APPENDIX 7-E. DETERMINATION OF FURNACE ENERGY USE IN THE LCC ANALYSIS

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7-E.1 0INTRODUCTION

DOE accounted for the fact that more efficient furnace fans will tend to contribute less heat and thereby require additional furnace operation. Since the heating load of each sample housing unit is known, it is possible to estimate what the furnace energy consumption would be if more efficient fan equipment, rather than the baseline equipment, was used in each housing unit.

The furnace energy consumption of non-furnace components in the LCC analysis is determined using the 2007 ASHRAE SPC 103R "Method of Testing for Annual Fuel Efficiency of Residential Central Furnaces and Boilers".[1] This approach requires the calculation of the average annual fuel energy consumption (E_F), the average annual electrical energy consumption (E_{AE}), and the national average number of burner operating hours (*BOH*) of furnaces.

The following calculations describe the determination of E_F, E_{AE}, and *BOH* for gas- and oil-fired furnaces.

7-E.2 0DETERMINATION OF AVERAGE ANNUAL FUEL ENERGY CONSUMPTION (E_F)

The average annual fuel consumption is calculated in Appendix C section 2 of the ASHRAE 103/2007 test procedure:[1]

$E_F = BOH_{SS} * (Q_{IN} - Q_P) + 8{,}760 * Q_P$, for single-stage furnaces,

$E_F = (BOH_H * Q_{IN}) + (BOH_R * Q_{IN,R}) + [8{,}760 - (BOH_H + BOH_R)] * Q_P$, for two-stage furnaces and

$E_F = (BOH_M * Q_{IN,M}) + (BOH_R * Q_{IN,R}) + [8{,}760 - (BOH_M + BOH_R)] * Q_P$, for continuous modulating[a1] furnaces

where,

BOH_{SS} = national average number of burner operating hours (see derivation in section 7-E.4),

BOH_H = national average number of burner operating hours at the maximum operating mode for two-stage furnaces (see derivation in section 7-E.4),

BOH_R = national average number of burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces (see derivation in section7-E.4),

[a] In this Technical Support Documentation, "continuous modulating" term is used instead of "step-modulating". Both terms are interchangeable used in the literature.

BOH_M = national average number of burner operating hours at the modulating operating mode for continuous modulating furnaces (see derivation in section7-E.4),
Q_{IN} = steady-state nameplate input rate in Btu/h for single-stage furnaces or steady-state nameplate maximum input rate in Btu/h for two-stage and continuous modulating furnaces,
$Q_{IN,R}$ = steady-state reduced fuel input rate,
$Q_{IN,M}$ = steady-state modulating fuel input rate, and
Q_P = pilot flame fuel input rate in Btu/h.

Q_{IN} is based on the baseline value for each product class. We set $Q_{IN,R}$ to be 69% of Q_{IN} for non-condensing two-stage equipment, 67% for condensing two-stage equipment, and 40% for continuous modulation equipment, where this value represents the average ratio $Q_{IN}/Q_{IN,R}$ as derived using manufacturer product literature and AHRI March 2012 Directory data for all listed two-stage furnace models.[2]

From the test procedure,[1] $Q_{IN,M}$ is calculated using $Q_{OUT,M}$ and $Effy_{SS,M}$ (as defined in section 11.4.8.10 or 11.5.8.8 in the ASHRAE SPC 103/2007 test procedure).[1] Q_P is zero for all product classes, except for the baseline manufactured-home gas furnace and gas boiler.

7-E.3 0Determination of Average Annual Electrical Energy Consumption (E_{AE})

Using the ASHRAE SPC 103/2007 test procedure,[1] the average annual auxiliary electrical energy consumption is calculated in Appendix C section 3:

$$E_{AE} = BOH_{SS} (y_P * PE + y_{IG} *PE_{IG} + y * BE)$$, for single-stage furnaces,

and

$$E_{AE} = BOH_R (y_{P,R}*PE_R + y_{IG,R} *PE_{IG,R} + y_R*BE_R) + BOH_{H\ or\ M} (y_P*PE_H + y_{IG} *PE_{IG,H} + y*BE_H)$$[b2], for two-stage and continuous modulating furnaces,

where

BOH_{SS} = as defined in section 7-E.4,
BOH_H = as defined in section 7-E.4,
BOH_M = as defined in section 7-E.4
BOH_R = as defined in section 7-E.4
y_P = ratio of induced or forced draft blower on-time to average burner on-time,
$y_{P,R}$ = ratio of induced or forced draft blower on-time to average burner on-time, measured at the reduced fuel input rate,

