CHAPTER 7. ENERGY USE CHARACTERIZATION

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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. The U.S. Department of Energy (DOE or the Department) 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 central air conditioner (CAC) and central heat pump equipment (CHP) as well as residential non-weatherized gas furnaces, manufactured home furnaces, and oil-fired furnaces. In contrast to the DOE test procedure, which uses typical operating conditions in a laboratory setting, the energy use characterization seeks to estimate the range of energy consumption of the products in the field.

7.2 CENTRAL AIR CONDITIONER AND CENTRAL HEAT PUMP

7.2.1 Introduction

The energy use analysis provides estimates of the distribution of annual energy consumption for central air conditioner and central heat pump equipment at the base case (*i.e.*, with no new standards) and at efficiency standard levels considered in the analysis. This information is used in the subsequent LCC and PBP analyses (chapter 8 of the technical support document [TSD]), which in turn provide the raw energy use data for the national impact analysis (chapter 10 of the TSD). Energy use in both the residential sector and the commercial sector is considered. In the energy use analysis, DOE developed energy consumption estimates for four equipment classes analyzed in the engineering analysis (chapter 5 of the TSD). For one equipment class, split-system air conditioners, two installation methods were separately considered: coil-only, where the indoor furnace fan is not replaced for higher efficiency equipment, and blower-coil, where the indoor blower is replaced, corresponding to the similar breakdown of this equipment class in the engineering analysis.

7.2.1.1 General Approach to the Energy Use Analysis – Residential

The general approach adopted in the energy use analysis for central air conditioner equipment used in residences was to utilize energy use and household characteristics data from the DOE Energy Information Agency (EIA) *2005 Residential Energy Consumption Survey* (RECS)[1] to provide estimates of cooling and heating energy for the sample households using central air conditioner and central heat pump equipment. This estimate reflects household stock equipment efficiency levels. The energy use estimates are then adjusted to reflect long-term average weather conditions and then further adjusted to reflect equipment energy consumption for the same households assuming that they were purchasing and using new equipment at the same rates as they would be in 2016 under a base-case standards scenario.

A sample population of U.S. homes using central air conditioner and central heat pump equipment was first identified from the RECS households surveyed. This sample provided a dataset of cooling and heating energy use for 2005 for households with central air conditioners and central heat pumps. These data were then adjusted (weather-normalized) to reflect corresponding energy-use figures for typical long-term climate conditions. Historical efficiency data for shipped central air conditioner and central heat pump equipment was used in conjunction with equipment age information from RECS to estimate the stock equipment efficiency for each household record used in the analysis. The annual energy consumption for equipment in the 2016 base case (*i.e.*, no new standards) was then calculated for each equipment class by multiplying the weather-adjusted cooling or heating energy use for each RECS household by the ratio of the efficiency (*e.g.*, seasonal energy efficiency ratio or SEER) of the stock unit in that household to that of an assumed efficiency for that household in the 2016 base case. This 2016 base case provides an efficiency level likely to be purchased for each household, assuming a new central air conditioner or central heat pump purchase in that year. The 2016 efficiency levels used for each household were randomly selected from a distribution of shipped efficiencies developed for each product class for the year 2016. This base case is also referred to as the market baseline case because the efficiency distribution is representative of the market for central air conditioner and central heat pump equipment in that year in the absence of new standards.

Once the base-case cooling energy use was established for a selected RECS household record, the corresponding annual cooling energy consumption for higher efficiencies under new standard scenarios was calculated by multiplying the cooling energy consumption for each household in the base case by the ratio of the SEER in the base case to that of the SEER in the standards case. In the case of heating energy use for heat pumps, the corresponding household annual heat pump heating energy consumption under new standard scenarios was calculated by multiplying the heat pump heating energy consumption for each household in the base case by the ratio of the heating seasonal performance factor (HSPF) in the base case to the HSPF in the standards case, and then further multiplied by a heat pump HSPF improvement degradation factor to account for the impact of climate on relative heating efficiency improvement. Figure 7.2.1 and Figure 7.2.2 provide flow diagrams for the calculation of cooling and heating energy for the residential energy use analysis.

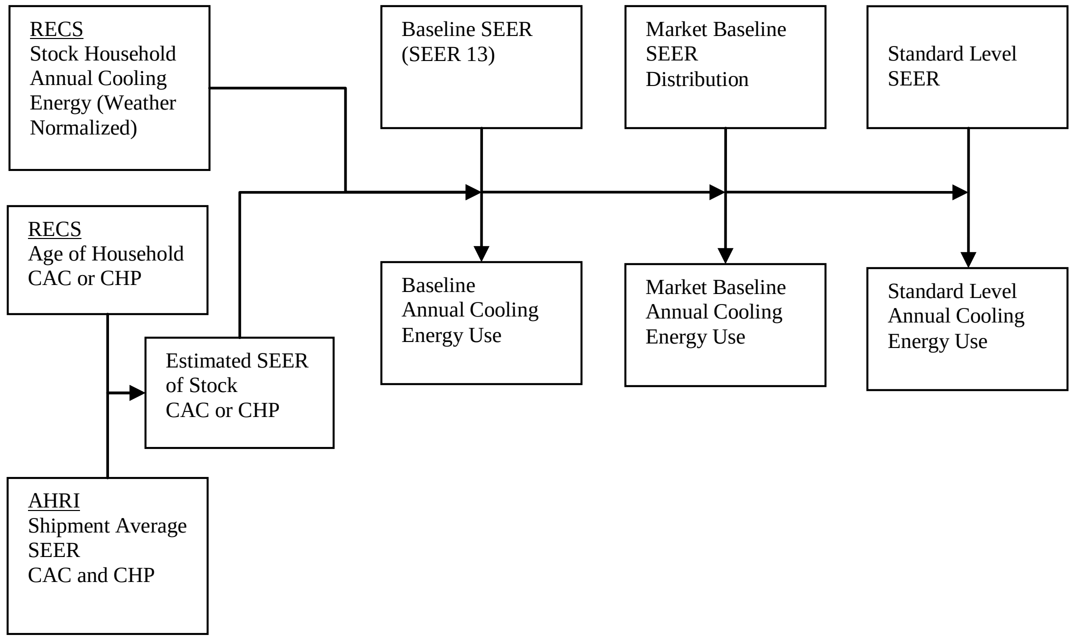

Figure 7.2.1 Flow Diagram for the Determination of Annual Space-Cooling Energy for Residential Central Air Conditioners and Central Heat Pumps

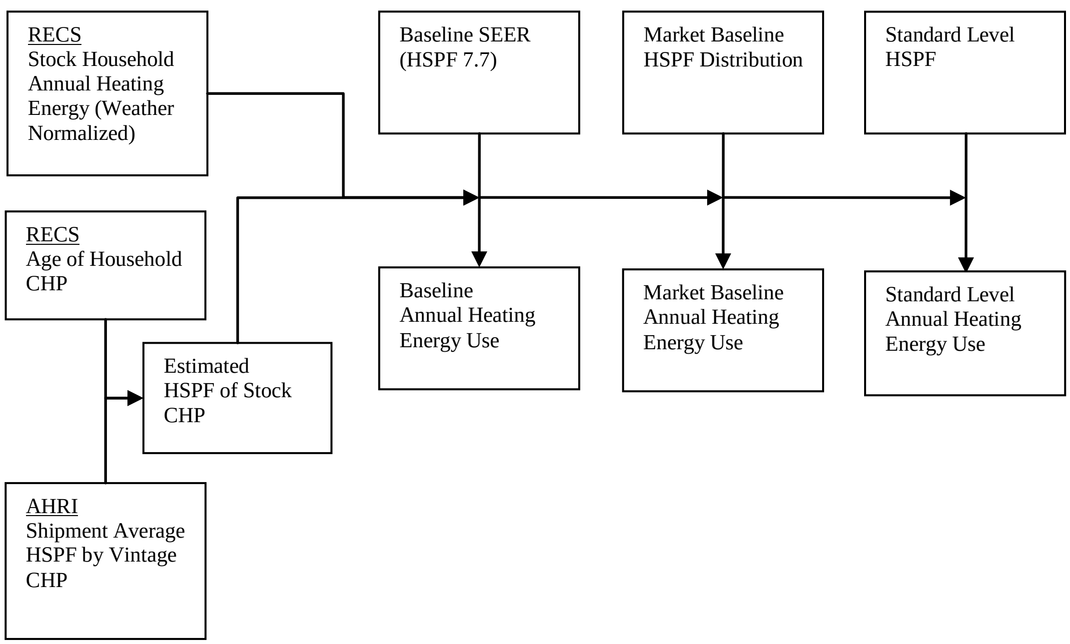

Figure 7.2.2 Flow Diagram for the Determination of Annual Space-Heating Energy for Residential Central Heat Pumps

7.2.1.2 General Approach to the Energy Use Analysis – Commercial

DOE also developed estimates for the annual energy use for central air conditioner and central heat pump equipment sold into the commercial building market. The commercial market is estimated to use approximately 7 percent of all central air conditioner and central heat pump equipment. For the commercial analysis, DOE relied on the use of the EnergyPlus building simulation software to estimate the energy consumption of this equipment at four specific efficiency levels—from baseline to the max-tech level—for 237 climates around the United States for a typical commercial application: a small office building. DOE extracted equipment sizing, supply fan, condenser, and heater energy use from these simulations. DOE then used these results to develop estimates of annual energy use for central air conditioner and central heat pump equipment at other efficiency levels defined in the engineering analysis via interpolation between the efficiency levels simulated. Figure 7.2.3 provides a flow diagram for the calculation of central air conditioner and central heat pump cooling and heating energy for the commercial energy use analysis.

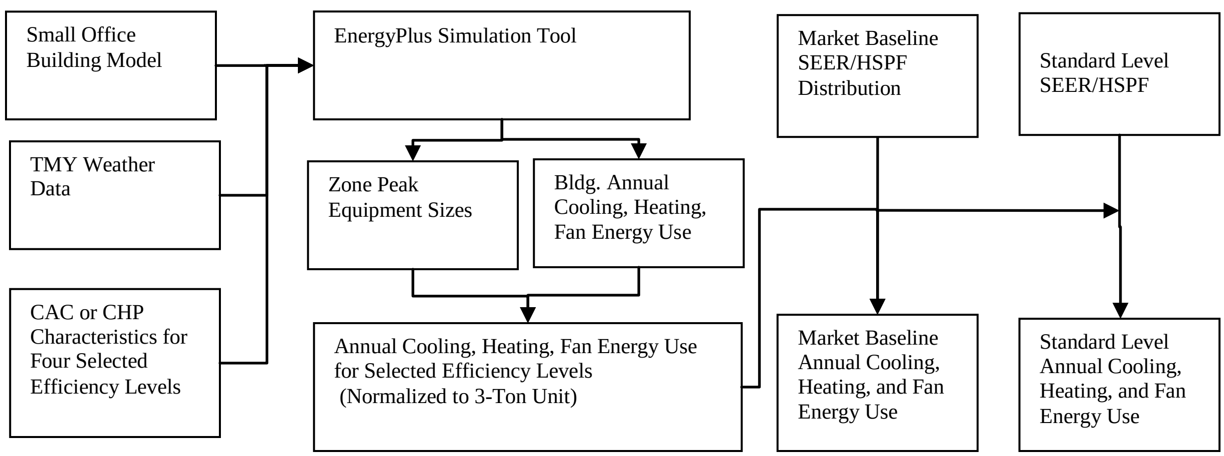

Figure 7.2.3 Flow Diagram for the Determination of Annual Space-Cooling and Space-Heating Energy for Central Air Conditioners and Central Heat Pumps in Commercial Use

7.2.1.3 Overview of Energy Use Analysis Inputs

The following are the principal inputs to the residential energy use analysis:

- Household cooling and heating energy from 2005 RECS
- Central air conditioner and central heat pump equipment age information for the RECS households
- Historical state average monthly cooling and heating degree-day data (1978–2007)

- Historical average cooling and heating efficiency data for central air conditioner and central heat pump equipment from the Air-Conditioning, Heating and Refrigeration Institute (AHRI)
- Base-case efficiency distributions for 2016 developed for this analysis
- Engineering efficiency levels to be analyzed

The following are the principal inputs to the commercial energy use analysis:

- Engineering efficiency levels to be analyzed
- Location-specific weather file data for use with building simulation tool
- Population-based weighting factors for each weather file

7.2.2 Analyzed RECS Households

The 2005 RECS includes data for 4,382 housing units, of which 2,317 were reported to have "CAC only" cooling systems. These include 416 housing units reporting their central air conditioner unit also being a cooling-performance heat pump. The numbers of households actually included in the LCC and PBP analyses were 1,854 for the central air conditioner systems and 339 for heat pumps. Of the 1,901 (2,317 – 416) households that could have been considered for analysis of central air conditioner energy consumption, 47 were not included in the analysis for the following reasons:

- The central air conditioner system was reported as not being used (40 households).
- The household reported a "heat pump" being the main heating equipment, contradicting a second response that the central air conditioner system is not a heat pump (7 households).
- For the seven households with conflicting responses, it was considered that the response regarding the main heating equipment being a heat pump should override the secondary response, and these records were included in the set for analyzing energy consumption for heat pumps.

For the heat pumps, out of the 423 (416 + 7) candidate households, DOE removed 84 for the following reasons:

- The system was reportedly not being used (6 households).
- The survey responses reported non-furnace heating equipment (*i.e.*, heating stove, fireplace, built-in wall furnaces, etc.) as the main heating equipment, thus implying that the heating energy use reported for the household should not be primarily attributed to the heat pump (17 households).
- Some households indicated a warm air furnace as the main heating equipment and no electrical energy use for space heating, implying that the heat pump function is not used

at all or that the RECS may be reporting the “heat pump” energy consumption or presence in error (36 households).

- Some households reported a warm air furnace as well as a heat pump, but questions on usage of any complementary fuel were skipped. This led to ambiguity about whether the heating energy use reported from the conditional demand model was representative of a heat pump or an electric furnace. Barring more detail on the analysis of these records by EIA, these households were removed from consideration in DOE’s analysis (25 households).

7.2.3 Baseline Annual Space-Cooling Energy Use – Residential

In order to estimate the energy savings for higher standards, DOE first established estimates of cooling and heating energy consumption for baseline equipment based on energy consumption in the current stock and product efficiency assumptions appropriate to the stock equipment and the efficiency of baseline products. The energy consumption of central air conditioners and central heat pumps in the equipment stock is related to the capacity and efficiency of these products, the climate, and individual household use patterns. The efficiency of the equipment in the building stock also varies depending on the vintage. The energy consumption of residential air conditioners and heat pumps in the current stock and estimates of the efficiency in the current stock are used in conjunction with the efficiencies of baseline equipment to provide an estimate of energy consumption of baseline equipment. The baseline annual space-cooling energy consumption for residential air conditioners and cooling-performance heat pumps was estimated for each RECS observation using equation 7.2.1.

$$UEC_{res\_base\_c} = UEC_{res\_stock\_c} \times \frac{SEER_{res\_stock}}{SEER_{base}} \qquad \textbf{Eq. 7.2.1}$$

Where:

$UEC_{res\_base\_c}$ = the baseline annual unit energy consumption for space-cooling,
$UEC_{res\_stock\_c}$ = the annual unit energy consumption space-cooling associated with the stock equipment,
$SEER_{base}$ = the space-cooling efficiency associated with the baseline equipment, and
$SEER_{res\_stock\_c}$ = the space-cooling efficiency associated with the stock equipment.

Thus, once the annual space-cooling energy consumption associated with the stock equipment, $UEC_{res\_stock\_c}$, and the space-cooling efficiency, $SEER_{res\_stock\_c}$, are determined, the baseline annual space-cooling energy consumption is estimated. In the next section, the methodology for obtaining $UEC_{res\_stock\_c}$ and $SEER_{res\_stock}$ is discussed.

7.2.3.1 Methodology for Estimating Stock Annual Space-Cooling Energy Use

The stock annual space-cooling energy consumption was estimated based on data from the 2005 RECS. This survey contains data on household characteristics, end-use energy consumption, general location in the United States (limited to location within census division and four large states: New York, Florida, Texas, and California), and approximate heating and cooling degree-days for each sample location for the year of the survey. The latter two statistics are purposefully kept general or sufficiently masked by EIA to preclude identification of the surveyed residences.

The household energy consumption for the individual surveyed households in RECS is obtained by EIA from the energy suppliers via monthly energy bill records. EIA uses a conditional demand analysis (CDA)[1] model to further break down the household energy use into end-use energy consumption estimates (*e.g.*, cooling, heating, lighting, and hot water energy), which it reports as annual end-use energy in the survey results. The cooling energy use for the selected households with central air conditioner or central heat pump products represents the cooling energy consumption associated with the stock equipment for 2005. Because 2005 may not be representative of typical weather for that location, the cooling energy consumption associated with the stock equipment in the RECS households is first adjusted (weather-normalized) using 30-year average (1978–2007) cooling degree-day (CDD) data (base 65 °F) and equation 7.2.2:

$$UEC_{res\_stock\_c} = UEC_{res\_stock\_c\_non-adj} \times \frac{CDD_{30\_yr\_avg}}{CDD_{res\_stock\_2005}} \qquad \textbf{Eq. 7.2.2}$$

Where:

$UEC_{res\_stock\_c\_non-adj}$ = annual space-cooling energy consumption associated with the stock equipment, extracted directly from RECS household data,

$UEC_{res\_stock\_c}$ = annual space-cooling consumption associated with the stock equipment, adjusted by using 30-year average CDD data for the RECS location,

$CDD_{res\_stock\_2005}$ = CDD in 2005 for the specific census division or state where the housing unit is located, and

$CDD_{30\_yr\_avg}$ = 30-year average CDD (1978–2007) for the specific census division or state where the housing unit is located.

7.2.3.2 Stock Annual Space-Cooling Energy Use

DOE first weather-normalized the cooling energy use data for the selected RECS households to better reflect long-term average weather conditions for each location. DOE obtained CDD data for each state on a monthly basis for 1978–2007 from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC).[2] DOE aggregated the monthly data for each year to produce annual CDD data for each state. These were then further aggregated geographically to the specific census divisions or four large state geographic regions used by RECS. The states included in each of these geographic regions are shown in Table 7.2.1.

In estimating annual CDD for each census division, the annual CDD for the states in each division are weighted according to the population in the component states for the specific year.

Population data from 1978 to 2007 were developed based on 1980, 1990, and 2000 U.S. Census Bureau data,[3] with estimates for other years obtained by linear interpolation or extrapolation as necessary. The resulting 30-year average CDD and the 2005 CDD for the regions are shown in Table 7.2.1.

