CHAPTER 7. ENERGY USE CHARACTERIZATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 7. ENERGY USE CHARACTERIZATION

7.1 INTRODUCTION

The life-cycle cost (LCC) and payback period (PBP) analyses described in chapter 8 require determination of the savings in operating cost consumers would realize from more energy-efficient products. Energy costs are the most significant component of consumer operating costs, with maintenance and repair costs the other contributors. DOE uses annual energy use, along with energy prices, to establish energy costs at various energy efficiency levels. This chapter describes the determination of annual energy use of residential gas-fired, electric, and oil-fired storage-type water heaters, gas-fired instantaneous water heaters, direct heating equipment, and pool heaters.

7.2 WATER HEATERS

The following sections describe factors that determine the amount of hot water and energy water heaters use, the characteristics of water heater energy efficiency, and water heater operating conditions.

7.2.1 Introduction

Water heaters may use gas, oil, or electric energy. In the engineering analysis, DOE used the DOE test procedure for each product to calculate the energy consumption of water heaters. For the LCC analysis, DOE estimated energy consumption of water heaters in actual housing units, as represented by the sample described in section 7.2.2.

DOE calculated the energy use of residential water heaters in each of the four product classes: gas-fired storage water heaters, electric storage water heaters, oil-fired storage water heaters, and gas-fired instantaneous water heaters. The calculation considers the primary factors that determine energy use:

- hot water use per household,
- the energy efficiency characteristics of the water heater, and
- water heater operating conditions other than hot water draws.

DOE used a hot water draw model to determine hot water use for each household in the sample. The characteristics of each water heater's energy efficiency were taken from the engineering analysis. DOE developed water heater operating conditions (other than hot water draws) from weather data and other relevant sources. Section 7.2.3 discusses hot water use; section 7.2.4 discusses the relevant characteristics of water heater energy efficiency and operating conditions to calculate the annual energy consumption for water heaters.

7.2.2 Household Sample

DOE's calculation of the annual energy use of residential water heaters relied on data from the Residential Energy Consumption Survey 2005[1] (RECS 2005), which was conducted by

DOE's Energy Information Administration (EIA). RECS collects energy-related data for occupied primary housing units in the United States. The RECS 2005 collected data from 4,381 housing units that represent almost 111.1 million households. For this notice of proposed rulemaking, DOE updated its analysis using the RECS 2005.

The subset of RECS 2005 records used to study water heaters met all of the following criteria.

- A water heater served as the primary source of heated water.
- The water heater used one of four heating fuels (electricity, gas, LPG, or oil).
- The water heater provided heated water for only one housing unit.
- The RECS 2005 record included an indication of water heater size.
- The water heater's energy consumption was greater than zero.

DOE divided the water heater subset into four further subsets designed to include households that use one of the four water heater product classes (Table 7.2.1). For gas-fired instantaneous water heaters, DOE used the same subset as for gas-fired storage water heaters, with the addition of 14 households with gas-fired instantaneous water heaters in the RECS 2005 sample.

Table 7.2.1 Selection of RECS 2005 Records for Water Heaters

Product Class	**Algorithm**	**No. of Records**	**No. of U.S. Households Represented** *(million)*
Natural Gas and LPG Storage	Storage Water Heater = Yes Fuel Type = Natural Gas or LPG Shared Water Heater = No	2166	55.2
Electric Storage	Storage Water Heater = Yes Fuel Type = Electricity Shared Water Heater = No	1523	39.5
Oil Storage	Storage Water Heater = Yes Fuel Type = Fuel Oil Shared Water Heater = No	100	1.8
Natural Gas and LPG Instantaneous	Storage/Instantaneous Water Heater = Yes Fuel Type = Natural Gas or LPG Shared Water Heater = No	2180	55.5

DOE used EIA's weightings for each RECS 2005 household. The weightings indicate how commonly each household configuration occurs in the general population. DOE believes that the household records, along with their weightings, are representative of housing nationwide (see appendix 7-A for details).

7.2.3 Hot Water Use

Hot water use differs widely among households, because it depends on characteristics of the household and the water heater, such as the number and ages of the people who live in the household, the way they consume hot water, the presence of hot-water-using appliances, the tank size and thermostat set point of the water heater, and the climate in which the residence is situated.

DOE developed the hot water draw model[2] to improve on a previously used model. The hot water draw model accounts for the key characteristics described above to estimate the average daily volume of hot water used by a household.

7.2.3.1 Equation for Hot Water Use

The hot water draw model uses an equation expressed as follows.

$$\begin{aligned} vol = \{ & sea\_coef + (per\_coef \times per) + (age1\_coef \times age1) + (age2\_coef \times age2) + \\ & [age34\_coef \times (age3 + age4)] + (T_{tank}\_coef \times T_{tank}) + (Tanksz\_coef \times Tanksz) + \\ & (T_{in}\_coef \times T_{in}) + (T_{air}\_coef \times T_{air}) + (home\_coef \times athome) - \\ & [(0.692 \times per + 1.335 \times \sqrt{per}) \times dw\_adj] - [(1.1688 \times per + 4.7737 \times \sqrt{per}) \times cw\_adj]\} \times \\ & (senior\_mf\ \_coef \times senior\_mf) \times (no\_pay\_coef \times no\_pay) \end{aligned}$$

Where:

vol =	hot water consumption, gallons per day, gal/day,
per =	total number of persons in household,
age1 =	number of preschool children, age 0–5 years, yr,
age2 =	number of school-age children, age 6-13, yr,
age3 =	number of adults, age 14–64, yr,
age4 =	number of adults, age 65 yr and above, yr,
T_{tank} =	thermostat setting of water heater, degrees Fahrenheit, °F,
Tanksz =	nominal tank size of water heater, gal,
T_{in} =	temperature of water heater inlet water, °F,
T_{air} =	outdoor air temperature, °F,
athome =	presence of adults at home during day,
dw_adj =	adjustment factor to account for the differences between the current energy conservation standard for dishwashers and the households that have no dishwasher,
cw_adj =	adjustment factor to account for the differences between the current energy conservation standard for clothes washers and the households that have no clothes washer,
senior_mf =	senior-only household in a multi-family building,
no_pay =	household that does not pay for hot water,

T_{tank}*_err* =	estimation error for the thermostat set point (normal distribution),
sea_coef =	coefficient for seasonal effects,
per_coef =	coefficient for total number of persons in household (normal distribution),
age1_coef =	coefficient for *age1* (normal distribution),
age2_coef =	coefficient for *age2* (normal distribution),
age34_coef =	coefficient for *age3* + age4" (normal distribution),
home_coef =	coefficient for *athome* (normal distribution),
Tanksz_coef =	coefficient for water heater tank size (normal distribution),
T_{tank}*_coef* =	coefficient for thermostat set point (normal distribution),
T_{inlet}*_coef* =	coefficient for water inlet temperature (normal distribution),
T_{air}*_coef* =	coefficient for average outdoor temperature (normal distribution),
senior_mf_coef =	coefficient for senior-only household in a multi-family building (normal distribution), and
no_pay_coef =	coefficient for household that does not pay for hot water (normal distribution).

7.2.3.2 Description of Key Variables Used in Draw Model

The following is a description of the primary variables used in the hot water draw model. See appendix 7-B for criteria used to determine each draw model variable.

- *Number of Persons in Household (per)*. The total number of household members.
- *Number of Preschool Children 0–5 (age1)*. The total number of infants and young children ages 0–5.
- *Number of School-Age Children 6–13 (age2)*. The total number of children, ages 6–13.
- *Number of Adults 14–64 (age3)*. The total number of adults, ages 14 to 64.
- *Number of Adults 65+ (age4)*. The total number of adults, age 65 or older.
- *Number of Thermostat Set point (*T_{tank}*)*. The thermostat setting of the water heater.
- *Water Heater Tank Size (Tanksz)*. The nominal size of the water heater tank.
- *Outdoor Air Temperature (*T_{air}*)*. The average annual outdoor air temperature.
- *Inlet Water Temperature (*T_{in}*)*. The temperature of the water entering the water heater.
- *Household Member (athome)*. The presence of an adult household member at home during the day.
- *Senior Only (senior_mf)*. A senior-only (age 65 or above) household in a multi-family building.
- *No-Pay Household (no_pay)*. A household that does not pay to heat water.
- *Coefficient for Seasonal Effects (sea_coef)*. Variable that adjusts hot water use for winter, spring, summer, and fall seasons.
- *Dishwasher (dw_adj)*. Adjustment factor to account for the differences due to the current energy conservation standard for dishwasher and for the cases of households with no dishwasher.
- *Clothes Washer (cw_adj)*. Adjustment factor to account for the differences between the current energy conservation standard for clothes washers and households that have no clothes washers.

The hot water draw model incorporates parameters that represent clothes washers and dishwashers as they existed in the 1990s. Since that time, the considerable changes made to clothes washer and dishwasher technologies have lowered hot water use. In particular, updated Federal energy conservation standards for clothes washers that became effective in 2007[3] and for dishwashers that will become effective in 2010[4] have a significant impact on hot water use by clothes washers and dishwashers. To account for changes in hot water use by clothes washers and dishwashers, DOE adjusted the parameters in the hot water draw model. See appendix 7-B, hot water draw model, for further discussion of the adjustment factors.

Water Use Chart. DOE applied the same equation for hot water use to all households, regardless of water heater fuel type. Figure 7.2.1 illustrates how the hot water draw model determines household hot water use.

