	Interzonal floor	R-13 fiberglass batt	1,2	0.68	$/ft^2 floor		
		R-19 fiberglass batt	3,4	0.81	$/ft^2 floor		
		R-30 fiberglass batt	4C,5,6	1	$/ft^2 floor		
		R-38 fiberglass batt	7,8	1.2	$/ft^2 floor		
	Carpet	80% carpet	All	0	$		

[6] This default composition to meet code will be discussed in 2013 to determine the most "standard" across the country

Group	Category	Option	BA Zone(s)	Cost	Cost Units	2nd Cost	2nd Cost Units
Thermal Mass	Floor mass	Wood surface	All	1.8	$/ft^2 floor		
	Exterior wall mass	½-in. drywall	All	1.2	$/ft^2 wall		
	Partition wall mass	½- in. drywall	All	1.2	$/ft^2 wall		
	Ceiling mass	½-in. drywall	All	1.4	$/ft^2 ceiling		
	Window areas	15.0% F25 B25 L25 R25	All	0	$		
Windows and Doors	Windows	Double-pane, low-gain low-e, nonmetal frame, air fill	1,2,3	22	$/ft^2 window		
		Double-pane, medium-gain low-e, nonmetal frame, argon fill	4,4C,5,6, 7,8	23	$/ft^2 window		
	Eaves	2 ft	All	5.8	$ft^2 eave		
	Overhangs[7]	None	All	0	$		
Airflow	Air leakage	7 ACH_{50}, 0.5 shelter coefficient	All	0.25	$/ft^2 finished floor		
	Mechanical ventilation	Exhaust	All	1100	$		
Major Appliances	Refrigerator	Benchmark	All	1100	$		
	Cooking range	Benchmark	All	920	$		
	Dishwasher	Benchmark	All	880	$		
	Clothes washer	Benchmark	All	590	$		
	Clothes dryer	Benchmark	All	760	$		
Lighting	Lighting	Benchmark	All	0.04	$/ft^2 living + garage		
Space Conditioning	Central air conditioner	SEER 13	All	64	$/kBtu/h	410	$(labor)
	Furnace	Gas, 78% AFUE	All	9	$/kBtu/h	1200	$(labor)
	Boiler	None	All	0	$		
	Electric baseboard	None	All	0	$		
	Air source heat pump	None	All	0	$		
	Ground source heat pump	None	All	0	$		
	Ducts	15% leakage, R-6	All	5.8	$/ft^2 duct surface		
	Ceiling fan	Benchmark	All	240	$/fan	290	$/fan (labor)
	Dehumidifier	None	All	0	$		

[7] Overhangs are defined as the shading provided over each window. The Benchmark building does not have overhangs.

Group	Category	Option	BA Zone(s)	Cost	Cost Units	2nd Cost	2nd Cost Units
Water Heating	Water heater	Benchmark	All	10	$/gal	640	$
	Distribution	Uninsulated, TrunkBranch, copper	All	8.6	$/ft Piping		
	Solar water heating	None	All	0	$		
	Solar water heating azimuth	Back roof	All	0	$		
	Solar water heating tilt	Roof pitch	All	0	$		
Power Generation	None			0	$		

References

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

ACCA. (2006). Manual J: Residential Load Calculations, Eighth Edition, Version 2.00. Arlington, VA: Air Conditioning Contrators of America.

ACCA. (1995). Manual S: Residential Equipment Selection. Arlington, VA: Air Conditioning Contrators of America.

AHRI. (2013). AHRI Directory of Certified Product Performance: Residential Water Heaters. www.ahridirectory.org/ahridirectory/pages/rwh/defaultSearch.aspx. Arlington, VA: Air-Conditioning, Heating, & Refrigeration Institute. Last accessed October 2013.

Aquacraft. (2008). "Hot & Cold Water Data from EPA Retrofit Studies – EBMUD & Seattle." Boulder, CO: Aquacraft Inc.

ASHRAE. (2013). BSR/ASHRAE Standard 105-2013: Standard Methods of Determining, Expressing, and Comparing Building Energy Performance and Greenhouse Gas Emissions. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, in press.

ASHRAE. (2012). *HVAC Systems and Equipment Handbook (I-P Edition)*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2010a). "Thermal Environmental Conditions for Human Occupancy," ASHRAE Standard 55-2010, Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2010b). Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. ASHRAE Standard 62.2-2010, Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2009). *Handbook—Fundamentals (I-P Edition)*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2007). *HVAC Applications Handbook (I-P Edition)*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2004). Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems, ASHRAE Standard 152-2004, Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

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

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

ASTM. (2007). Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization. ASTM E1554-07. Conshohocken, PA: American Society for Testing and Materials.

ASTM. (2003). Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. ASTM E779-03. Conshohocken, PA: American Society for Testing and Materials.

ASTM. (1994). *Moisture Control in Buildings*. Conshohocken, PA: American Society for Testing and Materials.

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

Becker, B.R.; Stogsdill, K.E. (1990). "Development of Hot Water Use Data Base." *ASHRAE Transactions* 96(2):422–427. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.