[b] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[3]

PE	=	burner (or draft inducer) electrical power input at full-load steady-state operation in kW,
PE_R	=	burner (or draft inducer) electrical power input at full-load steady-state operation in kW, measured at the reduced fuel input rate,
PE_H	=	burner (or draft inducer) electrical power input at full-load steady-state operation in kW, measured at the maximum fuel input rate,
y_{IG}	=	ratio of burner interrupted-ignition device on-time to average burner on-time,
$y_{IG,R}$	=	ratio of burner interrupted-ignition device on-time to average burner on-time, measured at the reduced fuel input rate,
PE_{IG}	=	electrical input rate to the interrupted ignition device on the burner,
$PE_{IG,R}$	=	electrical input rate to the interrupted ignition device on the burner, measured at the reduced fuel input rate,
$PE_{IG,H}$	=	electrical input rate to the interrupted ignition device on the burner, measured at the maximum fuel input rate,
y	=	ratio of blower or pump on-time to burner on-time,
y_R	=	ratio of blower or pump on-time to burner on-time, measured at the reduced fuel input rate,
BE	=	circulating-air fan or water pump electrical energy input rate in kW,
BE_R	=	circulating-air fan or water pump electrical energy input rate in kW, measured at the reduced fuel input rate, and
BE_H	=	circulating-air fan or water pump electrical energy input rate in kW, measured at the maximum fuel input rate.

The values y_P and $y_{P,R}$ are calculated using t_P (post-purge time). For this calculation, DOE took t_P to be 5 seconds for furnaces, which is less than or 30 seconds and is therefore set equal to 0 seconds, according to Appendix C section 1 of the ASHRAE SPC 103/2007. DOE calculated the values y and $y_{P,R}$ using t^+ (blower or pump on-delay) and t^- (blower or pump off-delay). For furnaces, $t^+ = 2$ min and $t^- = 0.5$ min, which are values obtained for the generic furnace models. For gas furnaces, PE is equal to 75 W for non-condensing furnaces and 90 W for condensing furnaces. For oil furnaces, PE is set to 220 W. [6] For design options which include modulating controls, we set PE_R and PE_H to have the same values as PE, since it is assumed that there is no inducer modulation. For gas furnaces, PE_{IG}, $PE_{IG,R}$, and $PE_{IG,H}$ are set equal to 400 W.[7] For oil furnaces, PE_{IG} is equal to 45 watts for oil equipment without interrupted ignition, and 25 watts with oil equipment with interrupted ignition.[8] For design options which include modulating controls, we set $PE_{IG,R}$ and $PE_{IG,H}$ to have the same values as PE_{IG}, since it is assumed that there is no ignition modulation.

7-E.4 0Determination of National Average Number of Burner Operating Hours (BOH_{SS})

From the ASHRAE SPC103/2007 test procedure,[1] the national average number of burner operating hours for furnaces and boilers is calculated in Appendix C section 1:

$BOH_{SS} = 2080 * 0.77 * A * (Q_{OUT} / (1 + \alpha)) - 2080 * B$, for single-stage furnaces,

$BOH_H = X_H * (2080) * (0.77) * A_H * (Q_{OUT} / (1 + \alpha)) - 2080 * B_H$, for two-stage furnaces at the maximum operating mode,