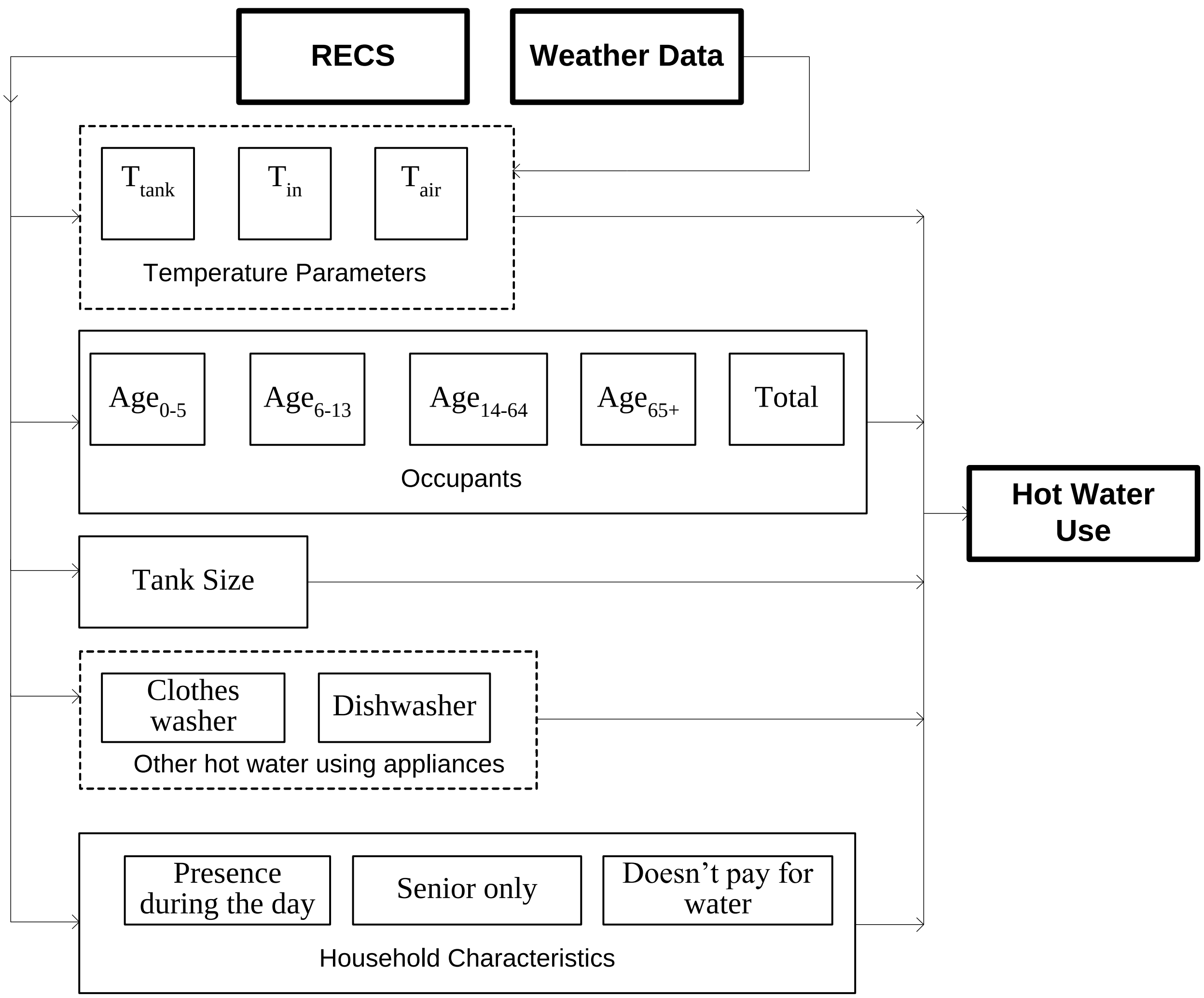

Figure 7.2.1 Hot Water Draw Model Determination of Hot Water Use

7.2.3.3 Assignment of Water Heater Tank Size

Calculating hot water use for each sample household requires assigning the water heater a specific tank size (referred to as rated volume). For each household, RECS reports one of three water heater tank sizes, small, medium, or large, as well as giving the size range in gallons. Table 7.2.2 shows RECS data on water heater tank size and the fraction of households that DOE assigned to each size within each product class. “Typical” water heater sizes, which are those most common for each fuel type, have the minimum energy factor allowed by current energy conservation standards. These “typical” units have the largest market share in their product class (50 gal/190 liter for electric, 40 gal/150 liter for natural gas and LPG, and 32 gal/120 liter for oil). In the LCC analysis, DOE expanded the range of sizes considered so that the analysis would accurately reflect the broad range of water heater sizes that consumers may encounter. The sizes in the expanded repertoire are referred to as “standard” sizes. Figure 7.2.2 depicts the process of assigning tank size to the sample households.

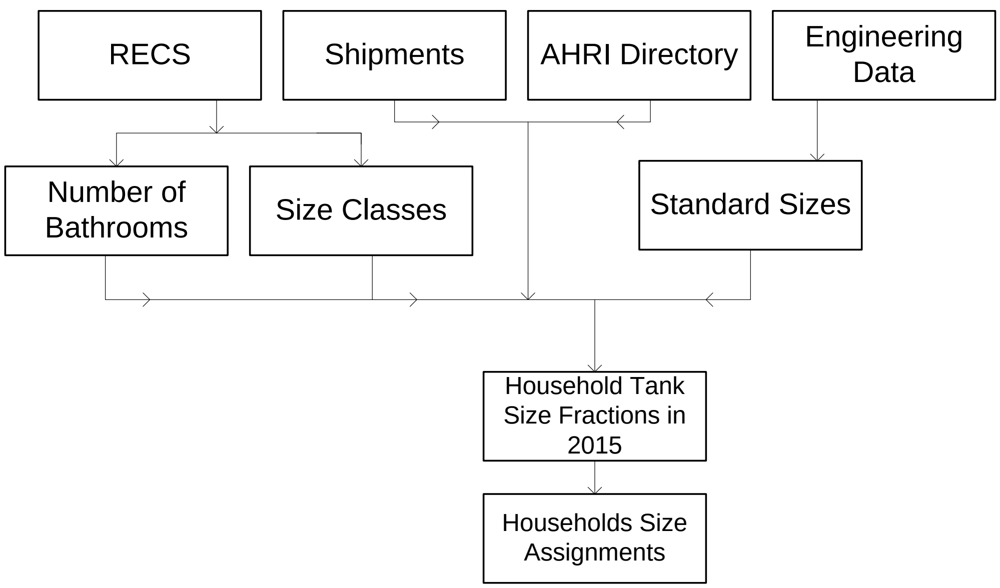

Figure 7.2.2 Assignment of Water Heater Tank Sizes

Step 1. Assignment of Water Heater Sizes. Table 7.2.2 shows the percentage of each standard size in recent shipments of water heaters. (See chapter 5, Engineering Analysis, for a discussion of how DOE chose standard sizes.) The percentages of standard sizes in shipments provide insight into the percentages one would expect to find in the housing stock. The table also shows the percentages of RECS households that were assigned to each standard size for the LCC analysis.

Table 7.2.2 Assignment of Water Heater Tank Sizes to Sample Households

Fuel Type	RECS 2005 Data			Standard Sizes Used in LCC Analysis *(gal)*	Percent of Historical Shipments* *(%)*	Size Assigned to Sample Households *(%)*
	Size Class	Size Range *(gal)*	Percent of Sample Households *(%)*			
Natural Gas and LPG	Small	≤30	13.7	30	16.9	13.7
	Medium	31-49	58.2	40	45.4	45.4
				50	35.7	37.1
	Large	≥50	28.1	65	1.9	1.9
				75	1.9	1.9
Electric	Small	≤30	23.3	30	22.5	23.3
	Medium	31-49	48.8	40	33.9	33.4
				50	34.6	34.2
	Large	≥50	27.9	66	9.0	3.4
				80		4.2
				119		1.4
Oil	Small	≤30	21.5	32	67.0	67.0
	Medium	31-49	54.0			
	Large	≥50	24.5	50	33.0	33.0

*Sources: Natural gas and LPG: 1988–1995 data from the Gas Appliance Manufacturers Association (GAMA),[5] 2004–2008 gas and electric storage shipments data from the Air Conditioning, Heating, and Refrigeration Institute (AHRI).[6] Electric: U.S. Census Bureau data (2003–2008).[7] 2007-2008 water heater shipments data from AHRI.[8] 1998–2007 oil storage shipments data from AHRI.[9, 10]

The 1995 GAMA shipments data show that 17 percent of shipments of gas-fired storage water heaters were the 30-gallon size. Historical RECS data[1, 11, 12, 13, 14] show that households having a small water heater declined from 21 percent in RECS 1990[14] to 14 percent in RECS 2005[1]. Furthermore, only 5 percent of RECS 2005 "new construction households" (households built in 2000–2005) have a small water heater. DOE assigned a 30-gallon water heater to all households having a small water heater (14 percent), based on this declining market share. DOE used the 1995 GAMA shipment data to assign 75-gallon water heaters to 2 percent of sample households. DOE assumed the share of the 65-gallon water heater to be equal to the 75-gallon water heater (i.e., 2 percent).

DOE assigned the remaining households that have a gas-fired storage water heater either a 40- or a 50-gallon water heater. Based on the 2007–2008 AHRI shipments data,[6, 8] DOE estimated that 45.4 percent of the total are 40-gallon. This leaves the 50-gallon size with the remaining 37.1 percent of the total. DOE assigned either a 40- or a 50-gallon water heater to all RECS 2005 households having medium water heaters, which resulted in assigning 40-gallon size to 78 percent of these households and 50-gallon size to 22 percent. All RECS households having a large water heater (after subtracting those assigned 75-gallon water heaters) were assigned a 50-gallon water heater.

For electric water heaters, 2002–2005 U.S. Census shipments data show that 22.5 percent of shipments were the 30-gallon size or smaller (including sizes smaller than 20-gallons and tabletop models, both of which are not subject of this rulemaking). In the RECS 2005 sample, 16.9 percent of households have a small water heater. DOE assigned a 30-gallon water heater to all households having small water heaters, and estimated that the rest of the shipments consisted of water heaters having less than a 20-gallon volume and tabletop water heaters.

DOE assigned 66-, 80-, or 119-gallon water heaters to 9 percent of households, based on 2003–2008 U.S. Census shipments data. Based on the February 2010 AHRI directory,[15] DOE divided this 9 percent fraction as follows: 34 percent have 66-gallon water heaters, 42 percent have 80-gallon water heaters, and 24 percent have 119-gallon water heaters.

DOE assigned the remaining households having electric water heaters either a 40- or a 50-gallon water heater. Based on U.S. Census shipments data, DOE estimated that 49.3 percent of the total is 40-gallon, and 50.7 percent is 50-gallon. Applying this 49/51 split to the remaining RECS 2005 households having medium and large water heaters resulted in assigning a 40-gallon size to 69 percent and a 50-gallon size to 31 percent. All RECS 2005 household having large water heaters (after subtracting those assigned 66- and 75-gallon sizes) were assigned a 50-gallon water heater, and all RECS 2005 households having medium water heaters were assigned either a 40- or a 50-gallon water heater.

For oil-fired water heaters, AHRI estimated that 67 percent of shipments are 32-gallon water heaters and 33 percent are 50-gallon water heaters.[9, 10] DOE assigned a 32-gallon water heater to all RECS 2005 households having a small water heater and assigned a 50-gallon water heater to all RECS 2005 households having a large water heater. DOE split the RECS 2005 households having medium water heater between 32- and 50-gallon sizes, assigning 84 percent of these households a 32-gallon water heater and the remaining 16 percent a 50-gallon water heater.

Step 2. Assignment of Household-Specific Water Heater Sizes**.** In exploring the correlation between water heater size and several other variables, DOE found that the highest correlation was with the number of bathrooms. Therefore, DOE further refined the assignment of water heater sizes to specific sample households by considering RECS data on the number of bathrooms per house. Table 7.2.3 shows how DOE combined the RECS data on water heater size and number of bathrooms to assign household-specific standard water heater sizes. See appendix 7-B, Hot Water Draw Model, for further discussion of the assumptions used.

For the small number of households with gas-fired instantaneous water heaters in the gas-fired instantaneous water heater sample, DOE randomly assigned tank sizes based on the percentages assigned to all households that reported a tank size.

Table 7.2.3 Water Heater Tank Sizes Selected for Sample Households

Fuel Type	RECS Size Class	No. of Bathrooms	Water Heater Tank Size *(gal)*	Percent Assigned to Size Class
Natural Gas or LPG	Small	Any # BR	30	100%
	Medium	Any # BR	40	77.9%
			50	22.1%
	Large	2 BR	50	100%
		≥ 3 BR	50	45.5%
			66	27.2%
			75	27.2%
Electric	Small	Any # BR	30	100%
	Medium	Any # BR	40	68.6%
			50	31.4%
	Large	< 2 BR	50	100%
		2 BR	50	64.6%
			66	24.6%
			80	10.8%
		≥ 3 BR	80	65.3%
			119	34.7%
Oil	Small	Any # BR	32	100%
	Medium	Any # BR	32	84.3%
			50	15.7%
	Large	Any # BR	50	100%

7.2.3.4 Determination of Hot Water Use for Instantaneous Water Heaters

DOE developed the hot water draw model for storage-type water heaters. Instantaneous water heaters have no “size” in terms of storage volume, so DOE did not explicitly model their hot water use. A feature of instantaneous water heaters is their potential to deliver “unlimited” hot water during times of high household demand. However, DOE did not find any usable data showing higher or lower hot water use for instantaneous water heaters, so DOE estimated that a household having an instantaneous water heater uses the same volume of hot water as it would with a storage-type water heater.

7.2.3.5 Overview of Hot Water Use Estimates

Using the hot water draw model, DOE calculated average daily hot water use to be 41.3 gallons for households having electric storage water heaters, 44.1 gallons for households having gas-fired storage water heaters, 44.9 gallons for households having oil-fired water heaters, and 44.2 gallons for households having gas-fired instantaneous water heaters. The variations primarily reflect differences in the average number of people in the households that use each type of fuel. These results are similar to recent hot water draw studies.[16, 17] Figure 7.2.3 shows the range in hot water use among sample households. Daily hot water draw volumes for each region and product class are listed in Table 7.2.4. More information on daily hot water draw volumes can be found in appendix 7-B.