Brand, L.; Yee, S.; Baker, J. (2013). "Improving Gas Furnace Performance: A Field and Laboratory Study at End of Life." NREL/SR-5500-60018; DOE/GO-102013-4112. Golden, CO: National Renewable Energy Laboratory.

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

Burch, J.; Erickson, P. (2004). "Using Ratings Data to Derive Simulation-Model Inputs for Storage-Tank Water Heaters." 2004 National Solar Energy Conference. Boulder, CO: American Solar Energy Society.

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

CEC. (2010). Appliance Efficiency Database. www.appliances.energy.ca.gov/. Sacramento, CA: California Energy Commission. Last accessed September 2010.

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

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

DEG. (2006a). "Field Survey Report: Documentation of Hot Water Distribution Systems in Sixty New California Production Homes." Report to Lawrence Berkeley National Laboratory under funding by the California Energy Commission. Davis, CA: Davis Energy Group.

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

DOE. (2010). Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule Technical Support Documents: Federal Register.

DOE. (2007). Technical Support Document: Energy Efficiency Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers.

www.eere.energy.gov/buildings/appliance_standards/residential/furnaces_boilers.html Washington, DC: U.S. Department of Energy. Last accessed December 2013.

DOE. (2005). "2005 Residential Energy Consumption Survey." www.eia.doe.gov/emeu/recs/contents.html Washington, DC: U.S. Department of Energy. Last accessed August 2010.

DOE. (2004a). 2004 Buildings Energy Databook. btscoredatabook.eren.doe.gov Washington, DC: U.S. Department of Energy. Last accessed June 2010.

DOE. (2004b). Code of Federal Regulations Title 10, Energy, Part 430, Subpart B, Appendices C, D, J, and J1, Washington, DC: U.S. Department of Energy.

DOE. (2003a). New and Alternative Insulation Materials and Products. Energy Savers Fact Sheet. www.eere.energy.gov/consumerinfo/factsheets/eb9.html (accessed August 2005). Washington, DC: U.S. DOE.

DOE. (2003b). Appliances and Commercial Equipment Standards. http://www1.eere.energy.gov/buildings/appliance_standards/. Washington, DC: U.S. Department of Energy. Last accessed May 2004.

DOE. (2002a). Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps. hwww.eere.energy.gov/buildings/appliance_standards/residential/central_ac_hp.html. Washington, DC: U.S. Department of Energy. Last accessed June 2010.

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

DOE. (2001a). Code of Federal Regulations Title 10, Energy, Part 430, Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters; Final Rule. www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/water_heater_fr.pdf. Washington, DC: U.S. Department of Energy. Last accessed August 2010.

DOE. (2001b). Residential Energy Consumption Survey. Washington, DC: U.S. Department of Energy.

DOE. (2000a). Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters. Appendix D-2. www.eere.energy.gov/buildings/appliance_standards/residential/waterheater.html. Washington, DC: U.S. Department of Energy. Last accessed June 2010.

DOE. (2000b). Final Rule Technical Support Document: Energy Efficiency Standards for Consumer Products: Clothes Washers. www.eere.energy.gov/buildings/appliance_standards/residential/clothes_washer.html. Washington, DC: U.S. Department of Energy. Last accessed June 2010.

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

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

DOE. (1993). Technical Support Document for Residential Cooking Products. Volume 2. www.eere.energy.gov/buildings/appliance_standards/residential/cooking_products_0998_r.html. Washington, DC: U.S. Department of Energy. Last accessed June 2010.

EPRI. (1987). *TAG Technical Assessment Guide: Volume 2: Electricity End Use*. EPRI P-4463-SR. Palo Alto, CA: Electric Power Research Institute.

EPRI. (1986). Trends in the Energy Efficiency of Residential Electric Appliances. EM-4539, Research Project 2034-9. Palo Alto, CA: Electric Power Research Institute.

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

Goetzler, W.; Foley, K.; Kar, R.; Sutherland, T. (2012). “Water Heater Performance Degradation Due to Aging.” ACEEE Hot Water Forum. Washington, DC: American Council for an Energy-Efficient Economy.

Greening, L.A.; Greene, D.L.; Difiglio, C. (2000). Energy Efficiency and Consumption – The Rebound Effect – A Survey. *Energy Policy* 28:389–401. Amsterdam, Netherlands: Elsevier B.V.

Hancock, E.; Norton, P.; Hendron, R. (2002). *Building America System Performance Test Practices: Part 2, Air-Exchange Measurements*. NREL/TP-550-30270. Golden, CO: National Renewable Energy Laboratory.

Hendron, R. (2008). *Building America Research Benchmark Definition Updated December 19, 2008*. NREL/TP-550-44816. Golden, CO: National Renewable Energy Laboratory.

Hendron, R.; Eastment, M. (2006). “Development of an Energy-Savings Calculation Methodology for Residential Miscellaneous Electric Loads.” ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC: American Council for an Energy-Efficient Economy.

Hendron, R.; Engebrecht, C. (2010). *Building America House Simulation Protocols*. NREL/TP-550-49426. Golden, CO: National Renewable Energy Laboratory.