$BOH_R = X_R * (2080) * (0.77) * A_R * (Q_{OUT} / (1 + \alpha)) - 2080 * B_R$, for two-stage and continuous modulating furnaces operating at the reduced operating mode,

and

$BOH_M = X_H * (2080) * (0.77) * A_M * (Q_{OUT} / (1 + \alpha)) - 2080 * B_M$, for continuous modulating furnaces operating at the modulating operating mode,

where

2080 = national average heating load hours,
0.77 = adjustment factor to adjust the calculated design heating requirements and heating load hours to the actual heating load experienced by the heating system,
A = $100{,}000/ [341300(y_P * PE + y_{IG,R} * PE_{IG,R} + y * BE) + (Q_{IN} - Q_P) * Effy_{HS}]$[c3],
A_H = $100{,}000/ [341300(y_P * PE_H + y_{IG,R} * PE_{IG,R} + y * BE_H) + (Q_{IN} - Q_P) * Effy_{U,H}]$[a],
A_R = $100{,}000/ [341300(y_{P,R} * PE_R + y_{IG,R} * PE_{IG,R} + y_R * BE_R) + (Q_{IN,R} - Q_P) * Effy_{U,R}]$[a],
A_M = $100{,}000/ [341300(y_P * PE_H + y_{IG,R} * PE_{IG,R} + y * BE_H) + (Q_{IN,M} - Q_P) * Effy_{U,M}]$[a],
B = $2 * (Q_P) * (Effy_{HS}) * (A) / 100{,}000$,
B_H = $2 * (Q_P) * (Effy_{U,H}) * (A_H) / 100{,}000$,
B_R = $2 * (Q_P) * (Effy_{U,R}) * (A_R) / 100{,}000$,
B_M = $2 * (Q_P) * (Effy_{U,M}) * (A_M) / 100{,}000$,
Q_{OUT} = maximum fuel input rate heating capacity,
α = oversize factor set to 0.7,
X_H = fraction of heating load at maximum fuel input rate operating mode,
X_R = fraction of heating load at reduced fuel input rate operating mode ($1-X_H$),
Q_{IN} = as defined in above,
$Q_{IN,R}$ = as defined in above,
$Q_{IN,M}$ = as defined in above,
Q_P = as defined in above,
y_P = as defined in above,
$y_{P,R}$ = as defined in above,
PE = as defined in above,
PE_R = as defined in above,
PE_H = as defined in above,
y_{IG} = as defined in above,
$y_{IG,R}$ = as defined in above,
PE_{IG} = as defined in above,
$PE_{IG,R}$ = as defined in above,
$PE_{IG,H}$ = as defined in above,

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[c] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[3]

y = as defined in section above,
y_R = as defined in section above,
BE = as defined in section above,
BE_R = as defined in section above,
BE_H = as defined in section above,
$Effy_{HS}$ = ratio of the average length of the heating season in hours to the average heating load hours,
$Effy_{U,H}$ = average part load efficiency at the maximum fuel input rate,
$Effy_{U,R}$ = average part load efficiency at the reduced fuel input rate, and
$Effy_{U,M}$ = average part load efficiency at the modulating fuel input rate.

The modified equations used in the LCC spreadsheet are as follows (Note that the maximum value for BOH is set to 8760):

$BOH_{SS} = A * HHL - 2080 * B$, for single-stage furnaces,

$BOH_H = X_H * A_H * HHL - 2080 * B_H$, for two-stage furnaces at the maximum operating mode,

$BOH_R = X_R * A_R * HHL - 2080 * B_R$, for two-stage and continuous modulating furnaces operating at the reduced operating mode,

and

$BOH_M = X_H * A_M * HHL - 2080 * B_M$, for continuous modulating furnaces operating at the modulating operating mode,

To calculate factors A, A_H, A_R, A_M, B, B_H, B_R, and B_M, DOE calculated y_P, $y_{P,R}$, PE, PE_R, PE_H, y_{IG}, $y_{IG,R}$, PE_{IG}, $PE_{IG,R}$, $PE_{IG,H}$, y, y_R, BE, BE_R, BE_H, PE, y_{IG}, PE_{IG}, y, BE, Q_{IN}, and Q_P y_P , as described in section 7-E.3 of this appendix. For factor B, if $Q_P = 0$, then $B = 0$, which is true for all cases except for the baseline manufactured-home gas furnace and the baseline gas boiler. We calculated $Effy_{HS}$, heating seasonal efficiency, as defined in sections 11.2.11, 11.3.11.3, 11.4.11.3, and 11.5.11.3 in ASHRAE SPC 103/2007 test procedure.[1] For $Q_P = 0$, $Effy_{HS}$ is equal to the annual fuel utilization efficiency (*AFUE*). For $Q_P > 0$, $Effy_{HS}$ is calculated using $Effy_{SS}$ (as defined in section 11.2.8.1[1]). $Effy_{SS}$ is calculated using Q_{OUT} (as defined below), K (factor that adjusts the jacket losses, where K = 1.7 for non-weatherized furnaces and Lj (jacket loss, where Lj = 1 is the default value as described in section 11.2.8.1[1])