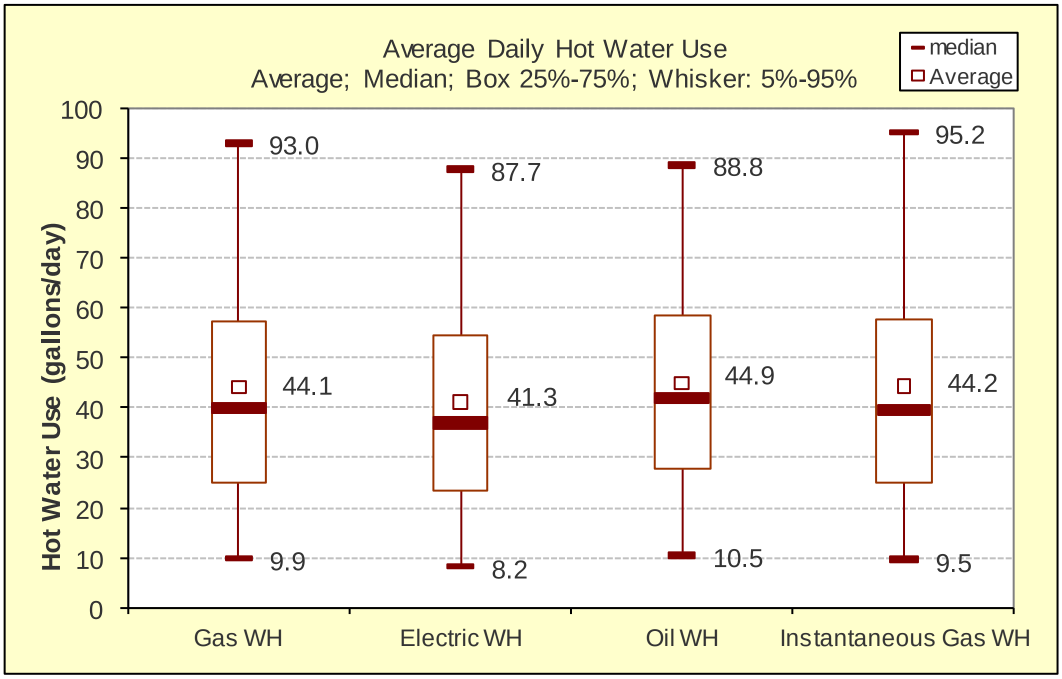

Figure 7.2.3 Range of Daily Hot Water Use in Sample Households for Each Water Heater Product Class

Table 7.2.4 Average Daily Hot Water Draw Volume by Product Class and Region

Region	**Gas and LPG** *(gal/day)*	**Electric** *(gal/day)*	**Oil** *(gal/day)*	**Gas Instantaneous** *(gal/day)*
1	34.1	30.0	41.6	37.7
2	43.5	40.0	43.4	45.4
3	39.3	37.0	N/A	39.8
4	43.1	38.1	N/A	40.8
5	43.7	41.0	40.0	45.7
6	45.4	40.0	N/A	44.0
7	44.9	36.4	N/A	42.5
8	45.9	46.4	N/A	44.4
9	48.9	47.0	N/A	47.8
10	42.7	38.3	49.9	43.3
11	48.1	35.8	N/A	48.2
12	48.9	48.4	N/A	50.9
13	55.1	44.5	N/A	49.5
National	44.1	41.3	44.9	44.2

7.2.4 Annual Energy Consumption

DOE calculated the energy use of water heaters using a simplified energy equation, the water heater analysis model (WHAM).[18] WHAM accounts for a range of operating conditions and energy efficiency characteristics of water heaters. To describe energy efficiency characteristics of water heaters, WHAM uses three parameters that also are used in the DOE test procedure:[19] recovery efficiency (*RE*), standby heat-loss coefficient (*UA*), and rated input power (P_{ON}). Water heater operating conditions are indicated by the daily hot water draw volume, inlet water temperature, thermostat setting, and air temperature around the water heater (ambient air temperature).

The current version of WHAM is appropriate for calculating the energy use of electric resistance storage water heaters. To account for the characteristics of other types of water heaters, energy use must be calculated using modified versions of the WHAM equation. These modified versions are discussed below.

7.2.4.1 Approach to Calculating Water Heater Energy Use

The WHAM equation yields average daily water heater energy consumption (Q_{in}). The equation is expressed as follows.

$$Q_{in} = \frac{vol \times den \times C_P \times (T_{tank} - T_{in})}{RE} \times \left(1 - \frac{UA \times (T_{tank} - T_{amb})}{Pon}\right) + 24 \times UA \times (T_{tank} - T_{amb})$$

Where:

Q_{in} = total water heater energy consumption in British thermal units per day, Btu/day,
RE = recovery efficiency, %,
P_{ON} = rated input power, Btu/h,
UA = standby heat-loss coefficient, Btu/h-^{o}F,
T_{tank} = thermostat set point temperature, ^{o}F,
T_{in} = inlet water temperature, ^{o}F,
T_{amb} = temperature of the ambient air, ^{o}F,
vol = volume of hot water drawn in 24 hours, gal/day,
den = density of stored water, set constant at 8.29 pounds per gallon, lb/gal, and
C_P = specific heat of stored water, set constant at 1.000743, Btu/lb-^{o}F.

Additional details about the WHAM equation are provided in appendix 7-C.

WHAM provides total water heater energy consumption. For gas-fired storage water heaters, gas-fired instantaneous water heaters, and oil-fired storage water heaters, Q_{in} is the sum of fuel and electricity consumption, and the values for electricity and fuel consumption must be disaggregated. DOE calculated electricity consumption as follows.

$$Q_{electricity} = \frac{Q_{in}}{P_{ON}} \times \left(P_{aux} - P_{standby}\right) - P_{standby} \times 24$$

Where:

$Q_{electricity}$ = electricity consumption, kWh/day,
Q_{in} = total water heater energy consumption, kWh/day,
P_{ON} = rated input power, kW,
P_{aux} = electricity demand when burner is on, kW, and
$P_{standby}$ = electricity demand when burner is off, kW.

DOE calculated gas consumption by subtracting electricity consumption from the total energy consumption for the water heater (Q_{in}).

For heat pump water heaters, energy efficiency and consumption are dependent on ambient temperature. To account for this factor, DOE expanded the WHAM to utilize the calculation approach used in the New York State Energy Research and Development Authority (NYSERDA) heat pump water heater site screening tool and DOE's weatherization assistance program.[20, 21] The equation for determining the energy consumption of heat pump water heaters is similar to the WHAM equation, but a performance adjustment factor that is a function of the average ambient temperature is applied to adjust *RE*. A heat pump water heater operates either in heat pump or in electric resistance mode. DOE assumed that the electric resistance mode of operation is used 100 percent of the time when the monthly ambient temperature is less than 32 ^{o}F or more than 100 ^{o}F. A heat pump water heater also operates in the electric resistance mode for part of the time even when the monthly ambient temperature is between 32 ^{o}F and 100 ^{o}F, because this product has a slower recovery rate than an electric resistance water heater. DOE determined that, depending on household hot water consumption patterns, the electric resistance mode of operation occurs for as much as 10 percent of the unit's operating time. (See appendix 7-C for a full description of the method). The equation is:

$$Q_{in} = vol \times den \times C_P \times \left(T_{tank} - T_{in}\right) \times \left[\begin{array}{l} \dfrac{HP\_frac}{RE_{HPWH} \times PA_{hpwh}} \times \left(1 - \dfrac{UA \times \left(T_{tank} - T_{amb}\right)}{P_{ON,HPWH}}\right) + \\ \dfrac{(1 - HP\_frac)}{RE_{ER}} \times \left(1 - \dfrac{UA \times \left(T_{tank} - T_{amb}\right)}{P_{ON,ER}}\right) \end{array}\right] + 24 \times UA \times \left(T_{tank} - T_{amb}\right)$$

Where:

Q_{in} = total water heater energy consumption, Btu/day,
vol = daily draw volume, gal/day,
den= density of water, lb/gal,
C_p = specific heat of water, Btu/lb-^{o}F,
T_{tank} = set point temperature for tank thermostat, ^{o}F,
T_{in}= temperature of inlet water, ^{o}F,

RE = recovery efficiency, %,
UA= stand-by heat-loss coefficient, Btu/h-°F,
T_{amb} = temperature of the ambient air, °F,
P_{ON} = rated input power, Btu/h,
PA_{hwh} = performance adjustment factor, and
HP_frac = fraction of water heating load that is satisfied by heat pump mode.

Heat pump water heaters draw heat from the space in which they are located. Thus, when such a water heater is located in a conditioned space, its use affects the load that the home's space heating and air conditioning equipment must meet. When the home is being heated, use of the heat pump water heater increases the heating load, and when the house is being cooled, its use decreases the cooling load.

In some cases where there is a significant effect, a household would likely choose to install a venting system to exhaust cooled air. DOE estimated that 50 percent of the households for which the heat pump cooling load generated during the heating season is greater than 3 MMBtu/h would have a venting system installed. Using calculations specific to each household in the subsample for electric water heaters, DOE estimated that 8 percent of replacement installations (or about 17 percent of indoor and heated basement installations) would incur this cost, which is described in chapter 8.

In the remaining cases, DOE believes the household would not want to incur the cost of a venting system, and would instead operate their heating and cooling systems to compensate for the effects of the heat pump water heater. To account for these indirect effects of heat pump water heaters on home energy use, DOE estimated the impact on space heating and air conditioning energy consumption for some of the homes in the RECS electric water heater subsample that have the water heater in the conditioned space.

For each such home, DOE estimated the impact on space heating in heating months only (when indoor temperature is 10 degrees greater than the average outdoor temperature), and the impact on air conditioning for cooling months only (when indoor temperature is 5 degrees less than the average outdoor temperature). DOE calculated the amount of cooling added (heat removed) by the heat pump water heater as follows:

$$CoolingInput = CoolingCap_{HPWH} \times \frac{vol \times den \times C_p (T_{tank} - T_{in})}{P_{ON,HPWH} \times RE_{HPWH} \times PA_{HPWH}}$$

Where:

$CoolingInput$ = amount of cooling added by the heat pump water heater, Btu/h,
vol = daily draw volume, gal/day,
den= density of water, lb/gal,
C_p = specific heat of water, Btu/lb-°F,
T_{tank} = set point of tank thermostat, °F,
T_{in} = indoor air temperature, °F,

$P_{ON,HPWH}$ = rated input power, Btu/h,
RE = recovery efficiency, %,
PA_{HPWH} = performance adjustment factor, and
$CoolingCap_{HPWH}$ = cooling capacity of heat pump water heater.

For the P_{ON} and cooling capacity of the heat pump water heater, DOE created distributions that apply for a range of possible heat pump water heater designs.[20, 21, 22] DOE used RECS data for each household to determine the primary heating system, fuel used to heat the house, and the type of cooling system. DOE then assigned an energy efficiency level to each type of equipment to determine the energy loss (from heating) or gain (from cooling). DOE based the energy efficiency of the heating and air conditioning equipment on the stock-average values for 2015 given in EIA's *Annual Energy Outlook (AEO) 2010*. [23] To account for the times during the summer months when the air conditioner is not operating, DOE reduced the estimated cooling benefits from the water heater by one-third.[a] See appendix 7-C for further details.

For instantaneous water heaters, DOE utilized the approach used for storage water heaters to calculate the energy use, modified to account for the absence of storage tank. DOE applied a performance adjustment factor to account for results from studies of instantaneous water heater performance under field conditions.[24, 25, 26, 27] Preliminary results from a study of instantaneous water heater installations conducted for the California Energy Commission (CEC) under field conditions at a single-family two-occupant residence indicated higher energy use than under the test procedure conditions. The report concludes that the discrepancy is due to the extra losses at small draw volumes.[24] The other studies have shown a similar effect. DOE's approach used data from Gas Technology Institute (GTI) and CEC studies to derive the adjustment factor as a distribution of values as a function of the household hot water use. Appendix 7-B provides details about the method.

The resulting equation is:

$$Q_{in} = \frac{vol \times den \times C_P \times (T_{tank} - T_{in})}{RE \times (1 + PA_{iwh})} \times \left(1 - \frac{Q_p}{P_{ON}}\right) + 24 \times Q_p \times (T_{Tank} - T_{amb})$$

Where:

Q_{in} = total water heater energy consumption, Btu/day,
vol = daily draw volume, gal/day,
den = density of water, lb/gal,
C_p = specific heat of water, Btu/lb-°F,
T_{tank} = set point of tank thermostat, °F,
T_{in} = inlet water temperature, °F,

[a] DOE believes it would be impractical for the occupants of the few households that use wood, coal, or kerosene as primary heating fuels to supplement heat produced by heat pump water heaters. Because DOE would find it difficult to quantify energy costs, DOE assumed that occupants would use an electric resistance heater to satisfy the additional heating requirements produced by the heat pump water heater.

RE = recovery efficiency, %,
PA_{iwh} = performance adjustment factor,
Q_p = pilot input rate, Btu/h,
P_{ON} = rated input power, Btu/h.