Table 7.2.1 The 30-Year Average CDD (1978–2007) and the 2005 CDD for the Nine Census Divisions and the Four Large States

Division	States	30-Year Average CDD	2005 CDD
1: New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	462	579
2: Middle Atlantic	New Jersey, Pennsylvania	737	991
3: East North Central	Indiana, Illinois, Michigan, Ohio, Wisconsin	758	983
4: West North Central	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota	989	1,171
5: South Atlantic	Delaware, District of Columbia, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	1,382	1,486
6: East South Central	Alabama, Kentucky, Mississippi, Tennessee	1,620	1,747
7: West South Central	Arkansas, Louisiana, Oklahoma	2,215	2,402
8: Mountain	Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, Wyoming	1,318	1,498
9: Pacific	Alaska, Hawaii, Oregon, Washington	226	226
Four Large States	New York	654	943
	California	949	837
	Texas	2,711	2,908
	Florida	3,505	3,436

Based on the 2005 RECS annual space-cooling energy consumption data and the CDD data, the weather-adjusted annual space-cooling energy consumption for each household was obtained by using equation 7.2.2. Statistics showing the weather-adjusted annual space-cooling energy consumption for the households that have air conditioners are shown in Table 7.2.2. Statistics showing the weather-adjusted annual space-cooling energy consumption for the households that have heat pumps are shown in Table 7.2.3. The frequency distribution of the weather-adjusted annual household energy consumption for space-cooling for central air conditioner and central heat pump equipment for the RECS observations is shown in Figure 7.2.4 and Figure 7.2.5.

Table 7.2.2 Weather Adjusted Space-Cooling Energy Consumption Statistics at Regional Level (CAC-Stock)

Division or State	Number of Observations	Min *kWh/yr**	Max *kWh/yr*	Average *kWh/yr*
New England	50	56	4,186	1,229
Middle Atlantic	127	289	5,420	1,650
East North Central	346	130	9,459	1,477
West North Central	224	207	9,882	2,067
South Atlantic	233	152	8,628	2,952
East South Central	173	331	11,573	3,653
West South Central	79	647	12,359	4,070
Mountain	130	65	26,078	3,167
Pacific	23	89	3,610	1,273
New York	34	333	5,361	1,295
California	160	36	17,335	1,835
Texas	181	44	29,326	5,780
Florida	94	1,508	14,688	6,104
National	1,854	36	29,326	2,851

* kilowatt-hours per year

Table 7.2.3 Weather Adjusted Space-Cooling Energy Consumption Statistics at Regional Level (CHP-Stock)

Division or State	Number of Observations	Min *kWh/yr*	Max *kWh/yr*	Average *kWh/yr*
New England	1	432	432	432
Middle Atlantic	10	214	2,182	1,460
East North Central	20	455	6,938	2,315
West North Central	12	234	5,634	2,413
South Atlantic	108	445	11,059	3,442
East South Central	54	1,157	11,586	3,968
West South Central	6	1,246	9,573	4,545
Mountain	23	3,220	12,893	7,194
Pacific	13	78	3,221	1,060
New York	1	761	761	761
California	11	312	6,449	2,492
Texas	15	2,166	11,363	6,423
Florida	65	1,805	17,380	6,738
National	339	78	17,380	4,264

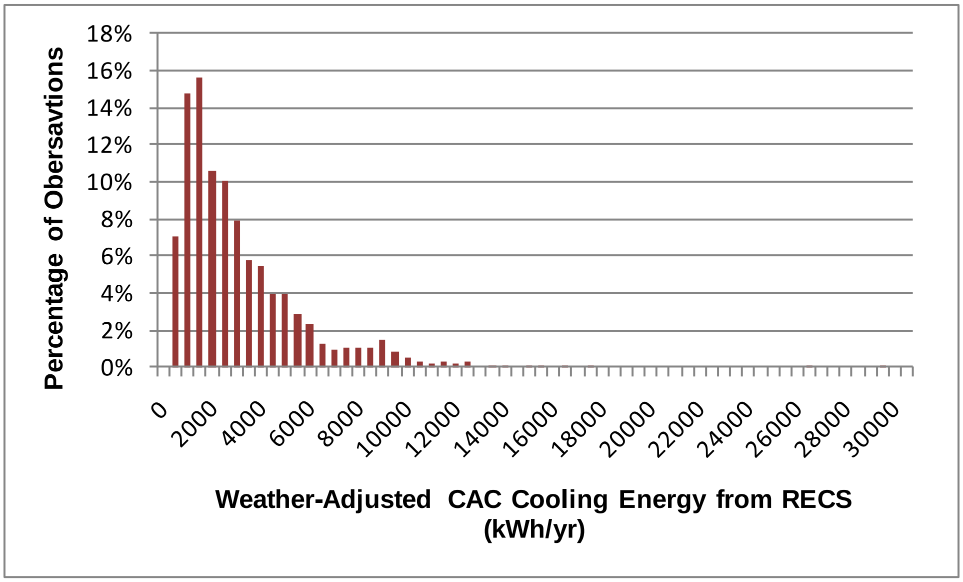

Figure 7.2.4 National Distribution of Weather-Adjusted Space-Cooling Energy for CAC-RECS Observations

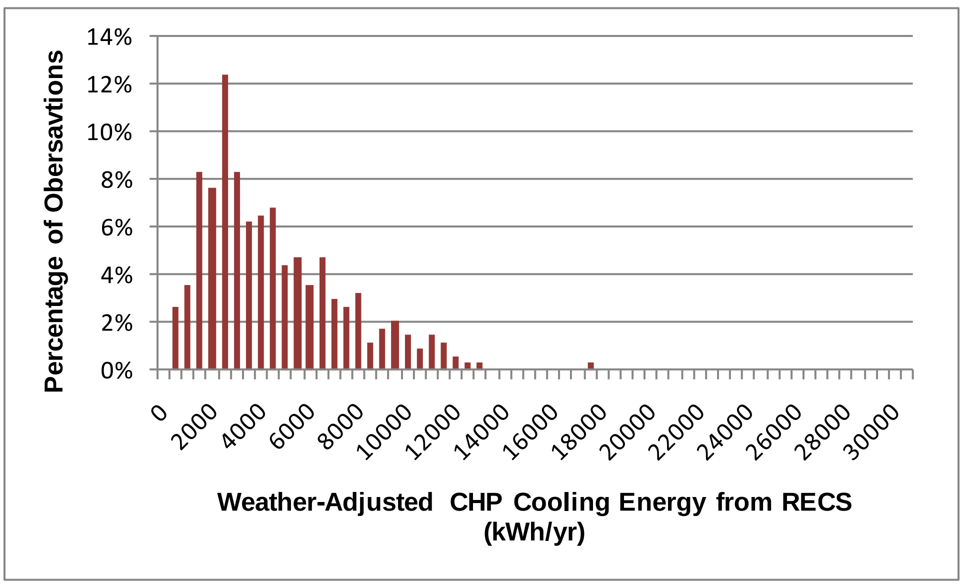

Figure 7.2.5 National Distribution of Weather-Adjusted Space-Cooling Energy for CHP-RECS Observations

7.2.3.3 Stock Space-Cooling Efficiency (SEER)

To estimate annual space-cooling energy consumption data at the baseline and higher efficiency levels, DOE relies on the cooling and heating energy calculated for the stock households and the historic space-cooling efficiency levels of the stock equipment, $SEER_{res\_stock}$. The space-cooling efficiency of stock equipment is related to the vintage of the equipment. In the 2005 RECS database, the age of the equipment is reported in terms of age groups and not the specific vintage year. The five age groups are "less than 2 years old," "2 to 4 years old," "5 to 9 years old," "10 to 19 years old," and "20 years or older." The data also include one additional age category: "as old as the home." In RECS the years of construction of each residence for older homes are also reported in age bands, though the specific year of construction is indicated for the newer homes. DOE assumed that the age of the central air conditioner system, within a given age group in the general population, would be approximately uniformly distributed throughout the range of the age band. For example, for the central air conditioner systems in the "less than 2 years old" age group, it was assumed that 50 percent of heat pumps were 1 year old and the other 50 percent were 2 years old. A similar technique was used in ascertaining the probable vintage year of the home and the equipment when the equipment was reported to be the age of the home. The resulting age distribution of the central air conditioners and central heat pumps in the RECS households identified for analysis is listed in Table 7.2.4 and shown in Figure 7.2.6 and Figure 7.2.7, respectively.

Table 7.2.4 Number of Observations for Each Age Group

Equipment Type	Less than 2 Years Old	2 to 4 Years Old	5 to 9 Years Old	10 to 19 Years Old	20 Years or Older	Total
Central Air Conditioners	243	321	472	502	316	1854
	13.1%	17.3%	25.5%	27.1%	17.0%	100%
Cooling-Performance Heat Pump	57	61	104	89	28	339
	16.8%	18.0%	30.7%	26.3%	8.3%	100%

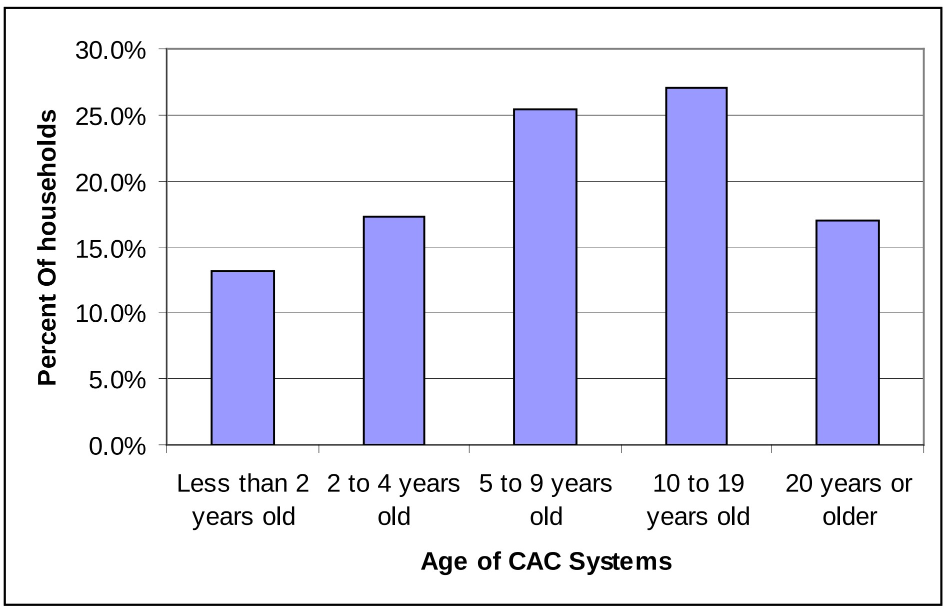

Figure 7.2.6 The Distribution of Central Air Conditioners in the RECS Sample by Age Groups

Once the age group into which the household equipment falls was established, DOE estimated the vintage of the equipment for each household in each age group by random assignment using the uniform age distribution assumption for each age group and the known 2005 survey year. For the 20-year and older age group, all equipment was assumed to be between 20 and 29 years old with the actual vintage assigned using a uniform distribution. The resulting vintage distribution of the residential air conditioners and heat pumps in the overall sample is shown in Figure 7.2.8.

DOE estimated the stock cooling SEER for each household using equipment vintage and average shipped efficiency for each vintage year. The latter was developed from AHRI data[4] and is shown in Table 7.2.5.

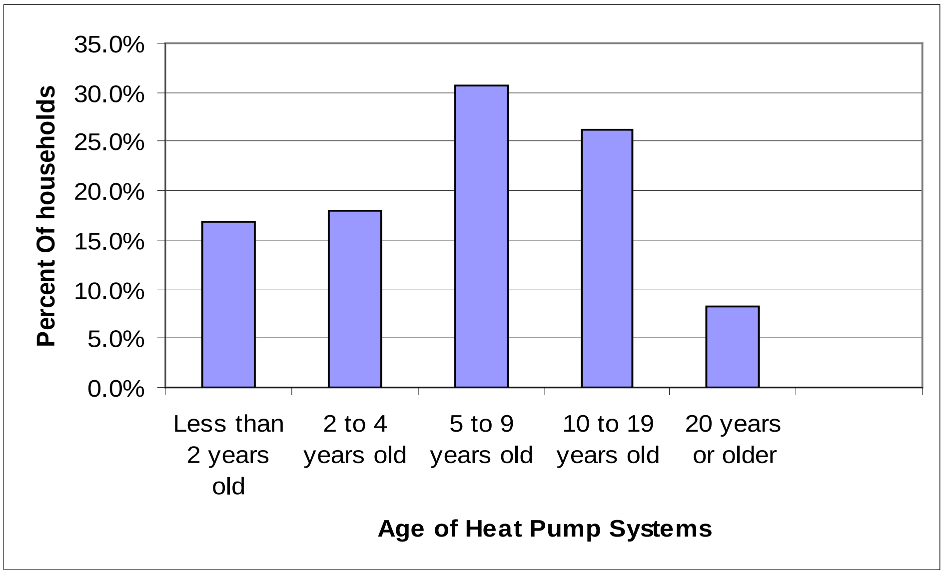

Figure 7.2.7 The Distribution of Central Heat Pumps in the RECS Sample by Age Groups

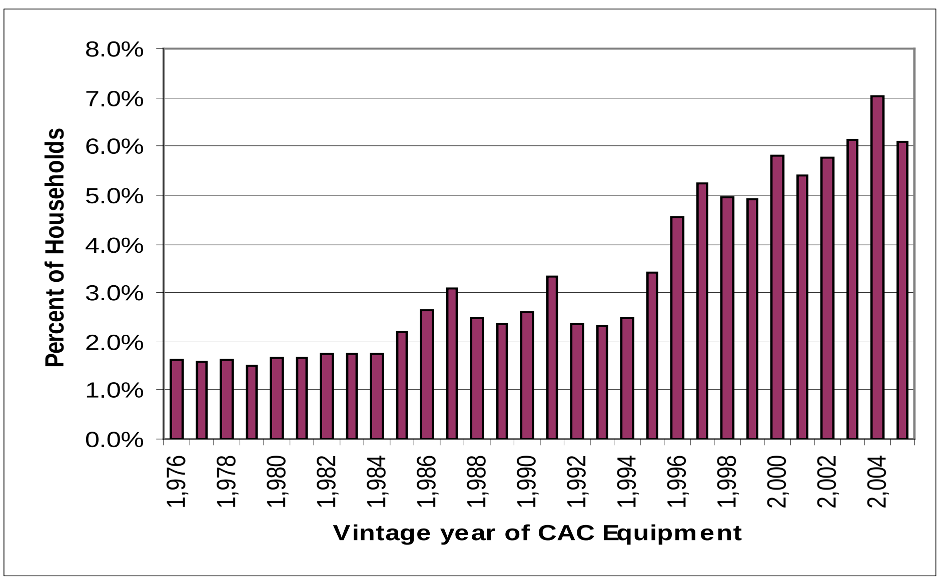

Figure 7.2.8 Distribution of RECS Households with Central Air Conditioners by Vintage

Table 7.2.5 Average Annual Shipped Space-Cooling Efficiency

Year	Central A/C *SEER*	Heat Pump *SEER*
1976	7.15	6.87
1977	7.18	6.89
1978	7.41	7.24
1979	7.45	7.34
1980	7.51	7.51
1981	7.73	7.70
1982	8.30	7.79
1983	8.44	8.23
1984	8.70	8.45
1985	8.84	8.56
1986	8.87	8.70
1987	8.95	8.93
1988	9.11	9.13
1989	9.23	9.26
1990	9.25	9.41
1991	9.44	9.73
1992	10.43	10.56
1993	10.52	10.82
1994	10.58	10.89
1995	10.64	10.93
1996	10.63	10.95
1997	10.62	10.93
1998	10.23	10.52
1999	10.86	11.24
2000	10.95	11.23
2001	11.07	11.31
2002	11.07	11.32
2003	11.22	11.48
2004	11.32	11.58
2005	11.33	11.69

7.2.3.4 Estimating Baseline Annual Space-Cooling Energy Use

For each class of equipment, the baseline annual space-cooling energy consumption for each equipment type (air conditioner or heat pump) was estimated by using equation 7.2.2. The key inputs are the weather-adjusted annual space-cooling energy consumption derived from the 2005 RECS data; the stock space-cooling efficiency estimates for air conditioners and heat pumps from Table 7.2.5; and the baseline cooling efficiency, 13 SEER.

Statistics for the baseline space-cooling energy consumption for RECS households at regional and national level are shown in Table 7.2.6 for air conditioners and Table 7.2.7 for heat pumps.

Table 7.2.6 Baseline (13 SEER) Space-Cooling Energy Consumption Statistics at Regional Level (Central Air Conditioner)

Division or State	Number of Observations	Min *kWh/yr*	Max *kWh/yr*	Average *kWh/yr*
New England	50	45	3,526	987
Middle Atlantic	127	246	4,550	1,270
East North Central	346	104	7,967	1,148
West North Central	224	145	8,324	1,593
South Atlantic	233	119	7,513	2,314
East South Central	173	247	10,078	2,864
West South Central	79	433	10,115	3,082
Mountain	130	53	21,344	2,536
Pacific	23	78	3074	1,029
New York	34	229	3645	1,016
California	160	24	15,095	1,440
Texas	181	30	25,536	4,520
Florida	94	1,234	12,372	4,860
National	1,854	24	25,536	2,231

Table 7.2.7 Baseline (13 SEER) Space-Cooling Energy Consumption Statistics at Regional Level (Central Heat Pump)

Division or State	Number of Observations	Min *kWh/yr*	Max *kWh/yr*	Average *kWh/yr*
New England	1	249	249	249
Middle Atlantic	10	118	1,823	1,236
East North Central	20	323	5,566	1,882
West North Central	12	190	4,911	1,962
South Atlantic	108	320	9,417	2,779
East South Central	54	909	9,465	3,203
West South Central	6	973	6,797	3,568
Mountain	23	2,424	8,876	5,616
Pacific	13	68	2,339	842
New York	1	663	663	663
California	11	263	5,492	1,960
Texas	15	1,473	9,191	5,278
Florida	65	1,311	13,677	5,339
National	339	68	13,677	3,412

7.2.4 Baseline Annual Space-Heating Energy Use for Central Heat Pump Equipment—Residential

The baseline annual space-heating energy consumption for the central heat pump system is estimated following procedures similar to that for estimating the baseline annual space-cooling energy consumption. The baseline annual space-heating energy consumption for residential heat pumps is estimated by using the following generic equation:

$$UEC_{res\_base\_h} = UEC_{res\_stock\_h} \times \frac{HSPF_{res\_stock}}{HSPF_{base}} \times DF \qquad \textbf{Eq. 7.2.3}$$

Where:

$UEC_{res\_base\_h}$ = the baseline annual space-heating energy consumption,
$UEC_{res\_stock\_h}$ = the annual space-heating energy consumption associated with the stock heat pump,
$HSPF_{res\_stock\_h}$ = the space-heating efficiency associated with the stock equipment,
$HSPF_{base}$ = the space-heating efficiency associated with baseline equipment, and
DF= HSPF improvement degradation factor.[a]

The DF term is a factor used to adjust the HSPF ratio to make it reflect the improvement in heating seasonal performance for a particular climate region. See appendix 7-A for a discussion of the derivation of the HPSF improvement degradation factor.