Q_{OUT} for all product classes is calculated using the following equations based on AHRI Directory data for Non-Weatherized Gas Furnaces:[2]

$Q_{OUT} = Q_{IN}$ (0.7247 * AFUE + 0.22346), for non-condensing equipment, and

$Q_{OUT} = Q_{IN}$ (0.8127 * AFUE + 0.17557), for condensing equipment.

DOE calculated X_H by using T_C (balance-point temperature as defined in section 11.4.8.4 of ASHRAE SPC 103/2007 test procedure[1]), α (the oversize factor, as calculated in Equation 11), Q_{OUT}, and $Q_{OUT,R}$ (reduced fuel input rate heating capacity). $Q_{OUT,R}$ is set equal to 69% Q_{OUT} for non-condensing equipment and 67% Q_{OUT} for condensing equipment, as derived using manufacturer product literature and AHRI Directory data for all listed two-stage furnace models.[2] X_R is set equal to 1-X_H. $Effy_{U,H} = Effy_{U,R}$ and therefore using the equation in section 11.5.11.3 of ASHRAE SPC 103/2007 test procedure is equal to $Effy_{SS}$. $Effy_{U,M}$ is calculated using the equation in section 11.4.9.2.3 of ASHRAE SPC 103/2007 test procedure.[1]

7-E.5 0DETERMINATION OF IMPACT ON FURNACE ENERGY USE WITH MORE EFFICIENT FURNACE FANS

DOE accounted for the fact that more efficient furnace fans will tend to contribute less heat and thereby require additional furnace operation. Since the heating load of each sample housing unit is known, it is possible to estimate what the furnace energy consumption would be if more efficient fan equipment, rather than the baseline equipment, was used in each housing unit.

DOE calculated the furnace fuel consumption (*FuelUse*) for each furnace fan efficiency level using the following formula based on the current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) test procedure SPC 103-2007 section C [d]:

$$FuelUse = BOH \times Q_{IN}\text{, for single-stage furnace, and}$$

$$FuelUse = (BOH_H * Q_{IN}) + (BOH_R * Q_{IN,R})\text{, for two-stage furnaces}$$

Where:

BOH = steady-state burner operating hours (hr),

Q_{IN} = input capacity of existing furnace (kBtu/h,).

BOH_H = burner operating hours at the maximum operating mode for two-stage furnaces (see derivation in section 7-E.4),

BOH_R = burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces (see derivation in section 7-E.4), and

$Q_{IN,R}$ = reduced fuel input rate.

[d] For natural draft equipment this formula is modified to include the pilot light consumption.

Recall from above that BOH is calculated using BE (furnace fan electrical energy input rate), which is equal to the furnace fan power during the heating operation calculated for each furnace fan efficiency level.

DOE also calculated the non-furnace fan furnace electricity consumption (i.e., the electricity used by the induce draft blower and the electricity used by the ignitor) for each furnace fan efficiency level using the following formula:

$$ElecUse_{non-furnace\_fan} = BOH_{SS} \times \left(y \times BE + y_p \times PE + y_{ig} \times PE_{ig}\right),$$ [e] for single-stage furnace, and

$$ElecUse_{non\text{-}furnac\_fan} = BOH_R\ (y_{P,R}{*}PE_R + y_{IG,R}\ {*}PE_{IG,R}) + BOH_H\ (y_P{*}PE_H + y_{IG}\ {*}PE_{IG,H})$$ [f2], for two-stage

Where:

BOH = steady-state burner operating hours (hr),

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, and

PE_{IG} = power consumption of the ignitor (kW).