7.2.4.2 Description of Key Variables

The following is a description of the key variables for calculating energy use by water heaters.

- ***Recovery Efficiency (RE)***. The recovery efficiency (*RE*) is the ratio of energy added to the water compared to the energy input to the water heater. It represents how efficiently energy is transferred to the water when the heating element is on or the burner is firing. *RE* covers steady-state energy efficiency only. It accounts for the amount of energy lost through the water heater jacket, the flue, and fittings while the burner is firing.

- ***Rated Input Power (P_{ON}).*** Rated input power is the nominal power rating the manufacturer assigns to a particular design of water heater expressed in kW for electric water heaters and Btu/h for gas-fired or oil-fired water heaters. For gas-fired water heaters the rated input power includes the pilot light.

- ***Standby Heat-Loss Coefficient (UA).*** The standby heat-loss coefficient (*UA*) indicates the water heater hourly standby energy losses, expressed in Btu/h-oF. *UA*, which is calculated by the DOE test procedure, is reported in terms of the energy input required to maintain the water at the set point temperature. It represents the rate at which energy must be added to the water heater when it is not heating water for delivery.

- ***Set Point of Thermostat (T_{tank}).*** The thermostat set point is the desired delivery temperature of the hot water.

- ***Inlet Water Temperature (T_{in}).*** The inlet water temperature is the temperature of the water supplied to the water heater.

- ***Temperature of the Air Surrounding the Water Heater (T_{amb}).*** The temperature surrounding the water heater is the ambient air temperature of the space where the water heater is located.

- ***Volume of Hot Water Drawn in 24-Hour Period (vol).*** The estimated daily household use of hot water.

- ***Density of Water (den).*** The density of hot water at the average of the set point and inlet temperatures (8.29 lb/gal). The density is mass per unit volume, expressed as lb/gal (kg/l).

- ***Specific Heat of Water (C_p).*** The specific heat of water at the average of the set point and inlet temperatures (1.000743 Btu/lb-°F). The specific heat is the amount of heat needed to increase or decrease the temperature of 1 pound mass of water by 1 °F (1 kJ/kg - Kelvin).

7.2.4.3 Derivation of Energy Parameters

Key parameters in DOE's calculation of water heater energy consumption are the recovery efficiency (*RE*), the standby heat loss coefficient (*UA*), and the rated input power (P_{on}). DOE's test procedure for water heaters provided the definitions for these parameters.[28] DOE developed the parameters for selected energy efficiency level as described below. (See chapter 5 for a discussion of DOE's selection of energy efficiency levels.)

Determining RE. For gas-fired and oil-fired storage water heaters, DOE based the *RE* values on the design features and the distribution of models at each energy efficiency level as given in the February 2010 AHRI Directory.[15] This approach captures the variation of *RE* among models in the market.

Table 7.2.5 shows the distribution of *RE* values for gas-fired storage water heaters by efficiency level. The same *RE* values apply to all four rated volume size categories (30, 40, 50, and 75-gallons), based on the assumption that the design characteristics at each energy efficiency level are the same across the size categories. DOE estimated the recovery efficiency for the condensing water heater to be 90 percent.

Table 7.2.5 Assignment of *RE* to Gas-Fired Storage Water Heaters

RE	Efficiency Level 0	Efficiency Level 1	Efficiency Level 2	Efficiency Level 3	Efficiency Level 4	Efficiency Level 5
71%	0.3%	-	-	-	-	-
73%	1.0%	-	-	-	-	-
74%	2.4%	-	-	-	-	-
75%	1.4%	-	-	-	-	-
76%	59.5%	41.9%	42.6%	34.6%	100%	28.6%
77%	11.3%	4.8%	-	-	-	-
78%	8.6%	1.6%	2.1%	3.8%	-	14.3%
79%	12.7%	22.6%	25.5%	11.5%	-	-
80%	2.7%	22.6%	27.7%	34.6%	-	-
81%	-	3.2%	2.1%	11.5%	-	28.6%
82%	-	1.6%	-	3.8%	-	21.4%
84%	-	-	-	-	-	7.1%
87%	-	1.6%	-	-	-	-

DOE estimated that the recovery efficiency for electric water heaters with immersed heating elements is 98 percent for most energy efficiency levels (Table 7.2.6). For heat pump water heaters, DOE calculated *RE* by using the UA value reported for the heat pump water heater manufactured by ECR.[21]

Table 7.2.6 Assignment of RE for Electric Storage Water Heaters

Efficiency Level	EF (50-gallon)	RE
0	0.90	98%
1	0.91	98%
2	0.92	98%
3	0.93	98%
4	0.94	98%
5	0.95	98%
6	2.00	225%
7	2.20	261%

The *RE* values for 32-gallon size oil-fired water heaters also apply to the 50-gallon size (Table 7.2.7).

Table 7.2.7 Distribution of *RE* for Oil-Fired Storage Water Heaters

Efficiency Level	EF (32-gallon)	RE
0	0.53	76%
1	0.54	76%
2	0.56	76%
3	0.58	76%
4	0.60	76%
5	0.62	76%
6	0.66	80%
7	0.68	82%

DOE based *RE* values for instantaneous water heaters at each energy efficiency level on the design features at each level and on the distribution of models at each EF.[29, 30] This approach captures the variability of *RE* among the models in the market. The same *RE* values apply to all input capacities, because the design characteristics at each energy efficiency level are the same across the size categories. The *RE* for each energy efficiency level is shown in Table 7.2.8.

Table 7.2.8 Assignment of *RE* for Gas-Fired Instantaneous Water Heaters

Efficiency Level	EF	RE
0	0.62	78%
1	0.69	78%
2	0.78	78%
3	0.80	80%
4	0.82	82%
5	0.84	84%
6	0.85	85%
7	0.92	92%
8	0.95	95%

Determining UA. DOE used the following equation to calculate values for stand-by heat loss coefficient (*UA*).

$$UA = \frac{\left(\frac{1}{EF} - \frac{1}{RE}\right)}{(T_{tank} - T_{amb}) \times \left(\frac{24}{Q_{out}} - \frac{1}{RE \times Pon}\right)}$$

Where:

UA = standby heat loss coefficient, Btu/h-^{o}F,
EF = energy factor,
RE = recovery efficiency; %.
T_{tank} = temperature of the air surrounding the water heater, ^{o}F;
T_{amb} = thermostat set point temperature, ^{o}F;
Q_{out} = heat content of the water drawn from the water heater, Btu/h, and
P_{ON} = the rated input power, Btu/h.

Appendix 7-C, LCC Energy Use Calculations, describes the derivation of the above equation. For calculating *UA*, DOE used values for tank and ambient temperatures from the DOE test procedure.

For heat pump water heaters, DOE estimated that *UA* equals that of a 50-gallon electric storage water heater having a 0.95 EF. The additional heat losses due to the plumbing connections between the storage tank and the heat pump components are offset by the significantly higher *RE* of the heat pump water heater.

Determining P_{ON}. For each category of rated volume within each product class, DOE determined appropriate bins for rated input power (P_{ON}) based on the models listed in the February 2010 AHRI Directory,[15] and then calculated the percentage of models in each bin. This approach captures the variability of input capacity among the products models in the market. The percentage of P_{ON} values in each gas-fired storage water heater volume category is shown in Table 7.2.9.

Table 7.2.9 Distribution of Input Capacity for Gas-Fired Storage Water Heaters

Input Capacity (*P_{ON}*) *(kBtu/h)*	**Rated Volume** *(gallons)*				
	30-gal *(%)*	**40-gal** *(%)*	**50-gal** *(%)*	**65-gal** (%)	**75-gal** *(%)*
30	59.3	1.1	-	-	-
32	27.8	1.1	-	-	-
33	-	0.6	-	-	-
34	1.9	9.5	0.7	-	-
35.5	9.3	2.2	2.0	-	-
36	-	11.7	5.9	-	-
38	-	12.8	6.6	2.6	-
40	1.9	55.3	44.1	5.3	-
42	-	1.1	8.6	2.6	5.6%
45	-	-	0.7	-	-
48	-	1.7	2.0	-	-
50	-	2.8	11.8	15.8	-
52	-	-	-	2.6	-
55	-	-	-	7.9	5.6%
60	-	-	4.6	-	11.1%
62.5	-	-	0.7	-	-
65	-	-	10.5	55.3	-
67	-	-	2.0	-	-
70	-	-	-	7.9	22.2%
75	-	-	-	-	55.6%

The percentages of P_{ON} values in each electric water heater volume category are shown in Table 7.2.10. For heat pump water heaters, DOE created distributions that apply for a range of possible heat pump water heater designs.[20, 21, 22] See appendix 7-C for further details.

Table 7.2.10 Distribution of Input Capacity for Electric Storage Water Heaters

Input Capacity (*P_{ON}*) *(kW)*	**Rated Volume** *(gallons)*					
	30-gal *(%)*	**40-gal** *(%)*	**50-gal** *(%)*	**66-gal** *(%)*	**80-gal** *(%)*	**119-gal** *(%)*
1.5	3.0	-	-	-	-	-
1.7	3.0	-	-	-	-	-
3.0	3.0	1.9	5.6	-	3.3	11.8
3.8	9.1	15.4	13.0	4.2	6.7	11.8
4.5	81.8	82.7	81.5	91.7	86.7	76.5
5.5	-	-	-	4.2	3.3	-

Table 7.2.11 shows the percentage of P_{ON} values in each oil-fired water heater volume category.

Table 7.2.11 Distribution of Input Capacity for Oil-Fired Water Heaters

Input Capacity *(P_{ON})* *(kBtu/h)*	**Rated Volume** *(gal)*	
	32-gal *(%)*	**50-gal** *(%)*
90	28.6	-
103	14.3	33.3
104	42.9	33.3
105	14.3	33.3

For gas-fired instantaneous water heaters, which have no rated volume, DOE estimated the percentage of each of the three input capacities using RECS data on the size of gas-fired storage water heaters in households. To households having a small tank (less than 30-gallons) DOE assigned a gas-fired instantaneous water heater having 140 kBtu/h input capacity. To households having a large tank (greater than 50-gallon) tank DOE assigned a gas-fired instantaneous water heater having 199 kBtu per hour input capacity. To households having a medium tank (31- to 49-gallons), DOE assigned some a gas-fired instantaneous water heater having 180 kBtu per hour input capacity, and the rest a gas-fired instantaneous water heater having 199 kBtu per hour input capacity (see Table 7.2.12).

Table 7.2.12 Distribution of Input Capacity for Gas-Fired Instantaneous Water Heaters

Range of Input Capacity *(kBtu/h)**	**Assigned Input Capacity** *(kBtu/h)*	**Fraction Assigned to Sample Households** *(%)*
140–169	140	22.2%
170–185	180	26.7%
186–199	199	51.1%

* DOE did not include units having a capacity <140 kBtu/h because such units are considered unsuitable for whole-house water heating.[31]

7.2.4.4 Derivation of Temperatures

The temperatures for thermostat set point, inlet water, and the ambient air are derived from the average annual outdoor air temperature for each sample household.

Outdoor Air Temperature. RECS 2005 provides data on heating and cooling degree-days, but not on air temperatures for each household in the sample. To each RECS 2005 household DOE assigned a physical location from which outdoor air temperatures could be derived as follows:

- DOE assembled weather data from 282 weather stations that provide 30-year averages for annual average outdoor air temperatures.[32, 33] DOE also gathered the heating and cooling degree-days at a base temperature of 65 ^{o}F for 2005 for those weather stations.[34] The

2005 heating and cooling degree-days match the period used to determine the degree-days in RECS 2005.

- RECS 2005 reports both heating and cooling degree-days to base temperature 65 ^{o}F for each housing record. DOE assigned each RECS 2005 household to one of the 282 weather stations by calculating which station (within the appropriate census region or large state) gave the best fit of RECS 2005 data to weather data.

Details about the derivation of the annual average outdoor air temperatures for the RECS 2005 water heater sample are provided in appendix 7-D, Weather Data and Temperature Parameters for LCC Analysis. DOE's analysis produced average outdoor temperatures of 59.2 ^{o}F for electric storage water heaters, 55.9 ^{o}F for gas-fired storage water heaters and gas-fired instantaneous water heaters, and 48.9 ^{o}F for oil-fired storage water heaters. Figure 7.2.4 shows the range of average annual outdoor air temperatures among sample households.