7.2.4.1 Estimating Stock Annual Space-Heating Energy Use

The annual space-heating energy consumption for the central heat pump systems in the stock was obtained from the 2005 RECS database for the heat pump sample identified. To account for the variation in weather conditions for the year 2005 from statistical normals, the annual space-heating energy consumption in 2005 was adjusted by using the following equation:

$$UEC_{res\_stock\_h} = UEC_{res\_stock\_h\_non-adj} \cdot \frac{HDD_{30\_yr\_avg}}{HDD_{res\_stock}} \qquad \textbf{Eq. 7.2.4}$$

Where:

$UEC_{res\_stock\_h}$ = annual space-heating energy consumption associated with the stock equipment after weather-adjustment,
$UEC_{res\_stock\_h\_non-adj}$ = annual space-heating energy consumption, obtained directly from RECS database,
$HDD_{30\_yr\_avg}$ = 30-year (1978–2007) average heating degree-day (HDD, base 65 °F) for the census division or state where the household is located, and
$HDD_{res-stock}$ = HDD in 2005 (base 65 °F) for the census division or state where the household is located.

State-wise monthly HDD data from 1978 to 2007 were obtained from the NOAA database center.[2] DOE aggregated the monthly data for each year to produce annual HDD for each state. The state annual HDD data were used to derive annual HDD for the regions identified in RECS (census divisions and separately four large states). In estimating divisional annual HDD, the annual HDD values for states within the regions were weighted by the state population in that year as described in section 7.2.1. The 30-year average HDD and the 2005 HDD for the nine census divisions and the four large states are shown in Table 7.2.8.

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[a] HSPF improvement degradation factors were assumed to be 1.0 for the calculation of baseline heating energy.

Table 7.2.8 30-Year Average HDD (1978–2007) and the 2005 HDD for the Nine Census Divisions and the Four Large States

Division or State	30-Year HDD Average	2005 HDD
New England	6,571	6,453
Middle Atlantic	5,602	5,612
East North Central	6,103	6,323
West North Central	5,989	6,506
South Atlantic	3,665	3,720
East South Central	3,309	3,496
West South Central	2,415	2,723
Mountain	4,666	5,142
Pacific	5,133	5,193
New York	5,912	5,929
California	2,450	2,488
Texas	1,686	1,944
Florida	647	657

By using equation 7.2.4, the weather-adjusted annual space-heating energy consumption was estimated for the equipment in each household. Statistics for the weather-adjusted space-heating energy consumption at both divisional and national level are shown in Table 7.2.9. The frequency distribution of the RECS sample households in different heating energy consumption bands is shown in Table 7.2.9.

Table 7.2.9 Statistics of Annual Weather-Adjusted Space-Heating Energy Consumption for RECS-Stock Central Heat Pump at Regional Level

Division or State	Number of Observations	Min *kWh/yr*	Max *kWh/yr*	Mean *kWh/yr*
New England	1	2,399	2,399	2,399
Middle Atlantic	10	581	5,177	2,871
East North Central	20	1,911	10,037	4,237
West North Central	12	926	4,778	2,702
South Atlantic	108	0	6,412	2,692
East South Central	54	0	5,667	2,468
West South Central	6	354	4,434	2,386
Mountain	23	424	1,630	891
Pacific	13	2,171	5,251	3,621
New York	1	3,409	3,409	3,409
California	11	324	3,850	1,391
Texas	15	998	3,788	1,671
Florida	65	200	1,470	625
National	339	0	10,037	2,179

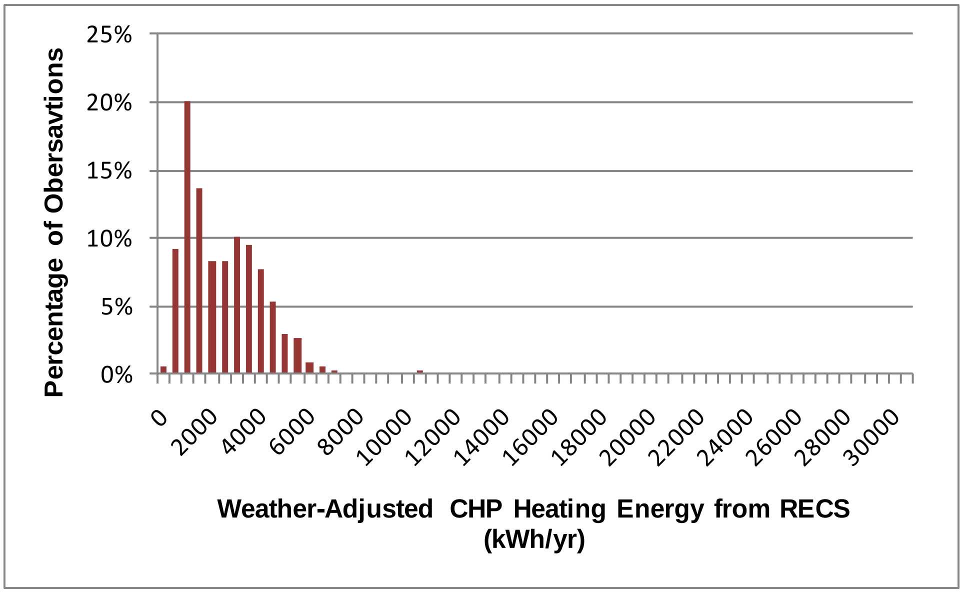

Figure 7.2.9 National Distribution of Weather-Adjusted Space-Heating Energy for RECS Observations

7.2.4.2 Stock Space-Heating Efficiency (HSPF)

The space-heating efficiency of central heat pump equipment has improved over time in response to both technology improvement and minimum efficiency standards. DOE related the space-heating efficiency of heat pumps in the stock to the equipment vintage, much as was done for the cooling efficiency. In the 2005 RECS database, the age groups of the equipment and not their specific vintage is given. The five age groups are “less than 2 years old,” “2 to 4 years old,” “5 to 9 years old,” “10 to 19 years old,” and “20 years or older.” The data reported also include one additional category: “as old as the home.” The years of construction of the home for older homes are also reported in age bands. It was assumed that the age of a heat pump, within a given age group, was uniformly distributed over the range of the age group. For example, for the heat pumps in the “less than 2 years old” age group, it was assumed that 50 percent of heat pumps were 1 year old and the other 50 percent were 2 years old. A similar technique was used in ascertaining the probable vintage year of the home and the equipment when both were reported to have the same age. The distribution of households with heating-performance heat pumps by age groups is shown in Figure 7.2.10 and the distribution of heat pump vintages is shown in Figure 7.2.11.

AHRI does not publish data on the historical average HSPF for central heat pump equipment. DOE developed historical HSPF estimates from two data sources. For the years from 1973 to 1993, DOE used data reported in the TSD for the 2001 CAC Rulemaking.[5] For the period from 1994 to 2005, DOE examined the 1994 Air-Conditioning & Refrigeration Institute (ARI) directory of Certified Products and developed a regression equation that relates the SEER of residential split-system heat pumps. DOE used the 1994 ARI Directory of Certified Equipment Database[6] to generate regressions between SEER and HSPF for central heat pump equipment on the market in 1994. For split systems, DOE used a regression based on data for all central heat pump equipment characterized by the AHRI designations HRCU-A-CB and HRCU-A-C. For packaged heat pumps, DOE used a regression for all central heat pump equipment with an HSP-A designation. Only single-phase equipment with ratings listed as “Active,” “not intended for export only,” were included. This resulted in two regression equations: one for the split-system heat pump equipment class and one for the single-package heat pump equipment class. The historical average HSPF for each equipment class was calculated using historical annual average SEER values by equipment class from AHRI[7] and the appropriate regression equation. The annual average HSPF for all central heat pump equipment was then developed by weighting the annual average HSPF values by class using historical shipment data by equipment class. Table 7.2.10 shows the resulting historical HSPF values by vintage.

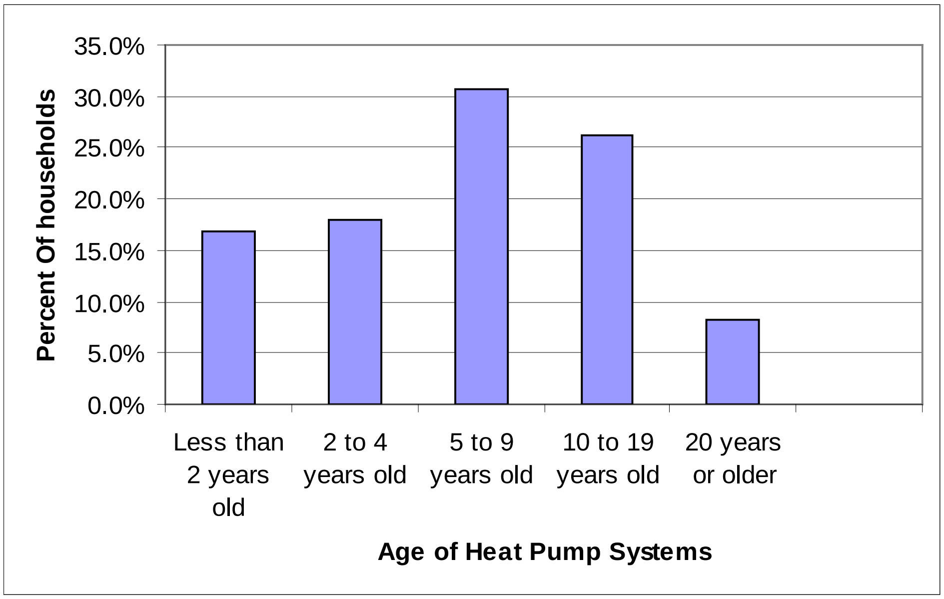

Figure 7.2.10 Distribution of Households with Heating-Performance Heat Pumps by Age Groups

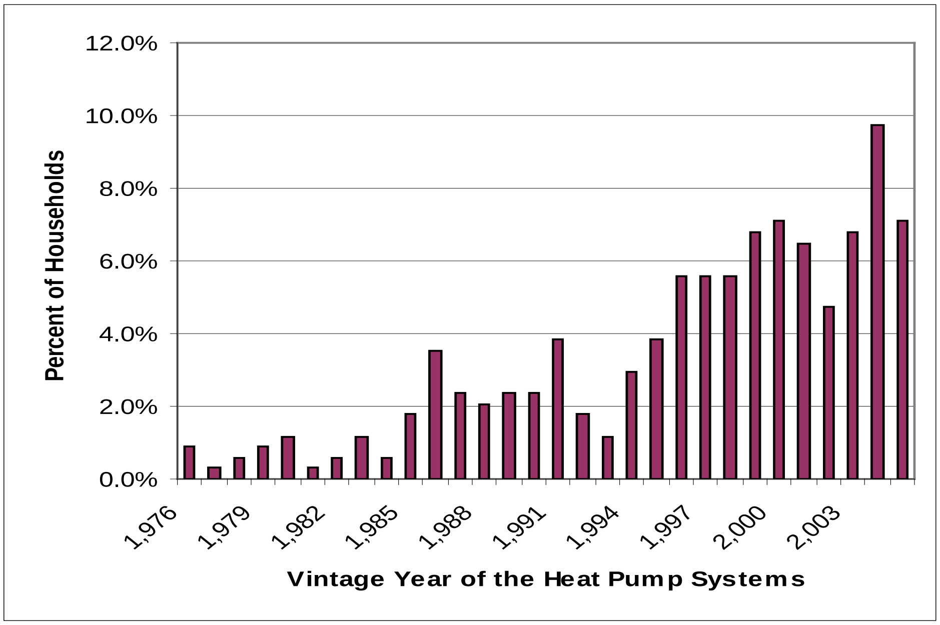

Figure 7.2.11 Distribution of RECS Households with Central Heat Pumps by Vintage

Table 7.2.10 Average Annual Heating Pump HSPF

Year	Average HSPF	Year	Average HSPF
1973	5.66	1990	6.98
1974	5.66	1991	7.08
1975	5.66	1992	7.19
1976	5.66	1993	7.30
1977	5.74	1994	7.38
1978	5.83	1995	7.39
1979	5.91	1996	7.40
1980	6.00	1997	7.39
1981	6.09	1998	7.29
1982	6.18	1999	7.47
1983	6.28	2000	7.46
1984	6.37	2001	7.49
1985	6.47	2002	7.49
1986	6.56	2003	7.53
1987	6.66	2004	7.56
1988	6.81	2005	7.58
1989	6.87		

7.2.4.3 Estimating Baseline Annual Space-Heating Energy Use

For each class of equipment, the baseline annual space-heating energy consumption for central heat pump equipment was estimated by using equation 7.2.4. The key inputs are the weather-adjusted annual space-heating energy consumption derived from the 2005 RECS data; the stock space-heating efficiency estimates for central heat pump equipment shown in Table 7.2.10; and the baseline heating efficiency, 7.7 HSPF.

Statistics showing the baseline space-heating energy consumption calculated for RECS households with central heat pump equipment at regional and national level are shown in Table 7.2.11.

Table 7.2.11 Baseline (13 SEER) Space-Heating Energy Consumption Statistics at Regional Level (Central Heat Pumps)

Division	Number of Observations	Min *kWh/yr*	Max *kWh/yr*	Average *kWh/yr*
New England	50	1,869	1,869	1,869
Middle Atlantic	127	443	5,030	2,778
East North Central	346	1,869	9,855	4,000
West North Central	224	789	4,585	2,546
South Atlantic	233	0	6,105	2,554
East South Central	173	0	5,068	2,323
West South Central	79	340	3,956	2,240
Mountain	130	346	1,329	824
Pacific	23	2,132	4,542	3,407
New York	34	3,356	3,356	3,356
California	160	287	3,745	1,305
Texas	181	982	3,684	1,580
Florida	94	170	1,351	586
National	1,854	0	9,855	2,058

7.2.5 Baseline Residential Cooling and Heating Results – Adjusted for RECS Sample Weights

Table 7.2.6, Table 7.2.7, and Table 7.2.11 directly reflect the RECS household sample data. These tabulated results do not take into account the sample weights assigned by RECS for the different households. Figure 7.2.12, Figure 7.2.13, and Figure 7.2.14 show the distribution of calculated baseline cooling and heating energy for central air conditioner and central heat pump products used in residences, taking into account the RECS household samples weights.

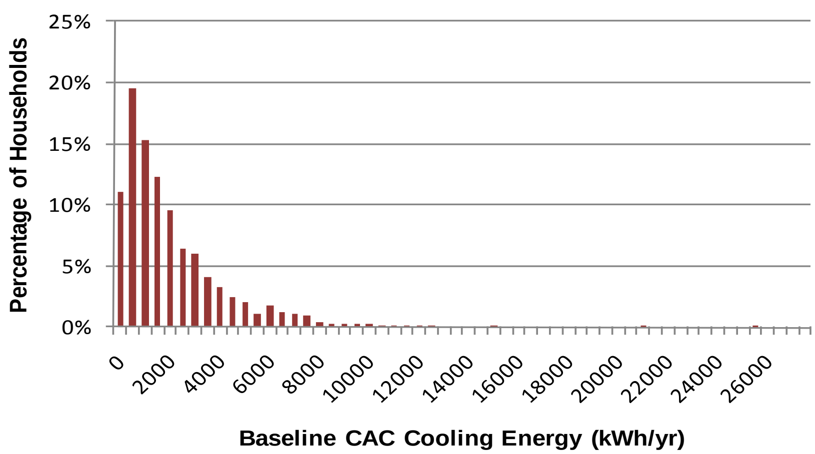

Figure 7.2.12 Baseline National Cooling Energy Distribution for Central Air Conditioners – Residential

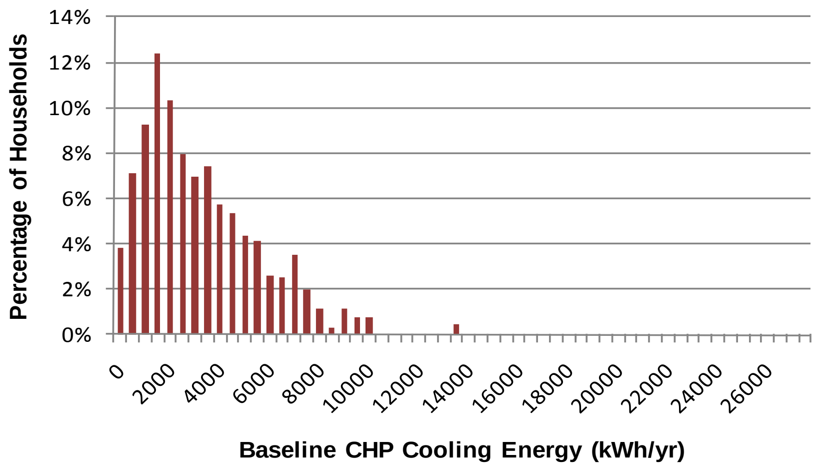

Figure 7.2.13 Baseline National Cooling Energy Distribution for Central Heat Pumps – Residential

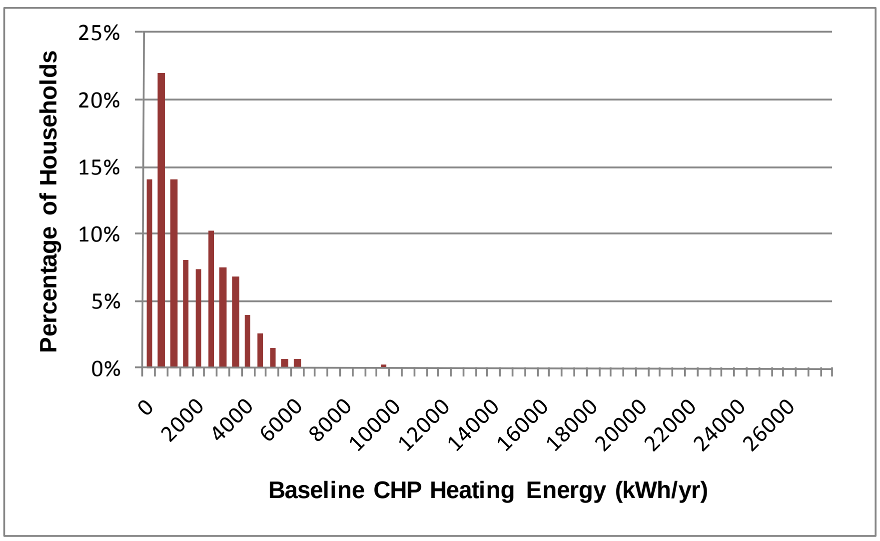

Figure 7.2.14 Baseline National Heating Energy Distribution for Central Heat Pumps – Residential

7.2.6 Baseline Commercial Central Air Conditioner and Central Heat Pump Energy Use

Seven percent of residential-type (*i.e.*, single-phase) central air conditioner and central heat pump applications are assumed to be in commercial buildings. While this equipment could be used in a wide variety of buildings, DOE believes that the vast majority is used in small buildings, in particular small retail and commercial buildings. This is primarily because central air conditioner and central heat pump equipment uses single-phase electricity, which limits the application to smaller buildings.