Huang, J.; Gu, L. (2002). Prototype Residential Buildings to Represent the U.S. Housing Stock. Draft LBNL Report. Berkeley, CA: Lawrence Berkeley National Laboratory.

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

ICC. 2009. International Energy Conservation Code 2009. Falls Church, VA: International Code Council.

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

Judkoff, R.; Balcomb, J. D.; Hancock, C. E.; Barker, G.; Subbarao, K. (2000). *Side-By-Side Thermal Tests of Modular Offices: A Validation Study of the STEM Method*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-550-23940.

KEMA. (2009). “Residential Lighting Metering Study: Preliminary Results.” February 2009 Presentation to Stakeholders. Oakland, CA: KEMA. www.energydataweb.com/cpuc/home.aspx.

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

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

Lstiburek, J. (1999). Heating Choices. Research Report – 9911. Somerville, MA: Building Science Corporation. www.buildingscience.com/documents/reports/rr-9911-heating-choices

Lutz, J.; Melody, M. (2012). "Typical Hot Water Draw Patterns Based on Field Data." Berkeley, CA: Lawrence Berkeley National Laboratory.

Maguire, J.; Krarti, M.; Fang, X. (2011). "An Analysis Model for Domestic Hot Water Distribution Systems." Presented at the 5th International Conference on Energy Sustainability and Fuel Cells, August 7–10, 2001. Washington, D.C. NREL/CP-5500-51674. http://www.nrel.gov/docs/fy12osti/51674.pdf

Metzger, C. Engebrecht; Wilson, E.; Horowitz, S. (2012). *Addendum to the Building America House Simulation Protocols*. NREL/TP-5500-57450. Golden, CO: National Renewable Energy Laboratory.

Mills, E. 2008. The Home Energy Saver: Documentation of Calculation Methodology, Input Data, and Infrastructure, LBNL-51938. Berkeley, CA: Lawrence Berkeley National Laboratory.

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

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

NREL (2013). "National Residential Efficiency Measures Database." Golden, CO: National Renewable Energy Laboratory. www.nrel.gov/ap/retrofits/

NREL. (2009). "Benchmark Midrise Apartment NewV1(2).1_3.1(SI)." Golden, CO: National Renewable Energy Laboratory.

Parker, D.; Fairey, P.; Hendron, R. (2010). Updated Miscellaneous Electricity Loads and Appliance Energy Usage Profiles for Use in Home Energy Ratings, the Building America Benchmark Procedures and Related Calculations. FSEC-CR-1837-10. Cocoa, FL: Florida Solar Energy Center.

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

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

Parker, D.; Sherwin, J.; Raustad, R.; Shirey, D. (1997). "Impact of Evaporator Coil Air Flow in Residential Air Conditioning Systems." Presented at the 1997 ASHRAE Annual Meeting, June 28-July 2, Boston, MA. FSEC-PF-321-97.

PNNL; ORNL. (2007). High-Performance Home Technologies: Guide to Determining Climate Regions by County. Building America Best Practices Series. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/climate_region_guide.pdf. Richland, WA: Pacific Northwest National Laboratory. Last accessed July 2010.

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

PSNH (2013). "Home Energy Usage Chart." Public Service of New Hampshire: A Northeast Utilities Company. www.psnh.com/downloads/Home%20Appliance%20Usage%20Costs.pdf?id=4294968770&dl=t

Rea, M. et al. (2000). IESNA Lighting Handbook, Ninth Edition. New York, NY. Section 3, Chapter 10: Illuminance Selection.

RESNET. (2012). RESNET Interim Guidelines for Thermographic Inspections of Buildings. April 4, 2012. www.resnet.us/standards/RESNET_IR_interim_guidelines.pdf

RESNET. (2006). 2006 Mortgage Industry National Home Energy Rating Systems Accreditation Standards. San Diego, CA: Residential Energy Services Network.

Sachs, H.M. (2005). Opportunities for Elevator Energy Efficiency Improvements. Washington D.C.: American Council for an Energy-Efficient Economy.

Sherman, M.H.; Grimsrud, D.T. (1980). "Infiltration-Pressurization Correlation: Simplified Physical Modeling." *ASHRAE Transactions* 86(2):778. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

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

Stokes, M.; Rylatt, M.; Lomas, K. (2004). "A Simple Model of Domestic Lighting Demand." *Energy and Buildings* 36:103–116. United Kingdom: Institute of Energy and Sustainable Development.

Szydlowski, R.; Cleary, P. (1988). "In-Situ Appliance Efficiency Audit Procedures." *ASHRAE Transactions* 94(1):1107–1023. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Taylor, Z.T.; Conner, C.C.; Lucas, R.G. (2001). "Eliminating Window-Area Restrictions in the IECC." Report No. PNNL-SA-35432. Richland, WA: Pacific Northwest National Laboratory.

Wenzel, T.; Kooney, J.; Rosenquist, G.; Sanchez, M.; Hanford, J. (1997). Energy Data Sourcebook for the U.S. Residential Sector. Berkeley, CA: Lawrence Berkeley National Laboratory, LBL-40297.