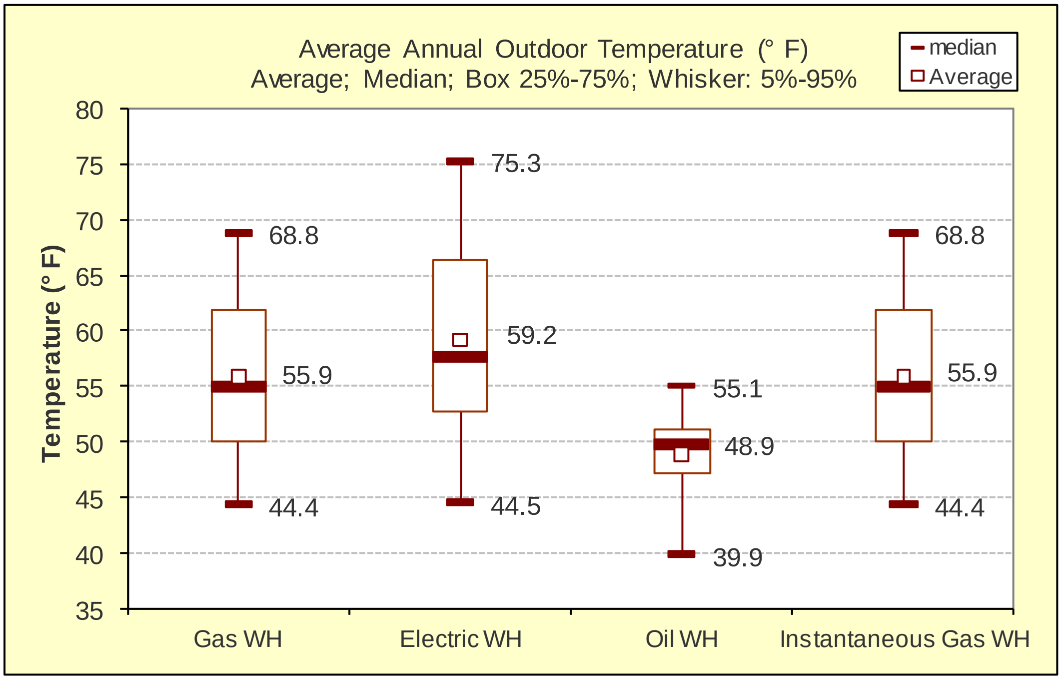

Figure 7.2.4 Range of Annual Outdoor Air Temperature for Sample Households by Water Heater Product Class

Inlet Water Temperature. The inlet water comes to the water heater either from a municipal treatment plant or from ground well sources. DOE determined the water source using RECS 2005, which enables one to identify whether a household has a water well. Households that don't have a water well presumably use water from municipal treatment plants.

DOE derived inlet water temperature using an approach developed by the National Renewable Energy Laboratory.[35, 36] This approach accounts for seasonal variations in inlet water temperature as a function of annual average outdoor air temperature. The monthly average inlet water temperature varies directly with the average annual outdoor air temperature corrected by an offset term. The equation for inlet water temperature has the following form:

$$T_{IN} = T_{air,avg} + offset + lag$$

The calculation details and the parameter definitions are described in appendix 7-D. DOE calculated the offset term separately for the households that use municipal treatment plants and those that use ground well sources. DOE used a method described by the Electrical Power Research Institute[37] to calculate the offset for the households that have water wells. This method suggests adding two degrees to the average annual outdoor air temperature to calculate the inlet water temperature for ground water sources. The offset for households using municipal treatment plants was calculated using typical average long-term water temperatures for households having water that comes from municipal treatment plants.[37] The derivation of those values is described in appendix 7-D.

The analysis identified an average inlet water temperature of 62.8 ^{o}F for electric storage water heaters, 59.6 ^{o}F for gas-fired storage water heaters and gas-fired instantaneous water heaters, and 55.1 ^{o}F for oil-fired water heaters. Figure 7.2.5 shows the range of inlet water temperatures among sample households.

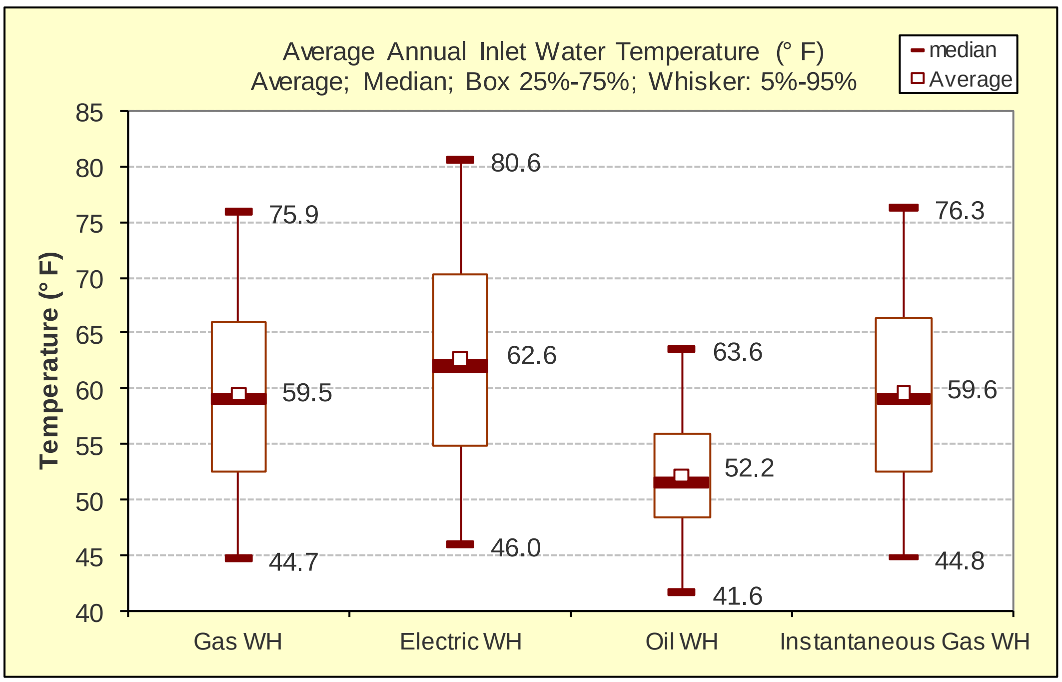

Figure 7.2.5 Range of Daily Average Annual Inlet Water Temperature for Sample Households by Water Heater Product Class

Water Heater Thermostat Settings. DOE assigned water heater thermostat settings to the RECS 2005 households based on a 2006 survey commissioned by *Plumbing & Mechanical* magazine.[38] The information about thermostat settings reflects the results from a survey of 343 plumbing/hydronic heating contractor firms that install water heaters throughout the United States in new and replacement markets.

The magazine survey indicated that 41 percent of responding contractors always install a water heater with a set point temperature of 120 °F; 20 percent always install the water heater with a set point temperature higher than 120 °F; and the other 39 percent usually install the water heater with a thermostat at 120 °F. Based on this information, DOE estimated that half of the latter water heater installations have a set point temperature of 120 °F, leading to a total of 61 percent of water heaters set to 120 °F, with 39 percent uniformly distributed between 121 °F and 140 °F.[b] This approach resulted in a mean temperature set point of 124.2 °F for the RECS 2005 water heater household sample.

Although water heaters are shipped having the thermostat set to 120 °F, several factors may cause contractors and/or household occupants to increase the set-point temperature, such as:

- High hot water draws: Increasing the set point temperature decreases the likelihood of running out of hot water.
- Cold inlet water: Increasing the set point temperature can help compensate for the mixture produced by very cold water and hot water.
- Small water heaters: A smaller water heater might be set to a higher set-point temperature to be more responsive to hot water needs.

Ambient Air Temperature. Ambient air temperature (the temperature of the air surrounding the water heater), which is used to calculate heat losses, differs based on where the water heater is installed. Water heaters most commonly are installed in garages, in basements, in crawlspaces, or inside the house.[20, 39] For single-family houses, RECS 2005 reports whether the house has a basement, whether the basement is heated or unheated, and the presence or absence of a garage, crawlspace, or attic. For houses that have a basement only, DOE assumed that the water heater was located in the basement. For houses that have a basement and garage, DOE estimated that half the water heaters are in the basement and half are in the garage. For two-story houses built after 1980 that have a garage and attic, DOE estimated that half the water heaters are in the garage and half in the attic. For all other houses with a garage, DOE assumed that the water heater was in the garage. For houses built after 1980 that have an attic only, DOE assumed that the water heater was in the attic. For houses that have a crawlspace only, DOE assumed that half the water heaters were in the crawlspace and half were inside the house. In the absence of a basement, garage, or crawlspace, DOE assumed that the water heater was inside the house (in a laundry room, kitchen, or utility closet). DOE further assumed that 50 percent of manufactured homes and 25 percent of multi-family houses in climates where the heating degree-days are less than 4,000 would have the water heater installed in an outdoor closet. The rest of the manufactured houses and multi-family houses were assumed to have the water heater installed indoors.

DOE assumed that oil-fired storage water heaters were not installed indoors or in the attic. In the absence of a basement, garage, or crawlspace, DOE assumed that the water heater was installed in an outdoor closet or a similar location.

[b] 140 °F is the maximum allowed to avoid scalding.

DOE determined ambient air temperatures based on information about typical locations of water heaters as follows:

- For heated basement installation, DOE assumed the ambient temperature equaled the home's average house indoor temperature given by RECS 2005.
- For unheated basement installation, DOE calculated the ambient temperature as the mean of the average house outdoor and indoor temperatures.
- For a garage, crawlspace, or outside closet installation, DOE assigned an ambient temperature that was 5 ^{o}F higher than the outdoor air temperature for that location.[39]
- For inside-the-house installations, DOE assumed the ambient temperature equaled the home's average house indoor temperature given by RECS 2005.
- For attic installation, DOE assigned an ambient temperature that was 5 ^{o}F higher than the outdoor air temperature for the months when the average outdoor air temperature is below 80 ^{o}F, and 10 ^{o}F higher than the outdoor air temperature for the months when the average outdoor air temperature is above 80 ^{o}F for that location.[39]

Table 7.2.13 shows the percentages of the various water heater locations as well as the ambient air temperature derivation for each installation location.

Table 7.2.13 Water Heater Location by Product Class

Location	**Temperature Derivation**	**Gas-Fired** *(%)*	**Electric** *(%)*	**Oil-Fired** *(%)*
Heated Basement	Avg. Indoor Temperature	18.6	9.7	20.5
Unheated Basement	(Avg. Indoor Temp + Avg. Outdoor Temp) / 2	11.6	8.4	48.4
Garage, Crawlspace, or Outdoor Closet	Avg. Outdoor Temp + 5 °F	42.6	40.3	31.1
Inside House	Avg. Indoor Temperature	24.6	39.2	0.0
Attic Installation	Avg. Outdoor Temp + 5 °F (winter), + 10 °F (summer)	2.6	2.5	0.0
Total		100	100	100

The analysis identified average annual ambient temperatures of 68.2 ^{o}F for electric storage water heaters, 65.8 ^{o}F for gas-fired storage water heaters and gas-fired instantaneous water heaters, and 59.2 ^{o}F for oil-fired water heaters. Figure 7.2.6 shows the range of annual ambient air temperature among sample households.