Cooling and heating energy use in commercial buildings can be distinctly different from such use in residential buildings, even for the same equipment. This is predominantly because commercial buildings are operated differently, often having defined operating hours when the equipment is used to condition the space, thermostatic setback during other hours, induced ventilation into the building structure to meet occupant needs, and, typically, continuous fan operation during occupied hours. Space heat gains in commercial buildings can be significantly different than in residential buildings due primarily to high internal thermal loads from lighting and electrical equipment during the occupied periods.

In addition, multiple cooling and heating units are commonly used. A similar data source to the RECS data discussed earlier is the EIA *Commercial Building Energy Consumption Survey* (CBECS),[8] which provides estimates of end-use energy consumption in commercial buildings. Because multiple pieces of cooling and heating equipment are the norm in most commercial buildings, and the number of units by equipment type is not captured in the survey, it is not possible to readily determine the energy use of individual pieces of central air conditioner and central heat pump equipment using CBECS. In addition, CBECS does not clearly distinguish equipment types by electrical phase. Hence, it is difficult to identify buildings that are predominantly served by central air conditioner and central heat pump equipment. Given these difficulties, DOE determined that CBECS could not be used to estimate the cooling and heating energy data for central air conditioner and central heat pump equipment used in commercial buildings. Instead, DOE relied on a building simulation approach to estimate the electrical energy usage of central air conditioner and central heat pump equipment in commercial buildings.

7.2.7 Overview of Commercial Energy Simulation Approach

In order to develop energy use statistics that reflect the use of central air conditioner and central heat pump equipment in commercial buildings, DOE performed an analysis similar to that described in the Framework for Central Air Conditioners.[9] DOE used the EnergyPlus[10] whole-building energy simulation software to estimate the energy consumption of central air conditioner and central heat pump used to satisfy the cooling, supply fan, and, in the case of central heat pump, the electrical heating energy required in a representative small office building. Simulations were carried out for 237 locations around the United States. The building model used was an existing single-story, 5,500 ft^2 office building model developed by DOE for energy benchmarking purposes for this analysis. This commercial reference building model is 1 of 16 commercial reference building models developed in support of DOE's Commercial Building Initiative program.[11]

Two variations were considered for the simulations: buildings were either entirely served by central air conditioner equipment with a gas furnace backup or were entirely served by central heat pump equipment. The simulated building used five individual central air conditioner (or central heat pump) units. For each equipment type, DOE simulated the equipment at four different efficiency levels, starting from the baseline level. For central air conditioner equipment, these levels were 13 SEER, 14 SEER, 16 SEER, and a max-tech level of SEER 24.5 based on blower-coil ratings. For central heat pump equipment, these levels were 13 SEER, 14 SEER, 16 SEER, and a max-tech level of SEER 22 based on blower-coil ratings. Equipment parameters used in the simulation were adjusted to reflect engineering designs corresponding to each efficiency level. Simulations were carried out using Typical Metrological Weather Files (TMY2) for the 237 U.S. locations.[12]

DOE extracted the annual energy consumption for cooling and fan energy use and heating from each modeled central air conditioner or central heat pump unit, as well as the equipment cooling capacity for each unit from each simulation run, and aggregated these to the whole-building level. Using these whole-building cooling and heating data, as well as the equipment capacities, DOE normalized the central air conditioner and central heat pump energy consumption for each location and efficiency level to that of an average 3-ton central air conditioner or central heat pump unit. These normalized energy use statistics were then further scaled linearly, as necessary, to reflect the energy use for a 2-, 3-, or 5-ton central air conditioner or central heat pump product, depending on the size of unit modeled in the LCC analysis.

To estimate the energy consumption for intermediate efficiency levels between those simulated, DOE linearly interpolated the energy use estimates for cooling energy, fan energy, and heating energy based on the results at the four simulated efficiency levels, the SEER or HSPF rating as the independent variable, and using the nearest lower and upper SEER or HSPF levels simulated.

7.2.7.1 Simulation Tool Description

DOE chose to use EnergyPlus version 3.0 for the energy analysis. EnergyPlus is the most recent of several large-scale software programs developed for whole-building energy simulation analysis and has been validated by comparing its results with thermal and energy use measurements on actual buildings and with other software tools and calculations. EnergyPlus predicts the hourly energy use of a building given: hourly weather information and a description of the building; the operation of the building; and its heating, ventilation and air-conditioning (HVAC) equipment. Energy use statistics for the building can be readily extracted for different time steps and at detailed sub-component levels if necessary. EnergyPlus is an integrated software tool, where both the building loads and how those loads are served by equipment are solved iteratively. EnergyPlus has a separate, but robust, ground heat transfer model, which is particularly useful in the simulation of smaller buildings. DOE is currently using EnergyPlus as the basis for most of its building energy simulation research, and the tool and its ongoing development are actively supported within DOE.

7.2.7.2 Efficiency Levels Analyzed and Corresponding Simulation Parameters

DOE simulated four efficiency levels for central air conditioner equipment and four efficiency levels for central heat pump equipment, corresponding to particular efficiency levels identified in the engineering analysis. In order to simulate the equipment within the confines of the simulation software, the SEER and HSPF rating from the engineering analysis must be converted to parameters used by the simulation software. These parameters are the cooling coefficient of performance (COP)—for central heat pump the heating COP—of the condensing unit at rated conditions and the fan power. The central air conditioner and central heat pump condensing unit parameters are in turn calculated from 95 °F energy efficiency ratio (EER) and

47 °F COP ($COP_{47\,°F}$) ratings for the equipment and the fan power at rated conditions. DOE first estimated these from the SEER and HSPF rating.

The EER rating reflects the cooling performance for central air conditioner equipment at a single-point rating condition defined by 95 °F outdoor temperature, 80 °F entering air dry bulb temperature, and a 67 °F entering air wet bulb temperature. The $COP_{47\,°F}$ rating reflects the heating performance of the heat pump at a single-point rating condition defined by 47 °F outdoor temperature, 70 °F entering air dry bulb temperature, and a maximum 60 °F entering air wet bulb temperature. The EER values for each SEER level modeled were established based on the median EER corresponding to that SEER level in the AHRI Certified Directory as established for equipment designated as "not for export only."[b] HSPF levels were established based on the engineering analysis HSPF values corresponding to the SEER modeled for split-system heat pumps. Because $COP_{47\,°F}$ ratings are not provided in the AHRI database, DOE relied on a relationship between HSPF and $COP_{47\,°F}$ established in the literature.[13] This curve fit is shown in equation 7.2.5.

$$COP_{47F} = -0.0255 \times HSPF^{2} + 0.6239 \times HSPF \qquad \textbf{Eq. 7.2.5}$$

In addition, DOE modeled the highest efficiency equipment as a multistage condenser system with two stages of operation. To properly account for two stages of operation, DOE used the EnergyPlus multi-speed unitary heat pump model for both air conditioners and heat pumps, disabling the heat pump heating capacity when modeling the unit as an air conditioner and relying on a gas furnace for backup heating.

For 13 SEER equipment, the fan power at rating conditions was established assuming a blower motor efficiency of 0.65, a fan efficiency of 0.58, and a constant total static pressure of 1.105 inches of water (in. H_2O) for the furnace/air handler. The same characteristics for fan power were also assumed to apply to the heat pumps at rating condition. The blower motor efficiency was assumed to be 0.65 for the 13 and 14 SEER ratings, consistent with that of a permanent split capacitor blower motor. The blower motor efficiency was assumed to be 0.80 for the 16 SEER and higher SEER ratings, consistent with that of an electronically commutated motor (ECM) blower motor in this size range. A transition to ECM blower motors between the 14 and 16 SEER ratings reflects the use of that technology in the central air conditioner/central heat pump market as determined in the engineering analysis, where ECM motors appear to be commonplace at 16 SEER, but not common at 14 SEER. These assumptions result in a blower power of 138 W/ton at rated conditions for 13 and 14 SEER equipment, and a lower fan power of 112 W/ton for higher SEER equipment at rated conditions. For comparison, using the test procedure default 365 W/1,000 cubic feet per minute (cfm) for a coil-only rating would provide the same power levels assumed for 13 and 14 SEER equipment at an airflow rate of 377 cfm/ton. The cooling and heating condensing unit COP values that are entered in the EnergyPlus software reflect the EER and $COP_{47\,°F}$ ratings, but are adjusted for the impact of the blower power. The blower power is directly incorporated into the total system power for these ratings but, because

[b] This refers to the AHRI Certified Directory information as of July 17, 2010, for air conditioning and heat pump units.

of the effect of fan heat, incorporating the blower reduces the cooling output and raises the heating output. Equations 7.2.6 and 7.2.7 provide cooling and heating COP ratings for the condensing unit alone after adjusting for the fan power and fan heat.

$$COP_{CUCool,95°F} = \frac{(EER/3.413+R)}{1-R} \quad \textbf{Eq. 7.2.6}$$

$$COP_{CUHeat,47°F} = \left(\frac{COP_{47°F} - R}{1-R}\right) \quad \textbf{Eq. 7.2.7}$$

Where:

R = ratio of supply fan power to total equipment power at the AHRI rating condition,
$COP_{CUCool,95\ °F}$ = condensing unit cooling COP, and
$COP_{CUHeat,47\ °F}$ = condensing unit heating COP.

Table 7.2.12 shows the resulting equipment performance statistics for the commercial building models.

Table 7.2.12 Central Air Conditioner and Central Heat Pump Blower and Characteristics Used in Modeling Commercial Cooling and Heating Energy Use

Equipment Class	SEER	HSPF	EER	47 °F COP	Blower Motor Energy Efficiency	Blower Power *W/ton**	Fan Power to Total Power (Rated Conditions)	Cool $COP_{95°F}$ (Condensing Unit Only)	Heating $COP_{47°F}$ (Condensing Unit Only)
CAC	13	NA	11.07	NA	0.65	138	0.127	3.86	NA
	14	NA	11.8	NA	0.65	138	0.135	4.15	NA
	16	NA	12.53	NA	0.80	112	0.117	4.29	NA
	24.5	NA	15.0	NA	0.80	112	0.140	5.27	NA
CHP	13	8	11.2	3.29	0.65	138	0.128	3.91	3.71
	14	82	11.8	3.36	0.65	138	0.135	4.15	3.75
	16	8.7	12.4	3.48	0.80	112	0.116	4.24	3.87
	22	10.1	14	3.72	0.80	112	0.130	4.87	4.10

* Calculated for rating conditions.

7.2.7.3 Small Office Building Characteristics

The small office building prototype model is a theoretical building modeled with characteristics typical of buildings of this size and use. The building is 5,500 ft^2, single-story, rectangular, 52 ft by 105 ft, with an aspect ratio of 1.5. The building has a window-area ratio of 21 percent with a 10-ft floor-to-ceiling height. The small office building is assumed to have slab-on-grade construction for the floor and an attic. A picture of the building structure is shown in Figure 7.2.15. The building is divided into five HVAC zones, four perimeter zones, and a core zone as illustrated in Figure 7.2.16, with a single central air conditioner or central heat pump unit assumed for each HVAC zone. The perimeter zone depth in the center of each zone is 16 ft.

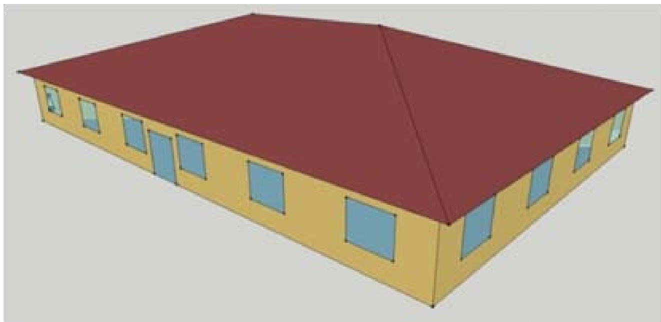

Figure 7.2.15 Small Office Building Design View

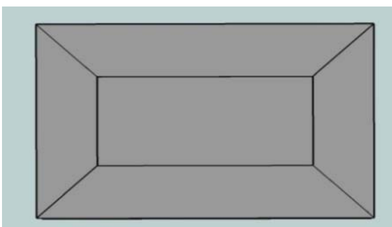

Figure 7.2.16 Small Office Building HVAC Zoning

The building model presumes wood frame construction and punch-out type windows. Where applicable, the building components for this model were assumed to "just meet" the minimum prescriptive requirements of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2004. Components not regulated by Standard 90.1 are assumed to be designed as is considered standard practice for a small office building. Standard practice is determined from various sources, including a review of the 2003 CBECS and the input of various design and construction industry professionals, including members of the ASHRAE 90.1 Standing Standard Project Committee. The following sections provide a review of the baseline building and how the baseline building is simulated in EnergyPlus, including characteristics of the building envelope, building internal loads (people, lighting, miscellaneous equipment, and infiltration), HVAC equipment, and service water heating.

7.2.7.4 Building Operating Characteristics

The building is assumed to follow typical small office occupancy patterns, with peak occupancy occurring from 8 a.m. to 5 p.m. weekdays and limited occupancy from 6 a.m. until 8 a.m. and from 5 p.m. extending until midnight for janitorial functions. The building is assumed to be unoccupied on weekends and holidays. Schedules for lighting and miscellaneous equipment were matched to occupancy schedules, with lower usage during unoccupied times. HVAC system schedules were matched to the occupancy schedules and allow for earlier startup times to bring the space to the desired temperature at the beginning of normal occupancy. Figure 7.2.17, Figure 7.2.18, Figure 7.2.19, and Figure 7.2.20 show the EnergyPlus schedules for lighting, plug loads, occupancy, and thermostat set point. Detailed schedules are shown in appendix 7-B for these as well as for HVAC fans, infiltration, and service hot water. These schedules represent multipliers to defined daily "peak" conditions. In the case of ventilation, it is assumed that ventilation occurs whenever the fan system is operational. In the case of infiltration, a maximum infiltration rate for each hour is calculated using wind speed and multiplied by the value shown in the hourly infiltration schedule. That value is 1.0 for hours when the ventilation is off and the building is assumed to be unpressurized. The schedule multiplier is assumed to be 0.25 during hours when the fan system is on and the building is pressurized.

The HVAC systems are scheduled to be on from 6 a.m. to 7 p.m. weekdays (13 hours/day) and are scheduled to be off on weekends and holidays. Building thermostats are set to 70 °F heating and 75 °F cooling during the occupied period. Thermostats are set back to 60 °F heating and 85 °F cooling during the unoccupied period. Between 6 a.m. and 7 a.m. weekday mornings, the thermostats are set to 65 °F cooling and 80 °F heating set points to provide a 1-hour thermostat ramp between the setback and occupied set points to prevent equipment sizing and temperature balance problems.

For the occupancy, lighting, plug use, and ventilation, the schedules shown in appendix 7-B are multipliers to defined peak densities. Lighting density was defined using the ASHRAE 90.1-2004 maximum lighting power density requirement of 1.0 W/ft^2. Plug load density (*e.g.*, computers and other miscellaneous loads) was 0.63 W/ft^2. Occupancy peak density was defined as 31 persons for the building (5.6 persons per 1,000 ft^2). Total outdoor air exchange during the occupied period (effective ventilation) was based on ASHRAE Standard 62-1999 and set to 0.1 cfm/ft^2 of floor area for each conditioned zone, corresponding to 0.6 air changes per hour. Ventilation was introduced directly into the zone and not through a mixed air box associated with the cooling system. The peak infiltration for the building was based on hourly wind speed, as discussed previously, averaging to 0.2016 cfm/ft^2 of total exterior conditioned zone wall area at a wind velocity of 10 miles per hour.