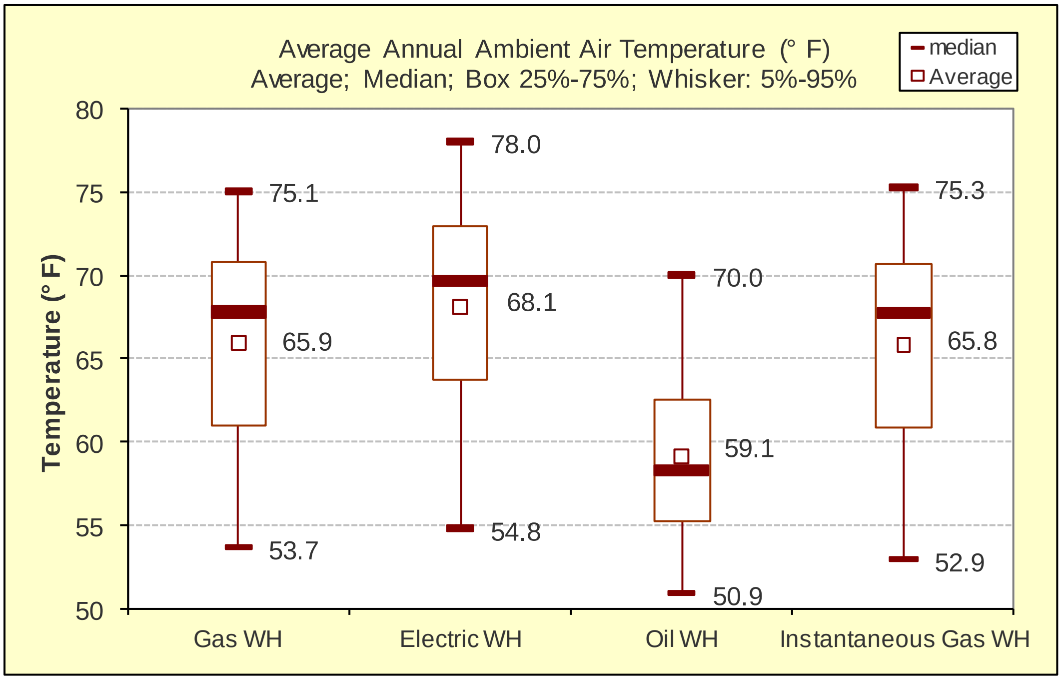

Figure 7.2.6 Range of Annual Ambient Air Temperature in Sample Households by Water Heater Product Class

7.2.4.5 Overview of Approach for Calculating Water Heater Energy Consumption

Figure 7.2.7 provides an overview of DOE's approach to calculating water heater energy use for each sample household.

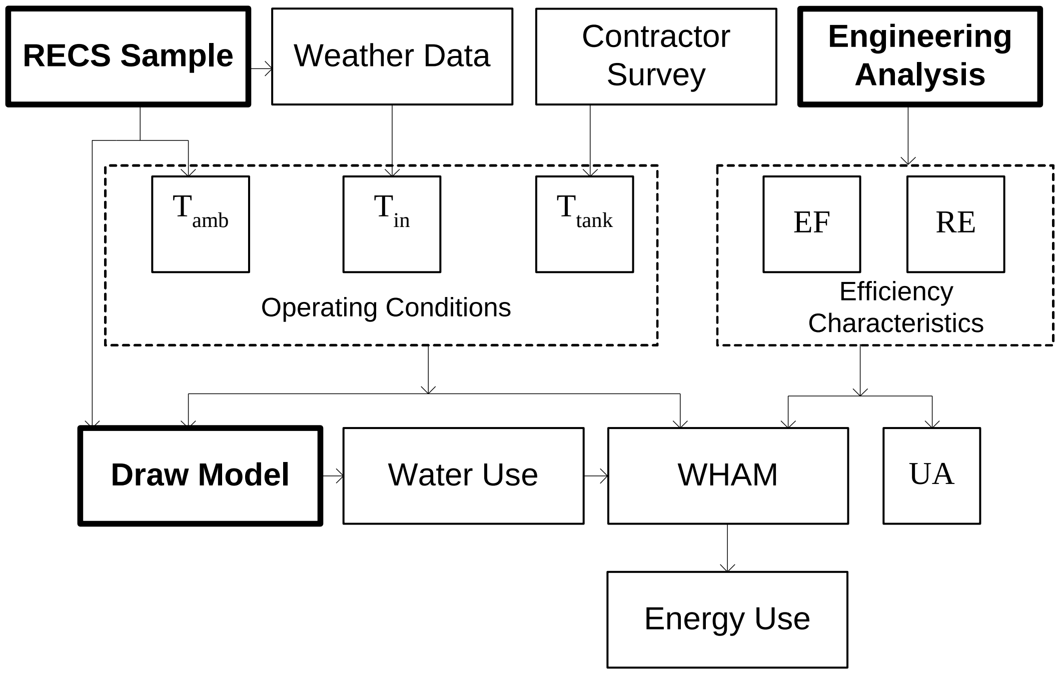

Figure 7.2.7 Process for Calculating Water Heater Energy Use

7.2.5 Average Annual Energy Consumption

This section presents the average annual energy use and the average energy savings for each considered energy efficiency level compared to the baseline energy efficiency for each water heater product class. For its LCC and PBP analyses, DOE used the full distribution of energy use values calculated for the sample households.

Table 7.2.14 lists the average annual energy use for gas-fired storage water heaters and the average energy savings for each considered energy efficiency level compared to the baseline water heater. The energy savings include the higher use of electricity at an EF of 0.64 and above.

Table 7.2.14 Annual Energy Consumption for Gas-Fired Storage Water Heaters

Energy Efficiency Level *(EF)*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
0.59 (baseline)	16.5	0.0	--
0.62	15.7	0.0	0.8
0.63	15.2	5.9	1.3
0.64	14.7	68.5	1.8
0.65	14.2	67.2	2.3
0.67	13.7	65.6	2.9
0.77	11.9	60.6	4.6

Table 7.2.15 lists average annual energy use for electric storage water heaters and average energy savings for each energy efficiency level evaluated in the LCC analysis, compared to the baseline water heater.

Table 7.2.15 Annual Energy Consumption for Electric Storage Water Heaters

Energy Efficiency Level *(EF)*	**Average Energy Consumption** *(kWh/yr)*	**Average Energy Savings** *(kWh/yr)*
0.90 (baseline)	2604	--
0.91	2569	35
0.92	2535	69
0.93	2515	89
0.94	2467	137
0.95	2431	173
2.00	1399	1205
2.35	1216	1388

Table 7.2.16 shows the average annual energy use for oil-fired water heaters and the average energy savings for each energy efficiency level compared to the baseline. The energy savings include the lower use of electricity at an EF of 0.54 and above.

Table 7.2.16 Annual Energy Consumption for Oil-Fired Storage Water Heaters

Energy Efficiency Level *(EF)*	**Average Energy Consumption**		**Average Energy Savings (Oil)** *(MMBtu/yr)*
	Fuel Oil *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
0.53 (baseline)	21.6	60.8	--
0.54	21.1	59.3	0.5
0.56	20.1	56.5	1.5
0.58	19.2	53.9	2.4
0.60	18.3	51.5	3.3
0.62	17.5	49.2	4.1
0.66	16.4	46.0	5.3
0.68	15.8	44.5	5.8

Table 7.2.17 lists the average annual energy use for gas-fired instantaneous water heaters and the average energy savings for each energy efficiency level compared to the baseline water heater. The energy savings include the higher use of electricity at an EF of 0.78 and above.

Table 7.2.17 Annual Energy Consumption for Gas-Fired Instantaneous Water Heaters

Energy Efficiency Level *(EF)*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
0.62 (baseline)	16.7	0.0	--
0.69	14.8	0.0	1.9
0.78	11.5	25.9	5.2
0.80	11.2	29.2	5.5
0.82	10.9	29.1	5.8
0.84	10.7	29.0	6.1
0.85	10.6	28.9	6.2
0.92	9.8	28.6	7.0
0.95	9.4	28.4	7.3

7.3 DIRECT HEATING EQUIPMENT

7.3.1 Introduction

Direct heating equipment utilizes both gas and electric energy. In the engineering analysis, DOE calculated energy consumption of baseline direct heating equipment using the DOE test procedure for those products. For the LCC analysis, DOE estimated energy consumption of direct heating equipment in actual housing units.

To represent actual households likely to purchase and use direct heating equipment, DOE developed a household sample from RECS 2005.[1] For each household in the sample, DOE used

RECS 2005 reported heating energy consumption (based on the existing heating system) to calculate the heating load of each household. The heating load represents the amount of heating required to keep a housing unit comfortable throughout an average year. DOE estimated the heating loads from the reported heating energy consumption and the estimated energy efficiency of the direct heating equipment in each sample housing unit. DOE assigned the energy efficiency of existing systems based on the distribution of energy efficiencies for direct heating equipment provided in the February 2010 AHRI directory.[15] The estimation of heating loads also required calculating the electricity consumption of the blower (when applicable), because heat from the blower contributes to heating the housing unit. To complete the analysis, DOE calculated the energy consumption of alternative (more energy efficient) products if they replaced existing systems in each housing unit.

7.3.2 Household Sample

The subset of RECS 2005 households used for evaluating the energy use of direct heating equipment met all of the following criteria:

- The household employed a wall or pipeless floor furnace, room heater, or fireplace as the primary or secondary source of heat.
- The heating fuel was natural gas or LPG.
- The equipment heated only one housing unit.
- Secondary fireplace equipment had a flue vent.
- The equipment had energy consumption greater than zero.

The subset of households using direct heating equipment represents 375 housing records, representing 9.4 million households (8.4 percent of the total weighted RECS sample). Appendix 7-A, RECS 2005 Values and Variables, describes the subset of households.

DOE matched each RECS heating equipment category to the direct heating equipment product classes using several assumptions. For gas wall fan and gas wall gravity DHE, DOE used a household sample that includes the RECS 2005 categories of floor/wall furnace for both primary and secondary equipment. For gas floor DHE, DOE used a household sample that includes only the RECS 2005 category for primary floor/wall furnaces.[c] For gas room DHE, DOE used a household sample that includes the RECS 2005 room heater categories for both primary and secondary equipment. For gas hearth DHE, DOE used a household sample that includes 90 percent of the time both primary and secondary equipment fireplace categories and 10 percent of the time both primary and secondary equipment room heater categories.

Table 7.3.1 lists the criteria used to develop the household sample and shows the number of households included in the analysis.

[c] RECS 2005 does not distinguish between wall and floor furnaces. Thus the samples for gas wall fan furnace, gas wall gravity furnace, and floor furnace direct heating equipment utilize the same household sample (not including secondary equipment which is only part of gas wall fan and gas wall gravity).

Table 7.3.1 Summary of Direct Heating Equipment Household Sample

Product Class Category	Selection Criteria	Fuel Type	No. of Records	No. of US Households Represented *(million)*
Primary Equipment				
Gas Wall Fan, Gas Wall Gravity, Gas Floor DHE	Primary Equipment Type = Floor/Wall Pipeless Furnace Number of Housing Units Heated = 1	Natural Gas	88	2.1
		LPG	7	0.2
Gas Room DHE	Primary Equipment Type = Room Heater Number of Housing Units Heated = 1	Natural Gas	77	1.9
		LPG	35	0.9
Gas Fireplace DHE	Primary Equipment Type = Fireplace Fireplace is Vented = Yes Number of Housing Units Heated = 1	Natural Gas	4	0.1
		LPG	6	0.2
Secondary Equipment				
Gas Wall Fan, Gas Wall Gravity	Secondary Equipment Type = Floor/Wall Furnace	Natural Gas	3	0.1
		LPG	3	0.1
Gas Room DHE	Secondary Equipment Type = Room Heater	Natural Gas	19	0.5
		LPG	22	0.6
Gas Fireplace DHE	Secondary Equipment Type = Fireplace Fireplace is Vented = Yes	Natural Gas	93	2.3
		LPG	18	0.5

7.3.3 Determining Annual House Heating Load

The annual house heating load (HHL) is the total amount of heat output from the direct heating equipment during the heating season. This amount includes heat from both the burner and the blower. DOE determined the HHL for each sample housing unit based on the household heating fuel consumption and the characteristics of the systems. DOE used the following calculations, which are based on the DOE test procedure.[19] Details are presented in appendix 7-C.

$$HHL = \left(\frac{Q_{YR,RECS} - 8760 \times Q_P}{A \times (Q_{IN} - Q_P)} + 4160 \times Q_P \times \eta_U \right) \times Adj\_Factor$$

Where:

$Q_{YR,RECS}$ =	annual fuel consumption for heating the housing unit, from RECS 2005, kBtu/yr,
Q_P =	pilot input rate, Btu/h,
Q_{IN} =	rated input capacity of direct heating equipment, Btu/h,
8,760 =	hours in a year, h,
4,160 =	average heating season hours according to test procedure, h,
A =	TP factor, h/kBtu = $\dfrac{100{,}000}{341{,}000 \times PE + (Q_{in} - Q_P) \times \eta_U}$,
PE =	power consumption of the direct heating equipment while the burner is on, W, and
η_U =	efficiency of part-load utilization (%),
Adj_Factor =	adjustment factor.