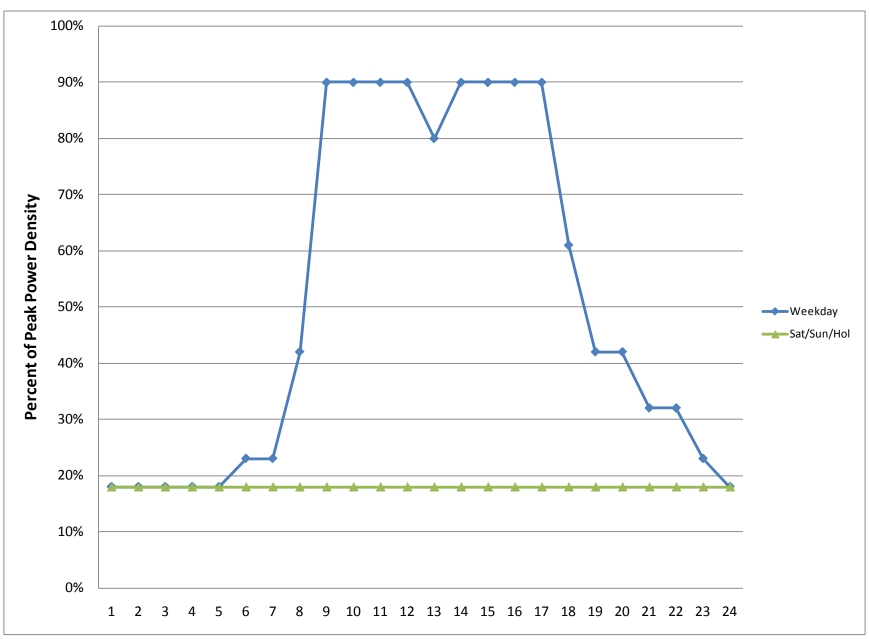

Figure 7.2.17 Small Office Lighting Schedule

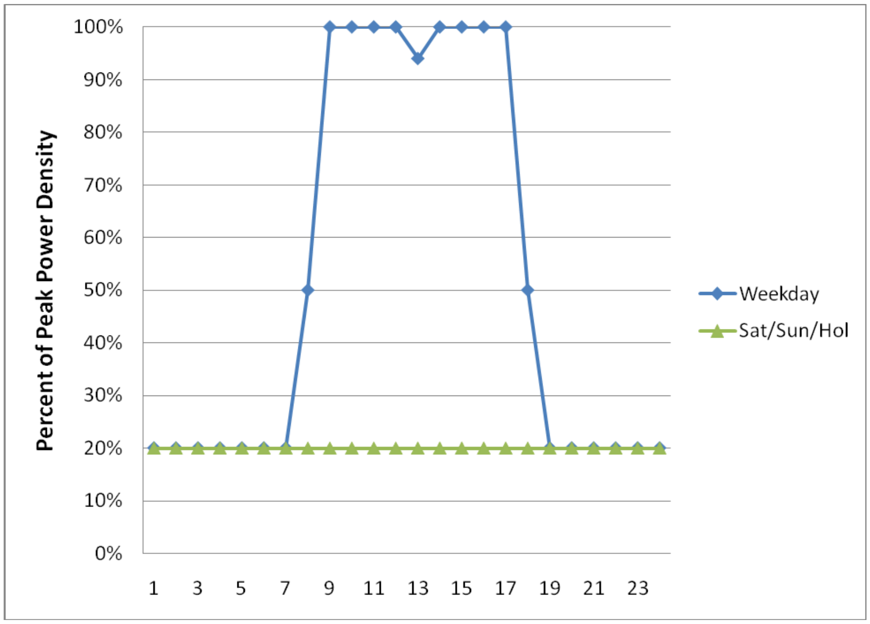

Figure 7.2.18 Small Office Plug Load Schedule

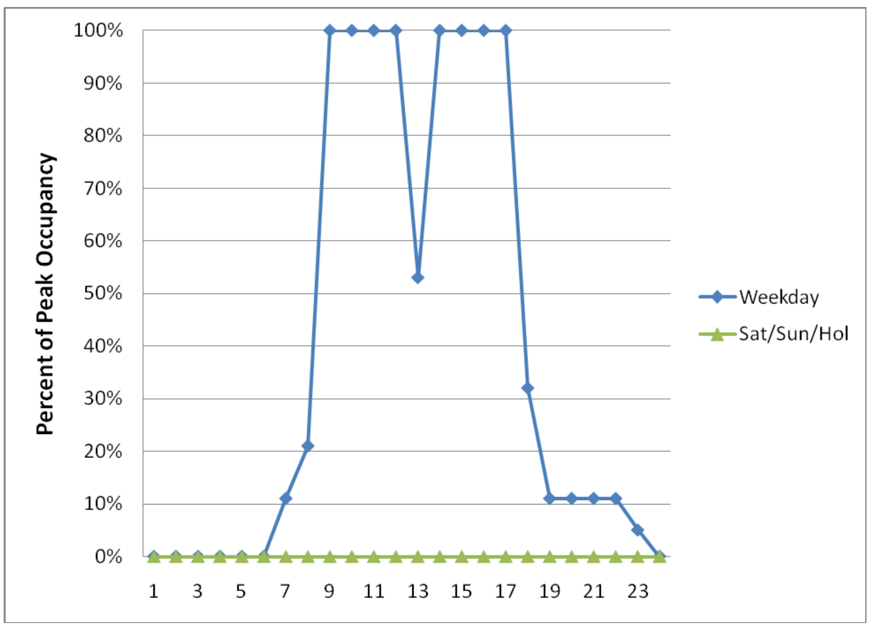

Figure 7.2.19 Small Office Occupancy Schedule

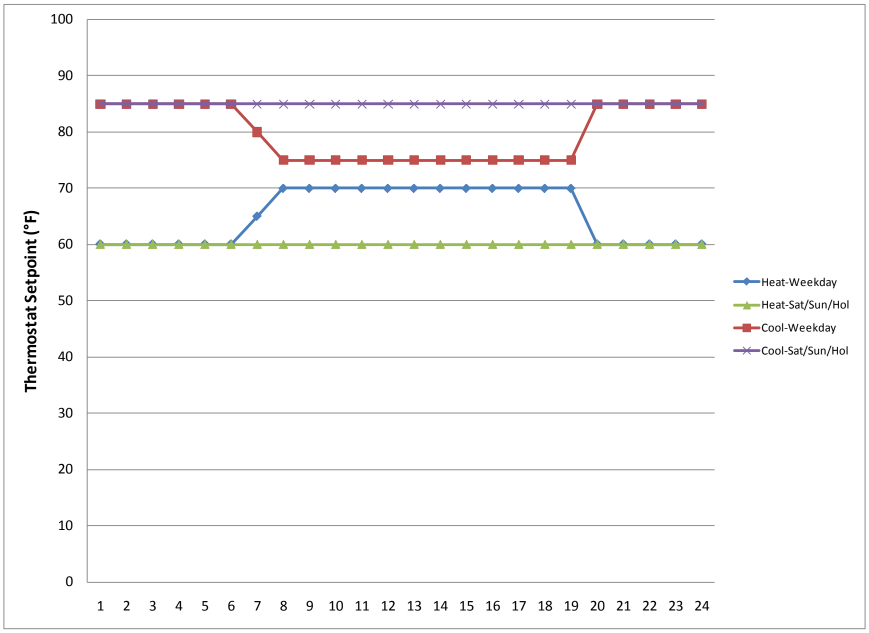

Figure 7.2.20 Small Office Thermostat Set Point Schedule

7.2.7.5 Building Mechanical Systems and Equipment

As discussed, the building used either five central air conditioner units or five central heat pump units, one for each conditioned zone, depending on which equipment class was analyzed. Equipment performance characteristics were developed using performance curves based on existing equipment. Performance curves and model inputs are documented in appendix 7-B.

Blower energy for the building model used the characteristics for blower motor and fan power efficiency discussed in section 7.2.7.2. However, the total fan static pressure was 1.45 in. H_2O based on the assumption used in the benchmark prototype, compared to 1.105 in. H_2O total static pressure used to characterize the equipment performance at rating conditions. DOE was not able to identify a specific source of information regarding the use of continuous air circulation for residential (single-phase) heat pumps in commercial buildings. A California study of 215 small air conditioners in commercial buildings found intermittent (cycling) ventilation operation during the occupied period in 38 percent of cases examined.[14] To emulate this, the commercial analysis had 40 percent (two out of five) of the HVAC zones operate in intermittent circulation model during the occupied period.

Cooling equipment was sized based on ASHRAE 2.5 percent cooling design-day sizing for all climates. A sizing run is done before the hourly simulations in EnergyPlus and is used to size all HVAC equipment. The design-day sizes are then used in the annual simulation runs. For the heat pumps, equipment sizing is based on cooling design-day, and electric resistance heat is used to make up any remaining heating load.

7.2.8 Baseline Commercial Energy Distribution

To be of use in the central air conditioner analysis, the baseline commercial central air conditioner and central heat pump use developed for the 237 TMY locations must have relative weighting factors associated with each TMY location, much as the residential analysis uses the representative RECS weights. DOE used population-based weighting factors developed for each TMY climate based on data from the 2000 U.S. Census to represent the importance of each climate in each state. The development and documentation of these weighting factors is found in appendix 7-C. Because certain TMY locations represent climates that cover more than one state (for instance, where the TMY location is on the border between two states), DOE originally developed weighting factors for a total of 543 TMY-State combinations. These weighting factors were then used in the subsequent LCC analysis in addressing central air conditioner and central heat pump energy use in commercial buildings. However, 17 locations in Alaska, which make up approximately 0.2 percent of the national weight, were removed from the energy analysis due to issues with electrical price data. Figure 7.2.21, Figure 7.2.22, and Figure 7.2.23 show distributions of commercial central air conditioner cooling and central heat pump cooling and heating energy use in the nation that accounts for the relative weights attached to each of the remaining 526 TMY-State combinations.

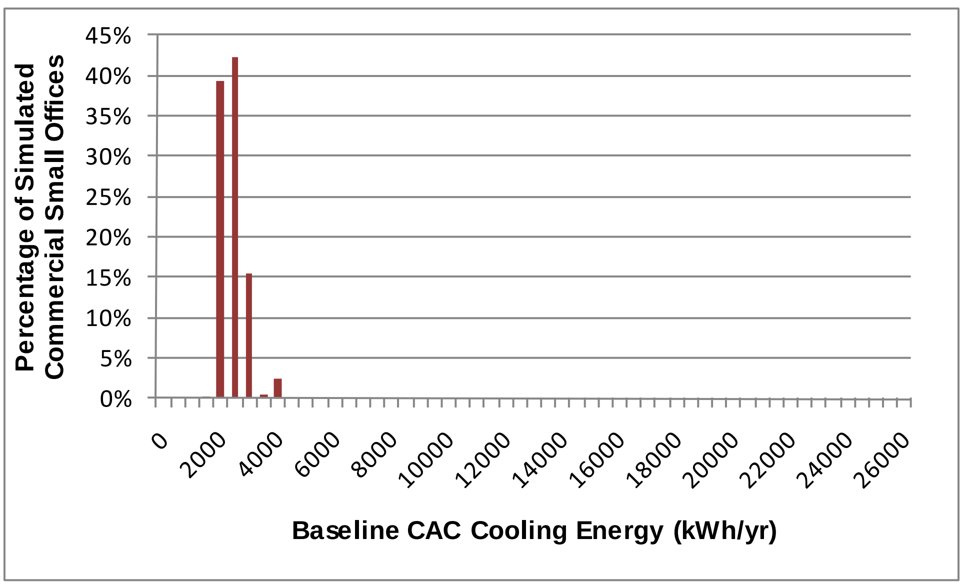

Figure 7.2.21 Baseline National Cooling Energy Distribution for Central Air Conditioners – Commercial, Weighted

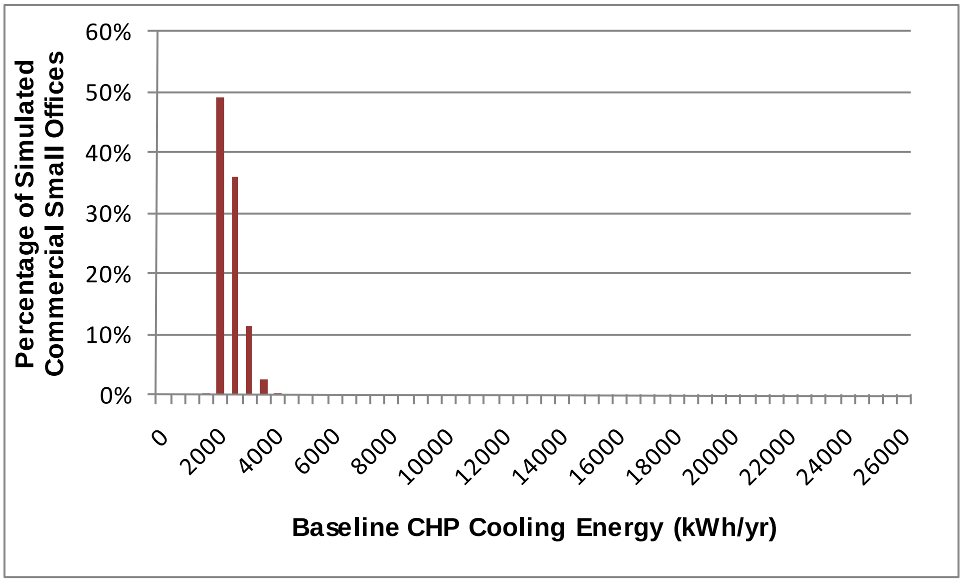

Figure 7.2.22 Baseline National Cooling Energy Distribution for CHC – Commercial, Weighted

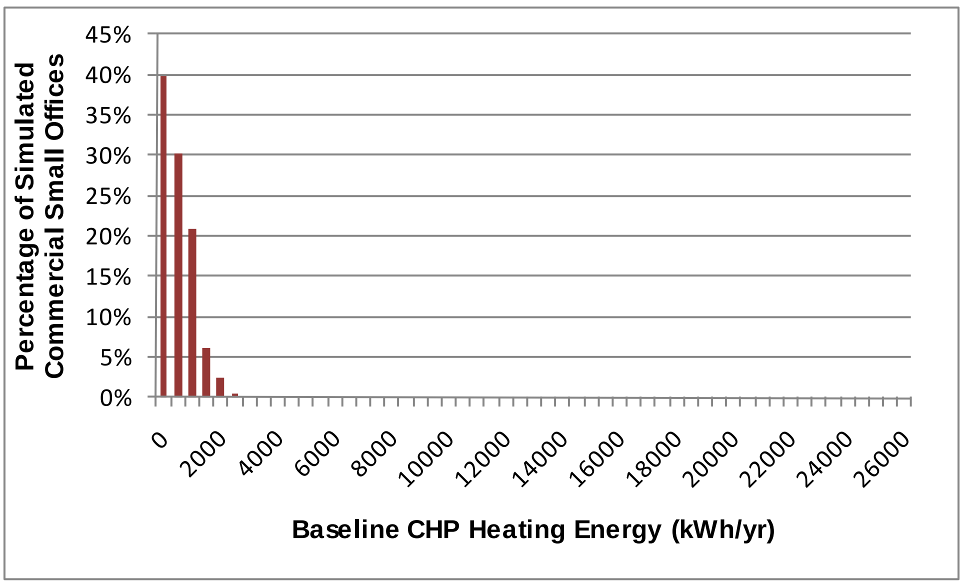

Figure 7.2.23 Baseline National Heating Energy Distribution for Central Heat Pumps – Commercial, Weighted

7.2.9 Commercial Energy for Intermediate Efficiency Levels

Calculation of commercial annual cooling and fan energy for intermediate efficiency levels not simulated was by linear interpolation between SEER levels simulated. Calculation of commercial heating energy use for heat pumps for intermediate levels not simulated was by interpolation between HSPF levels simulated.

7.2.10 Market Baseline Space-Cooling and Space-Heating Efficiencies

The analysis results presented in this chapter to this point present the development of the baseline space-cooling and space-heating energy use for central air conditioner and central heat pump equipment. "Baseline" in this discussion refers to the energy consumption if all equipment was brought to the current standard levels of SEER 13 and HSPF 7.7 for packaged and split-system central air conditioner and central heat pump product classes. Not all equipment is sold at the baseline efficiency levels. Much equipment exceeds the baseline level in the current market and is expected to continue to do so in the absence of new standards. In order to account for this within the LCC analysis discussed in the next chapter, DOE defined a base-case efficiency distribution for 2016, also referred to as the market baseline. The market baseline efficiency distribution was defined to represent the range of efficiencies likely sold into the market in 2016 in the absence of new standards. The market baseline energy consumption is calculated as the energy estimated to be consumed by each individual entity (as characterized by RECS household observation or commercial building TMY-State combination).

DOE estimated this energy use in the same manner used to estimate the baseline energy consumption. For RECS household records, DOE first randomly selected a 2016 efficiency level from the market baseline distribution. Then equations 7.2.1 and 7.2.3 were used to calculate the cooling and heating consumption for the RECS observations in the 2016 base case, by replacing the baseline efficiency (cooling or heating) with the selected efficiency for each observation in the base case. In the case of heat pump heating, HSPF improvement degradation factors were used as developed in appendix 7-A to adjust the HSPF improvement to reflect different climate regions used in DOE's analysis. For commercial TMY-State observations, DOE first randomly selected a 2016 efficiency level from the market baseline distributions and calculated the corresponding cooling fan and heating energy use for that observation in 2016 by linear interpolation between the efficiency levels simulated in the commercial energy analysis. See chapter 8 for the market distribution of efficiency levels by product class.

7.2.11 Determining Installed Equipment Capacity for RECS Observations

The notice of proposed rulemaking analysis was done using cost curves developed for three different sizes of split-system air conditioners and three different sizes of split-system heat pumps in order to capture variability in the costs to improve the efficiency of the equipment. In order to better analyze this within the market as a whole, DOE developed a process to assign a particular system size (2-, 3-, or 5-ton) to each RECS observation to support the LCC analysis discussed in chapter 8. DOE selected an appropriate capacity to assign to each RECS observation, taking into account the size of the residence and the geographic location of the residence as it influences the climate and sizing of equipment. The assignment of a cooling capacity is done to establish the first cost of equipment provided to the residence. The energy consumption is based on the RECS data, as adjusted for the baseline efficiency or other efficiency scenario.

The starting point for this process was to allocate all air conditioner and heat pump shipments to the capacities analyzed in the engineering analysis. The AHRI website provides a breakdown of monthly combined shipments of air conditioners and heat pumps by cooling capacity bins.[15] These data are not shown independently for the product classes, but are assumed to be representative for split systems, which are the vast majority of shipments.

For the residential equipment in question, eight cooling capacity bins encompassing capacities from 0 to 64.9 kilo British thermal units per hour (kBtu/h) are available. The SEER bins and unit shipments for 2009 are shown in the first two columns of Table 7.2.13 under AHRI Data. The data show that there are approximately equal values for combined air conditioner and heat pump shipments in the 22.0–22.9 kBtu/h and 33.0–38.0 kBtu/h bins, each corresponding to nominally sized 2- and 3-ton air conditioners, respectively. There are also significant shipments in the intermediate bin between these two. There are relatively fewer, but still significant, shipments above and below these bins. Because air conditioning equipment is typically sold in nominally one-half cooling ton increments, the estimated average cooling capacity for each bin was also estimated and is shown in Table 7.2.13. The distribution of shipments at these nominal sizes is shown in Figure 7.2.24. The average cooling capacity shipped was estimated from the AHRI data at 34.4 kBtu/h, or very close to a 3-ton unit.

DOE assigned the shipments in each bin to each of the cooling capacities identified in the engineering analysis (2-, 3-, or 5-ton). Most bins were wholly assigned to one of the engineering capacities. In the case of nominally 30 kBtu/h units (27.0–32.9 kBtu/h bin), shipments were equally divided between 2- and 3-ton sizes. In the case of the 48 kBtu/h units (44–53.9 kBtu/h bin), shipments were equally divided between 3- and 5-ton sizes. The resulting fraction of the market assigned to each of the engineering capacities is shown in Table 7.2.13. Also shown is the weighted average cooling capacity based on the overall actual shipments and corresponding nominal sizes allocated to each engineering capacity. For example, the engineering 2-ton units represent 40.1 percent of all shipments and, on average, those shipments had an actual capacity of 23.2 kBtu/h. The 3-ton units represent 44.5 percent of shipments, and the engineering 5-ton units are assumed to represent 14.5 percent of shipments. The average capacity of the shipments assigned to 2- and 3-ton units is very close to the nominal 2- and 3-ton engineering capacities. The weighted average of shipments assigned to the 5-ton engineering capacities is approximately midway between 4- and 5-ton nominal sizes.

Applying the market percentages assigned to each of the nominal 2-, 3-, and 5-ton engineering sizes yields an average market size of 34.9 kBtu/h. This corresponds closely with the 34.4 kBtu/h average capacity shipped estimated directly from the AHRI data, which suggests that the percentage weights assigned to the engineering sizes result in a good representation of the average total cooling capacity shipped.

Table 7.2.13 Development of Market Weights for 2-, 3-, and 5-Ton Air Conditioners and Heat Pumps

<table>
<tr><th colspan="3">AHRI Data</th><th colspan="4">Mapping to Engineering Sizes</th></tr>
<tr><th>SEER Bin
kBtu/h</th><th>Units
(2009
Shipped)</th><th>Est.
Avg.
Cooling
Capacity
kBtu/h</th><th>Assigned to
Engineering
Size
tons</th><th>Weighted
Average
Cooling
Capacity
Assigned
kBtu/h</th><th>Fraction
of
Market
%</th><th>Nominal
Engr.
Cooling
Capacity
kBtu/h</th></tr>
<tr><td>0 - 16.4</td><td>155,396</td><td>12</td><td>2</td><td rowspan="4">23.195</td><td rowspan="4">0.401</td><td rowspan="4">2</td></tr>
<tr><td>16.5 -21.9</td><td>380,779</td><td>18</td><td>2</td></tr>
<tr><td>22.0 - 26.9</td><td>1,006,905</td><td>24</td><td>2</td></tr>
<tr><td rowspan="2">27.0 - 32.9</td><td rowspan="2">854,454</td><td rowspan="2">30</td><td rowspan="2">50% 2-ton
50% 3-ton</td></tr>
<tr><td rowspan="4">36.053</td><td rowspan="4">0.445</td><td rowspan="4">3</td></tr>
<tr><td>33.0 - 38.9</td><td>1,039,122</td><td>36</td><td>3</td></tr>
<tr><td>39.0 - 43.9</td><td>428,931</td><td>40</td><td>3</td></tr>
<tr><td rowspan="2">44.0 - 53.9</td><td rowspan="2">591,554</td><td rowspan="2">48</td><td rowspan="2">50% 3-ton
50% 5-ton</td></tr>
<tr><td rowspan="2">55.314</td><td rowspan="2">0.154</td><td rowspan="2">5</td></tr>
<tr><td>54.0 - 64.9</td><td>461,598</td><td>60</td><td>5</td></tr>
<tr><td>Total</td><td>4,918,739</td><td></td><td colspan="4"></td></tr>
<tr><td colspan="2">Average Cooling Capacity (kBtu/h)</td><td>34.4</td><td colspan="4">34.9</td></tr>
</table>

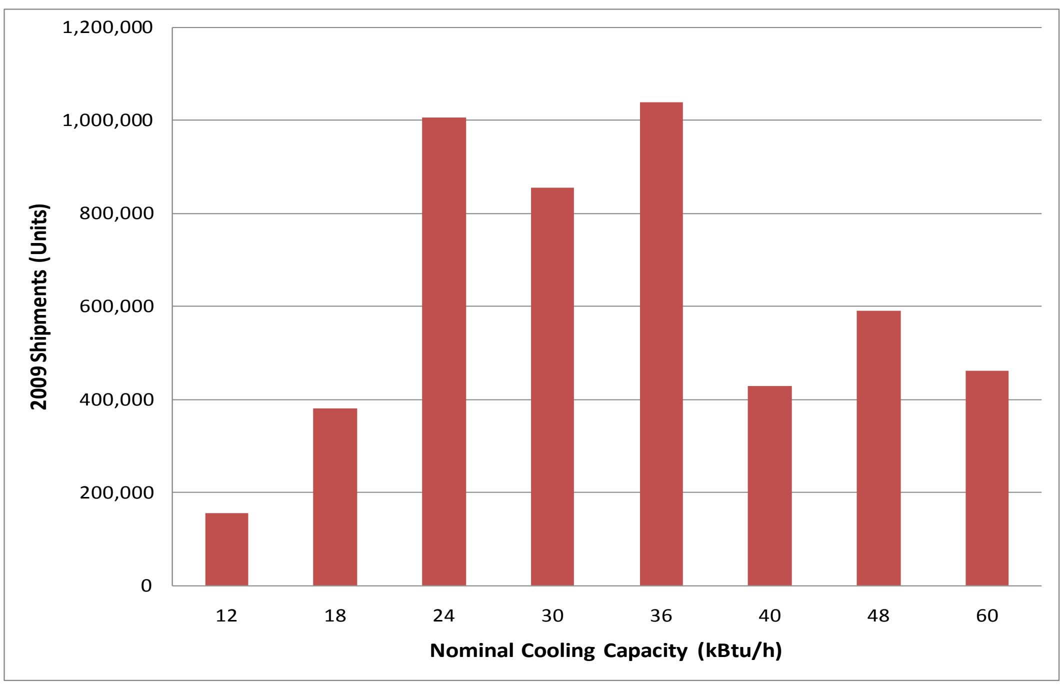

Figure 7.2.24 Shipments of Residential Air Conditioners and Heat Pumps by Capacity for 2009

In order to size the RECS households, DOE presumed that the distribution of shipment sizes described previously represented the distribution within the RECS sample after taking into account the household weights. For each household, DOE extracted all relevant household size data, including the cooled square footage of the home. DOE also used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature in each of the three analysis regions. For each region, DOE then developed a scaling factor to be applied to the home square footage and equal to:

$$SF_{design,r} = (T_{design,\,r} - 65) / (95 - 65) \qquad \textbf{Eq. 7.2.8}$$

Where:

$SF_{design,r}$ = design scaling factor, and
$T_{design,\,r}$ = average 1 percent ASHRAE design dry bulb temperature for region (°F).

This scaling factor was then multiplied by the reported cooled area for each household. A ±20 percent uncertainty factor was then applied to the cooled area to reflect some uncertainty in the sizing of the equipment to that observation, which provided some randomization in the size assignment to the RECS households. The RECS observations were then sorted by this new scaled cooled household area, and the central air conditioner equipment sizes (2-, 3-, and 5-ton) were assigned from smallest to largest area and according to each central air conditioner size's share in the overall market. As a check on the results, the estimated cooling full load operating hours[c] of the equipment (calculated based on the RECS reported cooling energy use, RECS estimated SEER, and the selected equipment size) were examined. In a few instances where the full load operating hours calculated were very high (*e.g.*, >4,000) and did not appear to represent reasonable estimates for the regions in question, DOE modified the assignment of equipment size by choosing the next larger size central air conditioner available from the engineering analysis.

It is noted that the design scaling factor is used as a proxy to represent lower cooling loads for the same household area in cooler climates and supports the allocation of the sizes across observations, but that the total relative allocation of sizes is unaffected. This end result was a distribution of sizes assigned to the weighted RECS samples that matches the distribution of sizes for shipments of residential air conditioners and heat pumps.

7.2.12 Regional Energy Consumption by Efficiency Level

Under the Energy Policy and Conservation Act, regional efficiency standards for central air conditioners may be defined for up to two regions consisting of contiguous groups of states. These regional standards are in addition to a base national standard efficiency that represents the minimum efficiency that a manufacturer could produce or that could be imported into the United States. As discussed in chapter 2, DOE defined two regions for regional standards: a hot-humid region and a hot-dry region. In addition, DOE defined the remainder of the states as "rest-of-country." For each equipment class, DOE developed energy use statistics for the market baseline

[c] Cooling full load operating hours are a measure of how many hours in a year the equipment would run at full capacity to provide the total estimated cooling load met by the equipment.

and for higher efficiency levels by using a Monte Carlo random selection process to select 10,000 observations in each region and 10,000 for the nation as a whole. Of those observations, 93 percent were residential and 7 percent were commercial instances of the use of central air conditioner (or central heat pump) equipment.

In addition, at the national level, energy use statistics for each equipment class are further influenced by relative shipments between each region, not captured in the RECS data. Shipments by region for each air conditioner class were provided by AHRI for the years 2008 and 2009.[d] These were converted to relative fractions of shipments for each product class by year. These relative shipment fractions by year are shown in chapter 9. DOE averaged the relative shipment fraction for each region across both years to provide product-specific regional weighting factors and used these to further adjust the weighting factors developed for each observation. For small duct high velocity equipment, AHRI did not provide a weighting factor. DOE used the product-specific regional weighting factor developed for split system air conditioners also for small duct high velocity equipment. These product-specific regional weighting factors are shown in Table 7.2.14.

Table 7.2.14 Fraction of Shipments by Product Class to Each Region

	Region		
Product Class	**Hot-Dry**	**Hot-Humid**	**Rest of U.S.**
Split System CAC	0.374	0.515	0.112
Split System HP	0.194	0.736	0.070
Single Package CAC	0.174	0.578	0.248
Single Package HP	0.033	0.719	0.248
Small Duct High Velocity AC	0.374	0.515	0.112

Source: AHRI

In the Monte Carlo simulations for each product class, the relative weighting factors for each residential household observation were multiplied by the product-specific regional weighting factors for that region that household was in. Similarly, the observation weights developed for each commercial observation (TMY-State combination) were multiplied by the product specific regional weighting factors for that region. Thus all the individual observation weighting factors in a given region were scaled by the same value. This scaling has no impact on the relative probability of selection for the observations within a given region, and thus no impact on the calculated results from the Monte Carlo simulations within a given region. However, when developing national results for each product class these product-specific regional weighting factors affect the relative probability of selecting an observation between regions. Further details for the Monte Carlo analysis procedure are found in chapter 8. Table 7.2.15 to Table 7.2.20 show the resulting baseline, market baseline, and higher efficiency annual energy statistics developed for each region for each product class analyzed.

[d] Shipments for hot-humid, hot-dry, and rest-of-country regions provided by AHRI for 2008 and 2009 in shipments data provided to DOE (Aug 2010).

Table 7.2.15 Split-System Air Conditioners: Average Annual Energy Use by Efficiency Level – Coil-Only Systems

Efficiency Level			Annual Energy Consumption *kWh/yr*							
			National		Hot-Humid		Hot-Dry		Rest of Country	
#	SEER	HSPF*	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
1	13.0	N/A	2,470	0	3,411	0	2,226	0	1,334	0
Market Baseline	Market Baseline	N/A	2,340	0	3,226	0	2,111	0	1,266	0
2	13.5	N/A	2,382	0	3,288	0	2,147	0	1,289	0
3	14.0	N/A	2,301	0	3,174	0	2,074	0	1,247	0
4	14.5	N/A	2,222	0	3,066	0	2,003	0	1,204	0
5	15.0	N/A	2,147	0	2,964	0	1,936	0	1,163	0
6	15.5	N/A	2,078	0	2,868	0	1,873	0	1,124	0
7	16.0	N/A	2,012	0	2,778	0	1,814	0	1,087	0
8	16.5	N/A	1,966	0	2,714	0	1,772	0	1,066	0
9	17	N/A	1,924	0	2,653	0	1,733	0	1,045	0
10	18	N/A	1,892	0	2,606	0	1,707	0	1,032	0

* N/A means not applicable.

Table 7.2.16 Split-System Air Conditioners: Average Annual Energy Use by Efficiency Level – Blower-Coil Systems

Efficiency Level			Annual Energy Consumption *kWh/yr*							
			National		Hot-Humid		Hot-Dry		Rest of Country	
#	SEER	HSPF*	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
1	13.0	N/A	2,468	0	3,409	0	2,227	0	1,333	0
Market Baseline	Market Baseline	N/A	2,200	0	3,025	0	1,986	0	1,190	0
2	13.5	N/A	2,381	0	3,286	0	2,148	0	1,288	0
3	14.0	N/A	2,299	0	3,172	0	2,074	0	1,246	0
4	14.5	N/A	2,220	0	3,063	0	2,003	0	1,203	0
5	15.0	N/A	2,146	0	2,962	0	1,937	0	1,162	0
6	15.5	N/A	2,076	0	2,866	0	1,874	0	1,123	0
7	16.0	N/A	2,011	0	2,776	0	1,815	0	1,087	0
8	16.5	N/A	1,952	0	2,695	0	1,762	0	1,057	0
9	17.0	N/A	1,898	0	2,618	0	1,713	0	1,028	0
10	18.0	N/A	1,797	0	2,478	0	1,622	0	976	0
11	19.0	N/A	1,726	0	2,377	0	1,556	0	941	0
12	20.0	N/A	1,662	0	2,286	0	1,497	0	910	0
13	21.0	N/A	1,604	0	2,204	0	1,444	0	882	0
14	22.0	N/A	1,550	0	2,129	0	1,394	0	856	0
			1,531	0	2,100	0	1,378	0	848	0
			1,504	0	2,061	0	1,356	0	836	0

* N/A means not applicable.

Table 7.2.17 Split-System Heat Pumps: Average Annual Energy Use by Efficiency Level

Efficiency Level			Annual Energy Consumption *kWh/yr*							
			National		Hot-Humid		Hot-Dry		Rest of Country	
#	SEER	HSPF	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
1	13.0	8.00	3,265	1,645	3,664	1,452	4,037	809	1,547	2,738
Market Baseline	Market Baseline	Market Baseline	3,030	1,594	3,401	1,407	3,747	784	1,439	2,656
2	13.5	8.1	3,149	1,629	3,532	1,437	3,891	801	1,494	2,713
3	14	8.2	3,040	1,606	3,410	1,416	3,756	788	1,445	2,680
4	14.5	8.3	2,936	1,588	3,293	1,400	3,627	780	1,395	2,653
5	15	8.5	2,838	1,567	3,184	1,380	3,507	762	1,348	2,648
6	15.5	8.6	2,747	1,554	3,082	1,367	3,394	755	1,303	2,635
7	16	8.7	2,661	1,538	2,985	1,353	3,287	747	1,261	2,613
8	16.5	8.8	2,583	1,526	2,898	1,342	3,192	741	1,226	2,594
9	17	8.9	2,510	1,508	2,815	1,326	3,102	731	1,193	2,569
10	18	9.1	2,378	1,487	2,667	1,307	2,940	719	1,133	2,538
11	19	9.4	2,289	1,466	2,567	1,289	2,811	707	1,099	2,506
12	20	9.6	2,207	1,445	2,477	1,269	2,695	694	1,068	2,476
13	21	9.8	2,134	1,429	2,395	1,255	2,589	685	1,040	2,454
14	22	10.1	2,109	1,421	2,367	1,248	2,557	679	1,029	2,437

Table 7.2.18 Single-Package Air Conditioners: Average Annual Energy Use by Efficiency Level

Efficiency Level			Annual Energy Consumption *kWh/yr*	
			National	
#	SEER	HSPF*	Cooling	Heating
1	13	N/A	2,703	0
Market Baseline	Market Baseline	N/A	2,648	0
2	13.5	N/A	2,606	0
3	14	N/A	2,517	0
4	14.5	N/A	2,430	0
5	15	N/A	2,349	0
6	15.5	N/A	2,273	0
7	16	N/A	2,202	0
8	16.5	N/A	2,138	0

Table 7.2.19 Single-Package Heat Pumps: Average Annual Energy Use by Efficiency Level

Efficiency Level			Annual Energy Consumption *kWh/yr*	
			National	
#	SEER	HSPF	Cooling	Heating
1	13	8	3,831	1,526
Market Baseline	Market Baseline	Market Baseline	3,682	1,484
2	13.5	7.9	3,694	1,495
3	14	8.1	3,566	1,466
4	14.5	8.3	3,444	1,438
5	15	8.4	3,329	1,425
6	15.5	8.6	3,222	1,398
7	16	8.8	3,121	1,376
8	16.5	9	3,029	1,354

Table 7.2.20 Small Duct High Velocity Air Conditioners: Average Annual Energy Use by Efficiency Level

Efficiency Level			Annual Energy Consumption *kWh/yr*							
			National		Hot-Humid		Hot-Dry		Rest of Country	
#	**SEER**	**HSPF***	**Cooling**	**Heating**	**Cooling**	**Heating**	**Cooling**	**Heating**	**Cooling**	**Heating**
1	13	N/A	2,469	0	3,409	0	2,227	0	1,334	0
Market Baseline	Market Baseline	N/A	2,469	0	3,409	0	2,227	0	1,334	0
2	13.5	N/A	2,381	0	3,287	0	2,148	0	1,289	0
3	14	N/A	2,300	0	3,173	0	2,075	0	1,247	0
4	14.5	N/A	2,203	0	3,046	0	1,986	0	1,185	0

* N/A means not applicable.

7.2.13 Off Mode Energy Consumption

DOE is considering national standards for off mode energy consumption, but does not intend to set regional standards for off mode energy consumption. DOE established annual off mode energy consumption estimates for each off mode technology option identified in the engineering analysis for air conditioners and for heat pumps. DOE estimated annual off mode energy consumption for air conditioners based on the shoulder season off mode power consumption (P1) and heating season off mode power consumption (P2) defined for each design option multiplied by the representative shoulder season rating hours (739 hours) and heating season rating hours (5,216 hours) established in the test procedure. DOE estimated annual energy consumption for heat pumps based only on the shoulder season off mode power consumption multiplied by the representative shoulder season rating hours (739 hours) established in the test procedure because heat pumps operate in active mode during the heating season. These seasonal hours are consistent with the rating hours used in the SEER and HSPF ratings for air conditioners and heat pumps.

DOE is considering national standards for off mode energy consumption, but does not intend to set regional standards for off mode energy consumption. It is recognized that there will be some variation in off mode hours depending on location and individual household usage, but DOE believes that the defined off mode hours in the test procedure represent a reasonable basis for calculation of energy savings from off mode energy conservation standards. DOE does not include in the off mode period the time during the cooling season when a unit cycles off because energy use during this period is captured in the seasonal SEER rating of the equipment. Similarly, DOE does not include in the off mode period the time during the heating season when a heat pump cycles off because energy use during this period is captured in the seasonal HSPF rating of the equipment. To avoid double counting the benefits of design options which reduce energy consumption during the heating or cooling off-cycles as opposed to the defined off mode time period, DOE relied on the representative off mode hours from the test procedure to estimate national average off mode period for the energy analysis.

The component that uses the most power during off mode is the crankcase heater, but it is not found in all products. Off mode energy use estimates for air conditioners and heat pumps were estimated for units with and without crankcase heaters.