The average pilot input rate for the above calculation is 400 Btu/h for gas wall fan and gas wall gravity DHE, 450 Btu/h for gas floor DHE, and 350 Btu/h for gas room and hearth DHE.[40] Section 7.3.4.1 describes the values for input capacity (Q_{IN}).

The *PE* value reflects a design that incorporates a draft inducer, electronic ignition, and air circulation fan components. To calculate *PE*, DOE used values given in the 1993 technical support document.[40] For gas room DHE that operate at higher energy efficiency levels, *PE* also includes the power consumption of the air circulation fan. Note that the efficiency of part-load utilization (η_U) depends on AFUE, the assignment of which is explained in Section 7.3.4.2.

The adjustment factor (*Adj_Factor*) takes into account future improvements to the building shell and increases in home area based on EIA's 2010 Annual Energy Overview (*AEO 2010*) projections for retrofit and new construction in 2013. [23]

For households for which the natural gas use for heating clearly is associated solely with use of the direct heating equipment as primary or secondary heating equipment, DOE used the annual fuel consumption for heating the housing unit, from RECS 2005. DOE adjusted the house heating load for households that used a gas furnace as the primary heating equipment and the direct heating equipment as secondary heating equipment. RECS 2005 reports the percentage of heating energy consumption attributable to secondary products. DOE derived the house heating load applicable to the direct heating equipment by subtracting the estimated amount of heat provided by the primary system. Details are presented in appendix 7-E, Derivation of Heating Load for Pool Heaters and Direct Heating Equipment.

7.3.4 Assigning Direct Heating Equipment to Sample Households

As explained in the framework document, DOE proposes to maintain the sixteen product classes for direct heating equipment established in the Energy Policy and Conservation Act of 1975 (EPCA). In its LCC analysis, however, DOE used a single representative product class for each product category (*i.e.*, for gas wall fan, gas wall gravity, gas floor, gas room, and gas hearth direct heating equipment). DOE extrapolated to the other classes the analytical results for the representative product class in each category of direct heating equipment.

DOE selected the class having the greatest percentage of shipments in its category to serve as the representative product class. Based on shipments data from the 1993 technical support document[40] for gas wall fan, gas wall gravity, gas floor, gas room, and gas hearth direct heating equipment, and the number of available models listed in February 2010 AHRI Residential Direct Heating Directory,[15] DOE chose the following product classes to represent each direct heating equipment category:

- gas wall fan direct heating equipment using more than 42,000 Btu/h;
- gas wall gravity direct heating equipment using more than 27,000 and up to 46,000 Btu/h;
- gas floor direct heating equipment using more than 37,000 Btu/h;
- gas room direct heating equipment using more than 27,000 and up to 46,000 Btu/h; and
- gas hearth direct heating equipment using more than 27,000 and up to 46,000 Btu/h.

7.3.4.1 Input Capacity of Existing Equipment

Table 7.3.2 shows the distribution of input capacities for the representative product classes listed above, based on February 2010 AHRI Residential Direct Heating Directory. Gas hearth DHE includes vented gas fireplace heaters as well as gas stoves and fireplace inserts.

Table 7.3.2 Distribution of Input Capacity for Representative Product Classes of Direct Heating Equipment

Input Capacity *(kBtu/h)*	Percentage of Models				
	Gas Wall Fan	Gas Wall Gravity	Gas Floor	Gas Room	Gas Hearth
27.3		-		-	0.3%
27.5		-		-	0.3%
28		-		-	7.9%
28.5		-		-	0.5%
29		-		-	2.2%
29.5		-		-	0.3%
29.6		-		-	0.3%
29.65		-		-	0.5%
30		12.5%		-	15.6%
30.4		-		-	0.5%
30.5		-		-	1.9%
30.8		-		-	0.3%
31		-		-	4.1%
31.3		-		-	0.3%
31.5		-		-	0.3%
32		25.0%		-	5.5%
32.5		-		-	0.5%
33		12.5%		-	6.0%
33.2		-		-	0.3%
33.5		-		-	0.3%
34		-		-	1.9%
34.25		-		-	0.5%
34.6		-		-	0.3%
35		50.0%		100.0%	8.7%
35.5		-		-	0.5%
35.6		-		-	0.3%
36		-		-	3.3%
37		-		-	3.0%
37.5		-	-	-	1.9%
38		-	-	-	5.7%
38.5		-	-	-	0.5%
39		-	-	-	3.0%
39.5		-	-	-	0.3%
40		-	-	-	10.7%
41		-	-	-	0.5%
41.4		-	-	-	0.3%
41.5		-	-	-	0.8%
42		-	-	-	3.3%
42.5	-	-	-	-	0.5%
43	-	-	-	-	2.2%
43.5	-	-	-	-	0.3%
44	-	-	-	-	1.4%
45	-	-	28.6%	-	2.2%
50	13.3%		14.3%		
55	46.7%		-		
60	6.7%		14.3%		
62	-		14.3%		
62.5	13.3%		-		
65	20.0%		14.3%		
75	-		14.3%		
Average *(kBtu/h)*	57.7	33.3	57.4	35.0	34.7

7.3.4.2 Efficiency of Existing Equipment

To represent the energy efficiency of existing direct heating equipment in the sample homes, DOE used the current Federal minimum energy conservation standards for such equipment that took effect in 1990.[41] This choice was based on product ages from RECS 2005 and the belief that energy efficiency changed little during the 1980s and 1990s. DOE assumed that existing direct heating equipment is equipped with a continuous pilot light. Table 7.3.3 shows the energy efficiency levels assigned for the representative product classes.

Table 7.3.3 Energy Efficiency of Existing Direct Heating Equipment

Representative Product Class	**Efficiency** *(AFUE)*
Gas Wall Fan More Than 42,000 Btu/h	74%
Gas Wall Gravity More Than 27,000 up to 46,000 Btu/h	64%
Gas Floor More Than 37,000 Btu/h	57%
Gas Room More Than 27,000 up to 46,000 Btu/h	64%
Gas Hearth More Than 27,000 up to 46,000 Btu/h	64%

7.3.5 Calculation of Energy Consumption

Knowing the heating load of each sample housing unit, one can estimate the energy consumption if more energy efficient products, rather than the existing baseline products, were used in each household.

7.3.5.1 Fuel Consumption

DOE calculated the fuel consumption for single-stage direct heating equipment using the following formula, which is taken from the current revision of DOE's test procedure.[42]

$$FuelUse = BOH \times (Q_{IN} - Q_P) + 8760 \times Q_P$$

Where:

FuelUse = fuel consumption, kBtu/year,
BOH = burner operating hours, h,
Q_{in} = input capacity, kBtu/h (at the max input rate),
8,760 = hours per year, and
Q_p = pilot light input rate, kBtu/h.

The value assigned to burner operating hours (BOH) is a function of the heating load, average heating season hours, efficiency of part-load utilization, and pilot light input rate. The BOH accounts for the contribution the electrical components make to heating the house. For each considered energy efficiency level, BOH has a different value. Calculation of fuel consumption is described in detail in appendix 7-C.

7.3.5.2 Electricity Consumption

DOE calculated the electricity consumed by direct heating equipment for the draft inducer, igniter, and air circulation fan and during stand-by mode. The current DOE test procedure accounts for only the total electricity demand when the product is firing (*PE*), but some components consume electricity when the unit is not firing. This standby consumption includes use by the ignition device, by the controls when the unit is off, and when the circulation fan is operating while the burner is off. DOE calculated the electricity consumption for single-stage direct heating equipment as follows.

$$ElecUse = BOH \times PE + (8760 - BOH) \times P_{stby}$$

Where:

$ElecUse$ = electricity consumed by direct heating equipment, kWh/year;
BOH = burner operating hours, h;
PE = electricity demand when the equipment is firing, kW; and
P_{stby} = stand-by power consumption (when the burner is off), kW.

The details for calculating electricity consumption are described in appendix 7-C.

7.3.6 Average Annual Energy Consumption and Energy Savings

The average annual energy use and energy savings for each considered energy efficiency level are shown in Tables 7.3.4 through 7.3.8 for each representative product class. For the LCC and PBP analyses, DOE used the full distribution of energy use values calculated for the sample households.

Table 7.3.4 Average Energy Consumption for Gas Wall Fan Direct Heating Equipment

Efficiency Level *(AFUE)*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
74 (baseline)	29.9	38.6	--
75	28.2	45.7	1.7
76	27.8	45.2	2.1
77	27.4	44.7	2.4
80	26.3	66.2	3.5

Table 7.3.5 Average Energy Consumption for Gas Wall Gravity Direct Heating Equipment

Efficiency Level *(AFUE)*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
64 (baseline)	29.9	0.0	--
66	29.0	0.0	0.8
68	28.2	0.0	1.6
69	27.8	0.0	2.0
70	26.5	17.7	3.4

Table 7.3.6 Average Energy Consumption for Gas Floor Direct Heating Equipment

Efficiency Level *(AFUE)*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
57 (baseline)	30.8	0.0	--
58	30.3	0.0	0.5

Table 7.3.7 Average Energy Consumption for Gas Room Direct Heating Equipment

Efficiency Level *(AFUE)*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
64 (baseline)	27.5	0.0	--
65	27.1	0.0	0.4
66	26.7	0.0	0.8
67	26.3	0.0	1.2
68	26.0	0.0	1.5
83	20.2	81.1	7.3

Table 7.3.8 Annual Energy Consumption for Gas Hearth Direct Heating Equipment

Efficiency Level *(AFUE)*	Average Energy Consumption		Average Energy Savings *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
64 (baseline)	16.6	0.0	--
67	14.6	15.3	2.0
72	13.5	38.6	3.1
93	10.4	47.1	6.2

7.4 POOL HEATERS

In the engineering analysis, DOE calculated energy consumption of pool heaters using the DOE test procedure for those products. For the LCC analysis, DOE estimated energy consumption of pool heaters in actual housing units. To represent actual households likely to purchase and use pool heaters, DOE used a combined household sample from RECS 2001 and RECS 2005.[1, 11, 12, 13] DOE did this in order to increase the sample size and have a more accurate account of the average pool heater energy use.

For each household, DOE used RECS-reported energy consumption for pool heating (based on existing systems) to calculate the pool-heating load of each sample household. The pool heater heating load represents the amount of heating required for a pool throughout a year. DOE estimated the pool-heating load from the reported pool-heating energy consumption and the estimated energy efficiency of the existing pool heater in each sample housing unit. To complete the analysis, DOE calculated the energy consumption of alternative (more energy efficient) products if they were installed in each housing unit in place of existing products.

7.4.1 Household Sample

The subset of records used to select a RECS 2001 and RECS 2005 household sample for pool/spa heaters met all of the following criteria (see appendix 7-A for details).

- The household had a swimming pool or spa.
- A pool heater was used to heat pool or spa water.
- The pool heater used natural gas or liquefied petroleum gas (LPG) as a heating fuel.

The combined RECS 2001 and RECS 2005 pool heater sample is weighted such that it represents the same number of households as in RECS 2005. Pool heaters used to heat spas only are assumed to represent 15% of the total spa/pool heater sample based on assumptions from the 1993 TSD. {U.S. Department of Energy-Office of Codes and Standards, 1993 #2949} Therefore, spa heaters sample is weighted to 24% of the original RECS weight.