DOE was not able to identify a data source establishing the fraction of central air conditioner or heat pump products in the U.S. market which would be tested with crankcase heaters or would be expected to have crankcase heaters installed in the field. A 2004 study of the Australian market estimated that one in six air conditioners in that market utilized crankcase heaters.[16] However, changes in compressor technology since 2004, in particular market growth in the use of scroll compressors, are expected to have resulted in a lower fraction of the air conditioner market with crankcase heaters in the U.S. today. DOE assumed that 10 percent of air conditioners within each air conditioner product class would utilize crankcase heaters. Crankcase heaters are more commonly used in heat pumps, which must be able to cycle on in cold weather. Based on discussions with manufacturers, DOE assumed that approximately two-thirds of heat pumps would utilize crankcase heaters in each heat pump product class.

The engineering technology options examined for off mode energy use do not impact blower energy consumption in off mode. For this reason, the energy savings from employing these options is identical for equipment utilizing either ECM or PSC blower motors. Annual off mode energy use for each technology above the baseline are shown in Table 7.2.21 to Table 7.2.23 for equipment with ECM motors and both with and without a crankcase heater.

While both ECM and PSC motors employing these technologies will have the same energy savings, DOE recognized that the wattage savings from the toroidal transformer design option was very small and that separate standard levels based on these design options that would be set at levels for which equipment with ECM blower motors could meet would not require the use of the toroidal transformer design option when PSC blower motors are used. Because of this certain efficiency levels options only apply to equipment with ECM motors. See chapter 8 for a detailed discussion.

Table 7.2.21 Split-System Blower Coil, Packaged, Space Constrained, and SDHV Air Conditioner Off Mode Energy Use

	Annual Off Mode Energy Consumption with an ECM Motor and Crankcase Heater ***kWh/yr***	**Annual Off Mode Energy Consumption with an ECM Motor and No Crankcase Heater** ***kWh/yr***
Baseline	286	66
Efficiency Level 1	212	61
Efficiency Level 2	180	NA
Efficiency Level 3	175	NA

Table 7.2.22 Split-System Coil-Only Air Conditioner Off Mode Energy Use

	Annual Off Mode Energy Consumption with an ECM Motor and Crankcase Heater *kWh/yr*	**Annual Off Mode Energy Consumption with an ECM Motor and No Crankcase Heater** *kWh/yr*
Baseline	220	0
Efficiency Level 1	146	NA
Efficiency Level 2	115	NA

Table 7.2.23 Split-System, Packaged, and Space Constrained Heat Pump Off Mode Energy Use

	Annual Off Mode Energy Consumption with an ECM Motor and Crankcase Heater *kWh/yr*	**Annual Off Mode Energy Consumption with an ECM Motor and No Crankcase Heater** *kWh/yr*
Baseline	38	10
Efficiency Level 1	24	10
Efficiency Level 2	23	NA

Not all equipment will be at the baseline efficiency level. DOE established a 2016 base case distribution of off mode energy use by efficiency level for each product class. This base case took into account that an estimated 10 percent of the split system air conditioner market are blower coil equipment and 90 percent are coil only equipment. It also took into account that approximately 27 percent of the current shipping blower coil split system and packaged air conditioner and the split system and packaged heat pump markets use ECM motors. See chapter 8 for discussion of the base case assumptions.

DOE determined energy savings for each technology option as compared to the base case in the LCC analysis using a special purpose off mode LCC spreadsheet. See chapter 8 for discussion of the off mode LCC analysis. For each equipment class, DOE developed energy use statistics for the base case and for each off mode efficiency level by using a Monte Carlo random selection process to select 10,000 observations using the base case off-mode efficiency distributions. The resulting national average energy use estimates from this process are shown in Table 7.2.24 by equipment class.

Table 7.2.24 National Average Off Mode Energy Use

Efficiency Level	**Average Annual Off Mode Energy Consumption** *kWh/yr*				
	Split Air Conditioners-Coil Only	**Split Air Conditioners-Blower Coil and SDHV**	**Split System Heat Pumps**	**Single Package Air Conditioners**	**Single Package Heat Pumps**
Baseline	22	88	28	88	29
2016 Base Case	19	84	24	84	24
Efficiency Level 1	15	80	19	80	20
Efficiency Level 2	11	77	19	77	20
Efficiency Level 3	11	77	NA	77	NA

7.3 FURNACES

The following sections describe the factors that determine the amount of heat load and energy that furnaces use, the characteristics of furnace energy efficiency, and furnace operating conditions.

7.3.1 Introduction

A furnace utilizes gas or oil fuel for heating and electric energy to power a blower, a draft inducer, an ignitor, and sometimes auxiliary equipment. DOE estimated the energy consumption of furnaces in actual housing units, as represented by the sample developed from RECS 2005.[17] This sample is further described in section 7.3.2.

DOE calculated the energy use of residential furnaces in each of the three product classes: non-weatherized gas furnaces, manufactured home furnaces, and oil-fired furnaces. 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 assigned the energy efficiency of existing systems based on a regional historical distribution of energy efficiencies for furnaces and RECS data on the age of the existing furnace. 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. In addition, DOE made adjustments based on historical weather data, projections of shell efficiency and building square footage, and for homes that had secondary heating equipment that used the same fuel as the furnace. 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

DOE's calculation of the annual energy use of residential furnaces relied on data from the RECS 2005[17]. RECS collects energy-related data for occupied primary housing units in the United States. The RECS 2005 included data from 4,381 housing units that represent almost 111.1 million households.

The subset of RECS 2005 records used to study furnaces met all of the following criteria:

- used a furnace as the main or secondary source of heat;
- used a heating fuel that is natural gas, liquefied petroleum gas (LPG), or fuel oil;
- heated only one housing unit; and
- had an energy consumption greater than zero.

DOE divided the furnace subset into three further subsets designed to include households that use one of the three furnace product classes (Table 7.3.1). Appendix 7-D presents the variables included and their definitions.

Table 7.3.1 Selection of RECS 2005 Records for Furnaces

Product Class	Algorithm	Region	No. of Records	RECS 2005 Number of Houses *million*	DOE 2016 Number of Furnaces *million*
Non-Weatherized Gas Furnace	Central heating equipment = furnace Heating fuel = gas Home type = single or multi-family Number of Housing Units Heated = 1	National	1726	45.5	45.2
		North	990	25.9	26.9
		South	736	19.6	18.3
Manufactured Home Gas Furnace	Central heating equipment = furnace Heating fuel = gas Home type = manufactured home Number of Housing Units Heated = 1	National	109	2.5	2.5
		North	58	1.2	1.2
		South	51	1.2	1.3
Oil-Fired Furnace	Central heating equipment = furnace Heating fuel = fuel oil Home type = manufactured home Number of Housing Units Heated = 1	National	150	2.9	3.0

DOE made some adjustments to EIA's weightings for each RECS 2005 household, in order to create a furnace population weight for 2016. The RECS 2005 weighting indicates how commonly each household configuration occurs in the general population in 2005. The first adjustment was to compensate for the fact that the RECS 2005 sample does not distinguish between weatherized and non-weatherized gas furnaces. Therefore, to account for non-weatherized gas furnaces, DOE assumed that a fraction of the households in the south with both a central air conditioner and gas furnace were using weatherized furnaces. Based on AHRI shipment data for weatherized and non-weatherized furnaces (which shows that about 10 percent of total furnace shipments are weatherized furnaces), DOE multiplied the RECS 2005 weight for households in the south region with both a central air conditioner and gas furnace by 0.80.

DOE also took into account the growth in population by region from 2005 to 2016 based on U.S. census population projections. For all product classes, the number of houses in the north was multiplied by a factor of 0.96 and the number of houses in the south by a factor of 1.04.

Finally, DOE adjusted the weightings to account for households with multiple furnaces. According to the 2008 American Comfort Survey, 7 percent of households in the United States have multiple gas furnaces.[18] For simplicity DOE assumed that these households had two furnaces. Therefore, for 7 percent of the households, the weighting was doubled, so it could be representative of the furnace weight. DOE believes that the household records, along with their adjusted weightings, are representative of housing nationwide in 2016 (see appendix 7-D for details).

7.3.3 Annual Heating Load Calculation

The annual house-heating load (HHL) is the total amount of heat output from the furnace that the house needs during the heating season. This includes heat from the burner and heat from the blower and the blower motor.

The Department determined HHL for each sampled housing unit, based on the burner operating hours (*BOH*) and the characteristics of the assigned existing furnace, using the following calculations:

$$HHL = \left(Q_{YR,RECS} \times AFUE_{ex} + 3.412 \times BE \times \left[BOH_{ex} + N \times \left(\frac{t^{+} - t^{-}}{3600} \right) \right] \right) \times Adj\_Factor \qquad \textbf{Eq. 7.3.1}$$

Where:

$Q_{YR,RECS}$ = annual fuel consumption for heating based on RECS 2005 (kBtu/yr),
$AFUE_{ex}$ = AFUE of the existing furnace (see section 7.3.5.4),
3.412 = constant to convert kW to kBtu/hr,
BE_{ex} = power consumption of the blower motor of the existing furnace (kW),
BOH_{ex} = as defined below (hr/yr),
N = number of cycles per hour (set equal to 5 for furnaces),
HLH = heating load hours (hr) (see appendix 7-E for the derivation),
t^{+} = off delay (seconds),
t^{-} = on delay (seconds), and
Adj_Factor = adjustment factor.

Burner operating hours (BOH_{ex}), the number of hours the existing furnace burner is on during a year, is a key variable in the calculation of HHL. The Department calculated BOH for the existing furnace as:

$$BOH_{ex} = \frac{Q_{YR,RECS}}{Q_{IN,ex}} \qquad \textbf{Eq. 7.3.2}$$

Where:

BOH_{ex} = burner operating hours of existing household (hr/yr),
$Q_{YR,RECS}$ = as defined above (kBtu/yr),
$Q_{IN,ex}$ = input capacity of the existing furnace (see section 7.3.5.1) (kBtu/hr).

The power consumption of the blower motor depends on the steady-state operating conditions (the pressure and airflow) for the furnace. This calculation is explained in appendix 7-F.

The Department made adjustments to reflect the expectation that newly built housing units in 2016 will have a somewhat different heating load than the housing units in the RECS 2005 sub-sample. The adjustment involves multiplying the calculated HHL for each RECS 2005 housing unit by a building shell efficiency index derived from the NEMS simulation performed for EIA's *AEO 2010*.[19] The building shell efficiency index sets the heating load value at 1.00 for an average home in 2005 (by type) in each census division. The values listed represent the change in heating load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows). This factor differs for new construction and replacement households. The value for households in 2016 is 0.87 for replacements and 0.77 for new construction, which means that the average new home in 2016 will require less heat energy to maintain indoor comfort. To add variability, the factor is varied by plus or minus 15 percent.

DOE also made adjustments to the HHL calculated using RECS 2005 data to reflect historical average climate conditions. Table 7.3.2 shows the 1895 to 2009 average heating degree days (HDD) as well as the 2005 average HDD for the nine census divisions. The adjustment factors are calculated using the equation below and are almost all positive, which means that 2005 had warmer temperatures compared to the 115-year average.

$$Adj\_Factor_{average\_climate} = \frac{HDD_{115\_yr\_avg}}{HDD_{res\_stock\_2005}} \qquad \textbf{Eq. 7.3.3}$$

Where:

$HDD_{res\_stock\_2005}$ = HDD in 2005 for the specific census division or state where the housing unit is located, and

$HDD_{115\_yr\_avg}$ = 115-year average HDD (1895–2009) for the specific census division where the housing unit is located.

Table 7.3.2 Heating Degree Day Adjustment Factors

Census Division		Average HDD		Adjustment Factor
		1895-2009	**2005**	
1	New England	6,559	6,567	1.00
2	Middle Atlantic	5,822	5,752	1.01
3	East North Central	6,307	6,102	1.03
4	West North Central	6,582	5,988	1.10
5	South Atlantic	2,756	2,757	1.00
6	East South Central	3,418	3,303	1.03
7	West South Central	2,175	1,928	1.13
8	Mountain	5,105	4,742	1.08
9	Pacific	3,217	3,031	1.06
Nation		4,416	4,246	1.04

For households in which it is clear that the fuel use for heating is associated solely with the use of furnace equipment as the 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 both a furnace (either as the primary or secondary heating equipment) and other heating equipment using the same fuel. RECS 2005 reports the percentage of heating energy consumption attributable to secondary products. DOE derived the house heating load applicable to the furnace by subtracting the estimated amount of heat provided by the other heating system. In the case when a household was determined to have multiple furnaces, the house heating load was divided by the number of furnaces. Details are presented in appendix 7-F.

7.3.3.1 Overview of Heating Load Estimates

DOE calculated that the national average annual heating load to be 32.0 for non-weatherized gas furnaces, 27.7 for manufactured home gas furnaces, and 60.7 for oil-fired furnaces. The variations between product types primarily reflect differences in the distribution of furnaces. These results are smaller than previous studies, primarily due to improvements in building shell efficiency and heating equipment efficiency. Table 7.3.3 shows the range in heating load among sample households.

Table 7.3.3 Range of Annual Heating Load for Each Furnace Product Class by Region

Region	**Min**	**Max**	**Average**	**Percentiles**				
				5%	25%	50%	75%	95%
Non-Weatherized Gas Furnaces								
National	0.3	190.5	32.0	5.7	16.3	28.7	43.0	69.8
North	1.5	190.5	40.5	14.9	26.9	37.1	50.2	76.3
South	0.3	133.2	19.1	3.6	9.0	15.5	25.1	46.5
Manufactured Home Gas Furnaces								
National	3.5	104.7	27.7	7.2	17.5	23.7	36.1	57.5
North	3.8	104.7	34.1	13.9	22.0	32.1	42.6	68.4
South	3.5	76.1	21.7	6.1	12.4	20.2	26.4	45.8
Oil-fired Furnaces								
National	0.0	220.9	60.7	27.7	41.2	60.3	76.2	99.9

7.3.4 Annual Energy Consumption

Once the heating load of each sample housing unit is known, it is possible to estimate what the energy consumption would be if more efficient equipment, rather than the baseline equipment, were used in each housing unit.

7.3.4.1 Fuel Consumption

The Department calculated the fuel consumption (*FuelUse*) for each furnace using the following formulas from the current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) test procedure SPC 103-2007 section C:

$FuelUse = BOH_{SS} \times Q_{IN}$,[e,f] for single-stage furnace **Eq. 7.3.4**

Where:

BOH_{SS} = steady-state burner operating hours (hr), and
Q_{IN} = input capacity of existing furnace (kBtu/hr).

The details for calculating energy consumption appear in appendix 7-F.

7.3.4.2 Electricity Consumption

The Department calculated furnace electricity consumption for the blower, the draft inducer, and the ignitor.[g] The blower moves heated air through the house whenever the furnace burner is on (adjusted for delay times between burner and blower operation). It also operates in the cooling season (summer) if the house is air conditioned, but the Department only considered use during the heating season. DOE also took into account the electricity consumption of such auxiliary equipment as condensate pumps and heat tape, which are sometimes installed with higher efficiency equipment. The Department calculated the electricity consumption as:

$$ElecUse = BOH_{SS} \times \left(y \times BE + y_p \times PE + y_{ig} \times PE_{ig}\right) + \left(8760 - BOH_{SS}\right) \times StbyE + BOH_{SS} \times CPE + OH_{HT} \times HTE$$

,[h] for single-stage furnace**,**

Eq. 7.3.5

Where:

BOH_{SS} = as defined above,
y = ratio of blower on-time to burner on-time,
BE = power consumption of the blower motor (kW),
y_P = ratio of induced-draft blower on-time to burner on-time,
PE = power consumption of the draft-inducer blower-motor (kW),
y_{IG} = ratio of ignitor on-time to burner on-time,
PE_{IG} = power consumption of the ignitor (kW),
$StbyE$ = power consumption during standby (kW),
CPE = power consumption of condensate pump (kW),
OH_{HT} = operating hours of heat tape (hours), and
HTE = power consumption of heat tape (kW).

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[e] For natural draft equipment this formula is modified to include the pilot light consumption.
[f] For modulating equipment this formula includes parameters for the operation at full, modulating, and reduced load.
[g] The DOE and ASHRAE test procedures do not count the electricity used by controls when the furnace is not firing.
[h] For modulating equipment this formula includes parameters for the operation at full, modulating, and reduced load. See appendix 7-G.

The ratio of blower on-time to burner on-time and the ratio of induced draft blower on-time to burner on-time are from the current ASHRAE test procedure SPC 103-2007[20] using delay times (pre-purge, post-purge, on-delay, and off-delay) derived from DOE's 2007 Furnace and Boiler Final Rule.[21] The ratio of ignitor on-time to burner on-time comes from the DOE test procedure and the ignition time derived from the 2007 final rule. The delay times are defined as follows: pre-purge and post-purge times are the lengths of time the draft inducer operates before and after a firing cycle. On-delay is the amount of time the blower waits to begin operating after the burner starts firing. Off-delay is the time the blower keeps operating after the burner turns off. Ignition time is the length of time the hot surface ignitor is on before gas is sent to the burner. The values for the delay and ignition times are shown in Table 7.3.4.

Table 7.3.4 Values for Delay and Ignition Times

Pre-Purge	Post-Purge	On-Delay	Off-Delay	Ignition
15 seconds	5 seconds	30 seconds	120 seconds	37 seconds

A common value for the power consumption of the draft inducer, PE, for basic non-condensing model furnaces is 75 W, and the average value is about 75 W, so DOE selected 75 W for all the non-condensing models. The Department found no correlation between the PE and input capacity or between PE and airflow capacity. For condensing furnaces, the Department used a PE of 90 W, which closely matches the mean for that group. Details on the derivation of these values can be found in appendix 7-H.

The standby power consumption (*StbyE*) values are dependent on the furnace motor blower type. DOE considered two motor types: PSC and ECM. Table 7.3.5 shows the fractions of installations with different motor types that DOE used based on a 2004 Canadian study of furnace fan market in Vancouver for non-weatherized gas furnaces.[22] Overall ECM furnace fans would represent 29 percent of the market by 2016. For manufactured home gas furnaces, oil-fired furnaces, and electric furnaces, DOE assumed that ECM furnace fans would represent 10 percent of the market in 2016. DOE believes that the furnace fan market in this study is a good proxy for the 2016 U.S. non-weatherized gas furnace market, based on the growing market share of ECM furnace fan motors. Table 7.3.6 summarizes the power consumption at each standby efficiency level. For the furnace energy use calculations only the baseline standby efficiency values are used. See appendix 7-G for more details.