Table 7.4.1 Criteria for Selecting Household Sample for Pool Heaters (RECS 2001–2005)

RECS Year	Fuel Type	Fuel Type	Algorithm	No. of Records	No. of US Households Represented *(million)*
RECS 2001	Pool Heater Sample	Natural Gas	Have Swimming Pool? = Yes Is it heated? = Yes Fuel Type = Natural gas	30	0.8
		Propane	Have Swimming Pool? = Yes Is it heated? = Yes Fuel Type = Propane	11	0.2
	Spa Heater Sample	Natural Gas	Have Spa? = Yes Is it heated? = Yes Fuel Type = Natural gas	31	0.8
		Propane	Have Spa? = Yes Is it heated? = Yes Fuel Type = Propane	4	0.1
RECS 2005	Pool Heater Sample	Natural Gas	Have Swimming Pool? = Yes Is it heated? = Yes Fuel Type = Natural gas	43	1.2
		Propane	Have Swimming Pool? = Yes Is it heated? = Yes Fuel Type = Propane	11	0.3
	Spa Heater Sample	Natural Gas	Have Spa? = Yes Is it heated? = Yes Fuel Type = Natural gas	29	0.8
		Propane	Have Spa? = Yes Is it heated? = Yes Fuel Type = Propane	6	0.2
Combined RECS 2001-2005	Pool/Spa Heater Sample	Natural Gas	Have Pool/Spa? = Yes Is it heated? = Yes Fuel Type = Natural gas	133	1.4
		Propane	Have Pool/Spa? = Yes Is it heated? = Yes Fuel Type = Propane	32	0.3

7.4.2 Input Capacity and Heating Load

DOE assigned all sample households a 250-kBtu/h pool heater, the most common rating for all covered models listed in the May 2009 FTC pool heater directory[43] and manufacturer literature. The annual pool heater heating load (*PHHL*) is the total heat output from the pool heater during a year. DOE used the following equation to determine *PHHL* for each sampled household.

$$PHHL = (Q_{RECS} - Q_p \times POH) \times E_t$$

Where:

$PHHL$ =	pool heater annual heating load;
Q_{RECS} =	pool heater annual fuel consumption (kBtu/yr);
Q_p =	pilot light input rate (kBtu/yr);
POH =	average number of pool operating hours (h/yr); and
E_t =	thermal efficiency of the existing pool heater associated with the household (%).

The pool heater annual fuel consumption (Q_{RECS}) for each household having a pool heater was taken from RECS 2001 and RECS 2005.

For units that have a pilot light, DOE assigned a pilot light input rate of 1,000 Btu per hour.[40, 44] DOE assigned pilot lights to 8 percent of the households that have pool heaters based on manufacturer data. DOE assumed the remaining 92 percent were equipped with electronic ignition.

The DOE test procedure uses an average value for pool heater operating hours (when the pilot light is on) of 4,464 hours per year. In the absence of adequate data on actual operating hours, DOE used a distribution around this average to assign values for pool heater operating hours to the sample households. The distribution ranges from 235 hours per year to 8,760 hours per year, where the upper limit represents a year-around operation. The value of 235 hours per year is the minimum value of the triangular distribution used to calculate pool operating hours.

DOE assigned the sample households an existing pool heater having thermal efficiency based on the survey year. DOE assumed that almost all pool heaters associated with RECS 2001 and RECS 2005 households were installed after EPCA mandated the 78-percent energy conservation standard. Therefore, the existing pool heater is assigned a 78-percent thermal efficiency.

7.4.3 Calculation of Energy Consumption

Knowing the pool heater heating load for each sample housing unit, one can estimate what the energy consumption would be if more energy efficient products, rather than the existing products, were used in each household. DOE used the method stipulated in the DOE test procedure to calculate the fuel consumption at the considered energy efficiency levels for each household.

$$E_F = BOH \times Q_{IN} + (POH - BOH) \times Q_p$$

Where:

E_F = average annual fuel energy for pool heater, kBtu/yr,
BOH= burner operating hours, h/yr,
Q_{in}= pool heater input rate, kBtu/h,
POH = pool operating hours, h/yr, and
Q_p = pilot light input rate, kBtu/h.

DOE calculated the electricity consumption at the considered energy efficiency levels for each household using the method provided in the DOE test procedure and adding stand-by electricity consumption.

$$E_{AE} = BOH \times PE - (POH - BOH) \times PE_{standby}$$

Where:

E_{AE} = average annual auxiliary electrical energy for pool heater (including stand-by electrical consumption), kWh/yr;
PE = electrical power when the burner is on, kW; and
$PE_{standby}$ = electrical power when the burner is off, kW.

The calculations for fuel and electricity consumption are detailed in appendix 7-C.

7.4.4 Average Annual Energy Consumption

The average annual energy consumption for each considered energy efficiency level for pool heaters is shown in Table 7.4.2. For its LCC and PBP analyses, DOE used the full distribution of energy use values calculated for the sample households.

Table 7.4.2 Annual Energy Consumption for Gas-Fired Pool Heaters

Efficiency Level *(Thermal Efficiency in Percent*	**Average Energy Consumption**		**Average Energy Savings (Gas)** *(MMBtu/yr)*
	Gas *(MMBtu/yr)*	***Electricity*** *(kWh/yr)*	
78 (baseline)	34.1	2.3	--
79	33.7	2.3	0.4
81	32.9	2.3	1.3
82	32.5	2.3	1.6
83	31.8	8.5	2.4
84	31.4	8.4	2.7
86	30.7	8.3	3.5
90	29.3	8.0	4.8
95	27.8	7.7	6.4

REFERENCES

1. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: 2005 Public Use Data Files,* 2005. <http://www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html>

2. Lutz, J. D., X. Liu, J. E. McMahon, C. Dunham, L. J. Shown, and Q. T. McGrue, *Modeling Patterns of Hot Water Use in Households,* 1996. Lawrence Berkeley National Laboratory. Berkeley. LBL-37805.

3. U.S. Department of Energy-Office of Energy Efficiency and Renewable Energy, 10 CFR Part 430 Energy Conservation Program for Consumer Products: Clothes Washer Energy Conservation Standards; Final Rule. *Federal Register*, 2001. 66 No.9

4. United States Cong. House. 110th Congress, *H. R. 6 Energy Independence and Security Act of 2007*. 2007. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

5. Gas Appliance Manufacturers Association, *Statistical Release*, 1999. Arlington, VA.

6. Air-Conditioning Heating and Refrigeration Institute, *AHRI Shipments Data,* March 3, 2008.

7. U.S. Department of Commerce-Bureau of the Census, *Current Industrial Reports for Major Household Appliances (MA335F),* 2003-2008.

8. Air-Conditioning Heating and Refrigeration Institute, *AHRI Shipments Data,* March 18, 2009.

9. Air-Conditioning Heating and Refrigeration Institute (AHRI), 1997-2007 Oil-fired Water Heaters Shipments Data. 2008

10. Oilheating Journal's Merchandising News, 1997-2007 Oil-fired Water Heaters Installations Data. 2008

11. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: 1993 Public Use Data Files* 1993. <http://www.eia.doe.gov/emeu/recs/93publicuse.html>

12. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: 1997 Public Use Data Files,* 1997. <http://www.eia.doe.gov/emeu/recs/public.html>

13. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: 2001 Public Use Data Files*, 2001. <http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html>

14. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: 1990 Public Use Data Files*, 1990. <http://www.eia.doe.gov/emeu/recs/recspubuse90/90publicuse.html>

15. Air Conditioning Heating and Refrigeration Institute, *Consumer's Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment (AHRI Directory February 2010)*, 2010. GAMA Product Directories. (Last accessed February, 2010.) <http://www.gamanet.org/gama/inforesources.nsf/vAllDocs/Product+Directories?OpenDocument>

16. Lutz, J., G.Ghatikar, E. Edelson, S. Meyers, *Hot Water Draw Patters: Findings from Field Studies*, 2006. Lawrence Berkeley National Laboratory. Berkeley.

17. Natural Resources Canada, *ACEEE Water Heating Forum Presentation: NRCan Hot Water Use Study (Field Test)*. 2008.

18. Lutz, J., C. D. Whitehead, A. Lekov, D. Winiarski, and G. Rosenquist, *WHAM: A Simplified Energy Consumption Equation for Water Heaters.*, in *1998 ACEEE Summer Study on Energy Efficiency in Buildings.* 1998: Asilomar, CA. p. 1.171-1.183.

19. Department Of Energy, *Appendix E to Subpart B of Part 430-Uniform Test Method For Measuring The Energy Consumption Of Water Heaters*. filed as "WH Test Procedure 10 CFR 430 subpart B, Appendix E".

20. Kelso, J., *Incorporating Water Heater Replacement into The Weatherization Assistance Program*, May 2003, 2003. D&R International, Ltd. Information Tool Kit.

21. Maxwell, J., Heat Pump Water Heater Economic Model, *personal communication.* NYSERDA. 2004.

22. Hiller, C., Consultant Report - Residential Heat Pump Water Heater Ratings. 2009

23. Energy Information Administration, *Annual Energy Outlook 2010 (Early Release) with Projections to 2035*, 2010. Washington, DC. Report No. DOE/EIA-0383(2010). <http://www.eia.doe.gov/oiaf/aeo/>

24. Davis Energy Group, *Measure Information Template: Tankless Gas Water Heaters*, May 18, 2006. Docket # 07-BSTD-1. <http://www.energy.ca.gov/title24/2008standards/prerulemaking/documents/2006-05-18_workshop/2006-05-11_GAS_WATER.PDF>

25. Bradford White Inc., *Tankless vs. Tank Type Storage Water Heater Efficiency Comparison Testing*, 2005. PM Engineer. (Last accessed 8/17/2007, <http://www.pmengineer.com/copyright/8cf9e86f7c298010VgnVCM100000f932a8c0>

26. Entchev, E., F. Szadlowski, L. Yang, J. Gusdorf, M. Swinton, D. Mackenzie, M. Manning, C. Zaloum,, *Benchmarking the Performance of Natural Gas Combination Systems - Project #5: Tankless Water Heater in Domestic Hot Water Application. CETC/SBE/IES project #00300-05*, 2005.

27. Gas technology Institute, *Water Heater Comparison Final Report*, 2007. Des Plaines, IL.

28. *Title 10, Code of Federal Regulations, Part 430 Appendix E, Subpart B-Uniform Test Method for Measuring the Energy Consumption of Water Heaters*, January 1, 1998.

29. Federal Trade Commission, *Appliance Energy Data - Water Heaters*, 2008. <http://www.ftc.gov/bcp/conline/edcams/eande/appliances/data/2008/waterheat/index.htm>

30. Air Conditioning Heating and Refrigeration Institute, *Consumer's Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment (AHRI Directory March 2009)*, 2009. GAMA Product Directories. (Last accessed March, 2009.) <http://www.gamanet.org/gama/inforesources.nsf/vAllDocs/Product+Directories?OpenDocument>

31. Stanonik, F. A., *GAMA Response to Energy Star Water Heaters Criteria Development*, 2007. <http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/GAMA_11.26.07.pdf>

32. National Oceanic and Atmospheric Administration, *Normal Daily Mean Temperature, Deg F*, 2004. <http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/meantemp.html>

33. Williams, C. N., Jr., M.J. Menne, R.S. Vose, and D.R. Easterling., *United States Historical Climatology Network Monthly Temperature and Precipitation Data.*, 2007. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy,. Oak Ridge, Tennessee. <http://cdiac.ornl.gov/epubs/ndp/ushcn/usa_monthly.html>

34. National Oceanic And Atmospheric Administration, *Degree Days Statistics*, 2005. <http://www.cpc.noaa.gov/products/analysis_monitoring/cdus/degree_days>

35. Burch, J. a. C. C., *Towards Development of an Algorithm for Mains Water Temperature*. National Renewable Energy Laboratory. <http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/AlgorithmForMainsWaterTemperature.pdf>

36. Hendron, R., R. Anderson, C. Christensen, and M. Eastment, P. Reeves, *Development of an Energy Savings Benchmark for All Residential End-Uses*, August, 2004. National Renewable Energy Laboratory. Report No. NREL/BK-610-28044.

37. Abrams, D. W. and A. C. Shedd, *Commercial Water Heating Applications Handbook*, 1992. Electric Power Research Institute. Palo Alto, CA. Report No. EPRI TR-100212. Prepared for Electric Power Research Institute, Final Report, Research Project 3169-01.

38. Clear Seas Research, *Water Heater Study* November, 2006. Plumbing and Mechanical.

39. U.S. Department of Energy - Energy Efficiency & Renewable Energy, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters*, 2001. Washington, DC.

40. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets*, 1993. Washington, DC Vol. 1 of 3. Report No. DOE/EE-0009.

41. *National Appliance Energy Conservation Act (NAECA) of 1987-Public Law 100-12,* March 17, 1987. NAECA.

42. Department Of Energy, 10 CFR Part 430 Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters; Final Rule. *Federal Register*, 2001. 66 No.11: pp. 4474-4497

43. Federal Trade Commission, *Appliance Energy Data - Pool Heaters*, 2009. <http://www.ftc.gov/bcp/conline/edcams/eande/appliances/data/2008/pool/index.htm>

44. Hamos, R., *Consultant Report - Pool Heater Pilot Size*, 2008.