Table 7.3.5 Fraction of Non-Weatherized Gas Furnace Fan Motors and Controls Shipments by Furnace Efficiency and Construction Type in 2016

Furnace Technology and Efficiency *AFUE*	PSC		ECM	
	Single-Stage	Two-Stage	Single-Stage	Two-Stage
Replacement Market				
Non-Condensing (80% AFUE)	50%	40%	0%	10%
Condensing (90%+ AFUE)	40%	10%	0%	50%
New Construction Market				
Non-Condensing (80% AFUE)	85%	10%	0%	5%
Condensing (90%+ AFUE)	70%	5%	0%	25%

Table 7.3.6 Standby Power Consumption by Efficiency Level and Furnace Type

Product Class	Energy Efficiency Level	PSC *Watts*	ECM *Watts*
Non-Weatherized Gas Furnaces	0 (baseline)	8	11
	1	8	9.8
	2	8	9
Manufactured Home Gas Furnaces	0 (baseline)	8	11
	1	8	9.8
	2	8	9
Oil-Fired Furnaces	0 (baseline)	9	12
	1	9	10.8
	2	9	10
Electric Furnaces	0 (baseline)	8	11
	1	8	9.8
	2	8	9

Some higher efficiency installations require the use of auxiliary equipment such as condensate pumps and heat tape. The electricity consumption of this equipment is calculated by DOE and added to the total electricity consumption. If a household required a condensate pump, DOE assumed that it consumed 60 watts and operated at the same time as the burner. If a household required heat tape to prevent the condensate pipe from freezing, DOE assumed that it consumed 3 watts per square foot (on average 45 watts total) and operated only when the average monthly outside temperature dropped below 45 °F. Details of how DOE determined whether a household required a condensate pump or heat tape can be found in chapter 8.

Details for the calculation of the blower motor energy consumption can be found in appendix 7-F.

The details for calculating electricity consumption appear in appendix 7-G.

7.3.5 Assigning Furnace Equipment Characteristics to Sampled Households

To estimate the heating load of each sample housing unit, DOE represented the existing furnace by assigning an input capacity, airflow capacity, and AFUE to the furnace in the RECS sample housing units.

7.3.5.1 Input Capacity of Existing and New Equipment

The Department assigned an input capacity for the existing furnace of each housing unit based on an algorithm that correlates the housing unit size and outdoor design temperature with the distribution of input capacity of furnaces. DOE assumed that, for the new furnace installation, the input capacity would remain the same. For manufactured home and oil-fired furnaces, DOE used a single fixed input capacity value of 80 kBtu/h and 105 kBtu/h, respectively. The following steps describe the assignment process for non-weatherized gas furnaces:

1) The Department ranked all the RECS housing units in ascending order by size (heating square foot) multiplied by a scaling factor to account for the outdoor design temperature (see equation 7.3.6) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.

2) The Department constructed percentile tables by input capacity of furnaces based on the historical shipment information and number of models in AHRI Directory (see Table 7.3.7).

3) After selecting a housing unit from the RECS database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.

4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the correlation was not perfect. The Department used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.

5) Using the percentile from Step 4, DOE looked up the input capacity from the input capacity percentile table in Step 2.

DOE used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature for each household (see appendix 7-E for more details). Using this data, DOE then developed a scaling factor to be applied to the home heating square footage and equal to:

$$SF_{design,h} = (65 - T_{design,\,h}) / (65 - 42) \quad \textbf{Eq. 7.3.6}$$

Where:

$SF_{design,h}$ = heating design scaling factor, and
$T_{design,\,h}$ = average 1 percent ASHRAE design dry bulb temperature (°F) for heating.

It is noted that the design scaling factor is used as a proxy to represent lower heating loads for the same household area in cooler climates and supports the allocation of the sizes across observations, but that the total relative allocation of sizes is unaffected. The end result was a distribution of sizes assigned to the weighted RECS samples that matches the distribution of sizes for shipments of residential furnaces by input capacity. Table 7.3.7 shows the distribution of input capacities for the most commonly available input capacity bins based on the June 2010 AHRI Residential Furnace Directory and AHRI shipment data.[23]

Table 7.3.7 Distribution of Input Capacity for Non-Weatherized Gas Furnaces

Input Capacity *kBtu/h*	AHRI 2001 Shipments *%*	2010 AHRI Directory Fraction of Models *%*	Shipment Weighted Fraction of Models *%*	Cumulative Fraction of Models *%*
45	9.4	10.2	6.8	6.8
50		3.8	2.6	9.4
60	8.6	16.5	8.6	18.0
70	24.8	1.7	5.0	23.0
75		6.6	19.8	42.8
80	13.7	17.2	13.7	56.4
90	23.2	4.6	4.8	61.3
100		17.4	18.4	79.6
110	20.4	5.3	4.9	84.5
120		6.2	5.7	90.2
125		7.7	7.1	97.4
140		2.8	2.6	100.0

7.3.5.2 Airflow Size of Existing Equipment

The Department classified furnaces by nominal maximum airflow in cfm at 0.5 in. w.g. of external static pressure. The Department assigned the airflow capacity of existing furnaces for housing units that had air conditioners in a manner similar to how it assigned furnace input capacity. Larger air conditioners go to larger housing units, according to the distribution of sizes of air conditioners sold the year the air conditioner was installed in that housing unit. The Department used the air conditioner nominal size of two, three, four, or five tons to set the airflow capacity with a ratio of 400 cfm per ton of cooling. The steps were:

1) The Department ranked all the RECS housing units in ascending order by size (cooling square foot) multiplied by a scaling factor to account for the outdoor design temperature (see equation 7.3.7) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.

2) Based on historical shipment information of residential central air conditioners by capacity, DOE constructed the airflow capacity percentiles table for air conditioners. (See Table 7.3.8). The Department restricted the airflow sizes to two, three, four, or five tons—the equivalent of 800, 1,200, 1,600, or 2,000 cfm at 0.5 in. w.g. static pressure. Since there are no available shipment data on the airflow capacity of furnaces, the Department used the airflow capacity of residential central air conditioners as a proxy.

3) After selecting a housing unit from the RECS database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.

4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the correlation was not perfect. The Department used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.

5) Using the percentile from Step 4, DOE looked up the airflow from the airflow percentile table in Step 2. The Department selected an input capacity and airflow combination with the identified airflow capacity, based on commonly available models (see Table 7.3.9). If no input capacity and airflow combination with the identified airflow capacity was available, the Department selected the input capacity and airflow combination with the same input capacity and the closest airflow capacity as a substitute.

DOE used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature for each household (see appendix 7-E for more details). Using these data, DOE then developed a scaling factor to be applied to the home cooling square footage and equal to:

$$SF_{design,c} = (T_{design,\,c} - 65) / (95 - 65) \qquad \textbf{Eq. 7.3.7}$$

Where:

$SF_{design,c}$ = cooling design scaling factor, and
$T_{design,\,c}$ = average 1 percent ASHRAE design dry bulb temperature (°F) for cooling.

It is noted that the design scaling factor is used as a proxy to represent lower cooling loads for the same household area in warmer climates and supports the allocation of the sizes across observations, but that the total relative allocation of sizes is unaffected. This end result was a distribution of sizes assigned to the weighted RECS samples that matches the distribution of sizes for shipments of residential furnaces. Table 7.3.8 shows the distribution of input capacities for the representative product classes listed above, based on AHRI shipment data.[24]

Table 7.3.8 Distribution of Airflow for Furnaces

Airflow Rating ***cfm***	**2010 AHRI Shipments** ***%***	**Cumulative Fraction** ***%***
800	37.3	37.3
1200	35.0	72.3
1600	16.8	89.0
2000	11.0	100.0

For non-weatherized gas furnaces, DOE selected 25 combinations (“bins”) of input capacity and maximum airflow. The marked cells in Table 7.3.9 reflect the input capacity and nominal maximum airflow for the most common input and nominal maximum airflow capacities of models in the June 2010 AHRI Directory.[25] Most basic models on the market fit into the 25 bins of input capacity and airflow capacity. Some models do not exactly match the bins, but their values are close enough that DOE included them in one of the 25 bins. For example, 40 kBtu/h and 45 kBtu/h models are grouped together into a single 45 kBtu/h bin. Most bins have at least two actual models.

Table 7.3.9 Common Furnace Input Capacity and Airflow combinations

Airflow Sizing in cfm ***tons***	**Input Capacity** ***kBtu/h***											
	45	50	60	70	75	80	90	100	115	120	125	140
800 cfm (2 tons)	x	x	x									
1,200 cfm (3 tons)	x	x	x	x	x	x	x	x				
1,600 cfm (4 tons)				x	x	x	x	x	x	x	x	
2,000 cfm (5 tons)							x	x	x	x	x	x

7.3.5.3 AFUE of Existing Equipment

The Department assigned the AFUE of existing furnaces based on the equipment age of the existing furnace as given by RECS and historical shipments by efficiency. The following steps describe this process:

1) After DOE selected a housing unit from the RECS database during each Monte Carlo iteration, the Department randomly assigned a percentile value and extracted the furnace age information from RECS (see Table 7.3.10). Using the extracted furnace age, DOE assigned an installation year from the installation year range for the applicable RECS equipment age bin.

2) Based on the historical furnace shipment information sorted by AFUE, DOE constructed percentile tables by AFUE shipments of furnaces for 2005 and prior years (see Table 7.3.11 to Table 7.3.13). AHRI shipments data for non-weatherized gas furnaces indicate that housing units in the northern region receive more efficient furnaces. Therefore, DOE developed two historical AFUE shipment distributions—one for the northern region and one for the southern region—for non-weatherized gas furnaces.

3) DOE determined the AFUE by looking it up from the AFUE percentile table from Step (2) corresponding to the age of the existing equipment in the housing unit and whether the housing unit was located in the northern or southern regions.

Table 7.3.10 Number of Observations for Each Age Group

RECS Bin	**Less than 2 Years Old**	**2 to 4 Years Old**	**5 to 9 Years Old**	**10 to 19 Years Old**	**20 Years or Older**	**Total**
Installation Years	**2004-2005**	**2001-2005**	**1996-2000**	**1986-1995**	**1966-1985**	
Equipment Type						
Non-Weatherized Gas Furnaces	206	229	367	477	302	1,726
	13.2%	13.3%	21.3%	27.0%	17.8%	100.0%
Manufactured Home Gas Furnaces	11	14	25	25	27	109
	8.5%	12.5%	24.4%	23.5%	23.3%	100.0%
Oil-Fired Furnaces	10	21	29	47	39	150
	9.0%	14.1%	14.5%	31.7%	29.7%	100.0%

Table 7.3.11 Historical Fraction of Regional Gas Furnace Shipments by AFUE Bins

Year	North Region			South Region		
	>78 AFUE	78 to <90	>90 AFUE	>78 AFUE	78 to <90	>90 AFUE
2005	0.0%	48.8%	51.2%	0.0%	81.6%	18.4%
2004	0.0%	52.2%	47.8%	0.0%	83.6%	16.4%
2003	0.0%	53.7%	46.3%	0.0%	83.6%	16.4%
2002	0.0%	59.0%	41.0%	0.0%	85.2%	14.8%
2001	0.0%	57.7%	42.3%	0.0%	86.0%	14.0%
2000	0.0%	64.6%	35.4%	0.0%	89.6%	10.4%
1999	0.0%	64.9%	35.1%	0.0%	89.5%	10.5%
1998	0.0%	64.6%	35.4%	0.0%	89.8%	10.2%
1997	0.0%	62.9%	37.1%	0.0%	87.8%	12.2%
1996	0.0%	64.8%	35.2%	0.0%	89.8%	10.2%
1995	0.0%	68.3%	31.7%	0.0%	88.9%	11.1%
1994	0.0%	66.6%	33.4%	0.0%	87.6%	12.4%
1993	2.4%	70.2%	27.4%	3.0%	86.8%	10.2%
1992	6.7%	59.3%	34.0%	9.1%	80.2%	10.7%
1991	46.3%	23.9%	29.7%	59.8%	30.9%	9.3%
1990	52.4%	22.3%	25.3%	64.6%	27.4%	7.9%
1989	58.3%	17.4%	24.3%	71.2%	21.2%	7.6%
1988	54.8%	19.6%	25.7%	67.8%	24.2%	8.1%
1987	58.0%	18.3%	23.7%	70.4%	22.2%	7.4%
1986	71.1%	18.7%	10.2%	76.7%	20.1%	3.2%
1985	66.5%	17.3%	16.2%	75.3%	19.6%	5.1%
1984	64.0%	18.2%	17.8%	73.5%	20.9%	5.6%
1983	69.3%	7.8%	22.9%	83.4%	9.4%	7.2%
1982	72.6%	8.2%	19.2%	84.4%	9.6%	6.0%
1981	75.9%	8.6%	15.6%	85.4%	9.7%	4.9%
1980	79.1%	9.0%	11.9%	86.5%	9.8%	3.7%
1979	90.2%	3.9%	5.9%	94.1%	4.1%	1.9%
1978	98.6%	1.4%	0.0%	98.6%	1.4%	0.0%
1977	99.1%	0.9%	0.0%	99.1%	0.9%	0.0%
1976	99.5%	0.5%	0.0%	99.5%	0.5%	0.0%
1966 to 1975	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%

Table 7.3.12 Historical Fraction of Manufactured Home Gas Furnace Shipments by AFUE Bins

Year	>78 AFUE	78 to <90 AFUE	>90 AFUE
2005	15.0%	80.0%	5.0%
2004	15.0%	80.0%	5.0%
2003	15.0%	80.0%	5.0%
2002	15.0%	80.0%	5.0%
2001	15.0%	80.0%	5.0%
2000	15.0%	80.0%	5.0%
1999	15.0%	80.0%	5.0%
1998	15.0%	80.0%	5.0%
1997	7.2%	92.8%	0.0%
1996	7.2%	92.8%	0.0%
1995	7.2%	92.8%	0.0%
1994	7.2%	92.8%	0.0%
1993	7.2%	92.8%	0.0%
1992	7.2%	92.8%	0.0%
1991	65.9%	34.1%	0.0%
1990	70.1%	29.9%	0.0%
1989	75.7%	24.3%	0.0%
1988	72.3%	27.7%	0.0%
1987	74.8%	25.2%	0.0%
1986	77.9%	22.1%	0.0%
1985	78.4%	21.6%	0.0%
1984	77.0%	23.0%	0.0%
1983	89.3%	10.7%	0.0%
1982	89.2%	10.8%	0.0%
1981	89.2%	10.8%	0.0%
1980	89.1%	10.9%	0.0%
1979	94.1%	5.9%	0.0%
1978	98.6%	1.4%	0.0%
1977	99.1%	0.9%	0.0%
1976	99.5%	0.5%	0.0%
1966 to 1975	100.0%	0.0%	0.0%

Table 7.3.13 Historical Fraction of Oil-Fired Furnace Shipments by AFUE Bins

Year	>78 AFUE	78 to <90 AFUE	>90 AFUE
1992-2005	0.0%	100.0%	0.0%
1991	4.0%	96.0%	0.0%
1990	4.0%	96.0%	0.0%
1989	61.0%	39.0%	0.0%
1988	70.0%	30.0%	0.0%
1987	77.5%	22.5%	0.0%
1966-1986	85.0%	15.0%	0.0%

7.3.6 Furnace Energy Consumption Results

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 furnace product class. For its LCC and PBP analyses, DOE used the full distribution of energy use values calculated for the sample households.

Table 7.3.14 lists the average annual energy use for non-weatherized gas furnaces and the average energy savings for each considered energy efficiency level compared to the baseline for the nation and the northern and southern regions.

Table 7.3.14 Annual Energy Consumption for Non-Weatherized Gas Furnaces

Energy Efficiency Level ***AFUE***	**Average Energy Consumption**		**Average Energy Savings (Gas)** ***MMBtu/yr***
	Gas ***MMBtu/yr***	**Electricity** ***kWh/yr***	
National			
80 (baseline)	37.8	312	-
90	33.7	289	4.1
92	33.0	283	4.8
95	32.0	275	5.8
98	30.7	363	7.1
North			
80 (baseline)	47.4	369	-
90	42.2	342	5.2
92	41.3	335	6.1
95	40.1	325	7.3
98	38.4	438	8.9
South			
80 (baseline)	23.5	228	-
90	20.9	211	2.5
92	20.5	206	3.0
95	19.9	200	3.6
98	19.1	251	4.4

Table 7.3.15 lists average annual energy use for manufactured home gas furnaces and average energy savings for each energy efficiency level evaluated in the LCC analysis, compared to the baseline furnace.

Table 7.3.15 Annual Energy Consumption for Manufactured Home Gas Furnaces

Energy Efficiency Level *AFUE*	Average Energy Consumption		Average Energy Savings (Gas) *MMBtu/yr*
	Gas *MMBtu/yr*	Electricity *kWh/yr*	
National			
80 (baseline)	43.7	282	-
90	39.0	257	4.7
92	38.1	252	5.6
96	36.6	241	7.1
North			
80 (baseline)	53.4	344	-
90	47.6	314	5.8
92	46.6	307	6.8
96	44.7	295	8.7
South			
80 (baseline)	34.4	223	-
90	30.7	203	3.7
92	30.0	199	4.4
96	28.8	191	5.6

Table 7.3.16 shows the average annual energy use for oil-fired furnaces and the average energy savings for each energy efficiency level, compared to the baseline.

Table 7.3.16 Annual Energy Consumption for Oil-Fired Furnaces

Energy Efficiency Level *AFUE*	Average Energy Consumption		Average Energy Savings (Oil) *MMBtu/yr*
	Oil *MMBtu/y)*	Electricity *kWh/yr*	
National			
82 (baseline)	67.3	483	-
83	66.5	477	0.8
84	65.7	472	1.6
85	64.9	466	2.3
97	57.1	410	10.1

7.3.7 Standby Energy Consumption Results for Furnaces

Table 7.3.17 shows the average annual standby energy use for furnaces and the average energy savings for each energy efficiency level, compared to the baseline.

Table 7.3.17 Annual Standby Energy Consumption for Furnaces

Energy Efficiency Level	Average Energy Consumption Electricity *kWh/yr*	Average Savings *kWh/yr*
Non-Weatherized Gas Furnaces		
0 (baseline)	73.6	-
1	70.9	2.7
2	69.1	4.5
Manufactured Home Gas Furnaces		
0 (baseline)	69.2	-
1	68.2	0.9
2	67.6	1.6
Oil-fired Furnaces		
0 (baseline)	75.5	-
1	74.6	0.9
2	73.9	1.5
Electric Furnaces		
0 (baseline)	79.4	-
1	78.5	1.0
2	77.8	1.6

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