BOH_H = burner operating hours at the maximum operating mode for two-stage furnaces (see derivation in section 7-E.4),

BOH_R = burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces (see derivation in section 7-E.4), and

$y_{P,H}$ = ratio of induced-draft blower on-time to burner on-time, measured at the maximum fuel input rate,

PE_H = power consumption of the draft-inducer blower-motor (kW), measured at the maximum fuel input rate,

$y_{IG,H}$ = ratio of ignitor on-time to burner on-time, measured at the maximum fuel input rate, and

$PE_{IG,H}$ = power consumption of the ignitor (kW) measured at the maximum fuel input rate.

$y_{P,R}$ = ratio of induced-draft blower on-time to burner on-time, measured at the reduced fuel input rate,

PE_R = power consumption of the draft-inducer blower-motor (kW), measured at the reduced fuel input rate,

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[e] For two-stage equipment this formula includes parameters for the operation at full, modulating, and reduced load.

[f] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[3]

$y_{IG,R}$ = ratio of ignitor on-time to burner on-time, measured at the reduced fuel input rate, and

$PE_{IG,R}$ = power consumption of the ignitor (kW) measured at the reduced fuel input rate.

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 furnace fan equipment, rather than the baseline equipment, were used in each housing unit.

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[1] using delay times (pre-purge, post-purge, on-delay, and off-delay) derived from DOE's 2007 Furnace and Boiler Final Rule.[4] 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 average values for the delay and ignition times are shown in the next table.

Table 7-E.5.1 Average 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. DOE found no correlation between the PE and input capacity or between PE and airflow capacity. For condensing furnaces, DOE used a PE of 90 W, which closely matches the mean for that group.

7-E.6 Assigning Furnace Equipment Characteristics to Sample 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-E.6.1 Input Capacity of Existing and New Equipment

DOE 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. The following steps describe the assignment process for furnaces:

1) DOE 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 below) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.
2) DOE constructed percentile tables by input capacity of furnaces based on the historical shipment information and number of models in AHRI Directory.
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. DOE 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. Using this data, DOE then developed a scaling factor to be applied to the home heating square footage and equal to:

$$SF_{design,h} = (65 - T_{design,\,h}) / (65 - 42)$$

Where:

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

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-E.6.1shows the distribution of input capacities for the most commonly available input capacity bins for non-weatherized gas furnaces based on the 2012 AHRI Residential Furnace Directory.[2] See the LCC spreadsheet, worksheet “Furnace & AC Spec” for the distributions of input capacities for other product classes.

Table 7-E.6.1 Distribution of Input Capacities for Non-Weatherized Gas Furnaces

	Non-Condensing		Condensing	
Input Capacity *kBtu/h*	**2012 AHRI Directory Fraction of Models** *%*	**Cumulative Fraction of Models** *%*	**2012 AHRI Directory Fraction of Models** *%*	**Cumulative Fraction of Models** *%*
40	10.9	10.9	10.9	10.9
50	3.3	14.2	1.8	12.7
60	17.6	31.8	17.1	29.8
70	5.4	37.2	6.7	36.5
80	18.5	55.7	20.4	56.9
90	1.8	57.5	7.5	64.4
100	17.4	75.0	16.0	80.4
110	6.5	81.5	6.7	87.1
120	9.1	90.6	10.5	97.6
130	3.4	94.0	2.2	99.8
140	3.4	97.5	0.2	100.0
150	2.0	99.5	0.0	100.0
160	0.5	10.9	0.0	100.0

7-E.6.2Airflow Size of Existing Equipment

DOE classified furnaces by nominal maximum airflow in cfm at 0.5 in. w.g. of external static pressure. DOE 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. DOE 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) DOE 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 below) 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-E.6.2). Since there are no available shipment data on the airflow capacity of furnaces, DOE 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. DOE 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. DOE selected an input capacity and airflow combination with the identified airflow capacity, based on commonly available models. If no input capacity and airflow combination with the identified airflow capacity was available, DOE 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. Using these data, DOE then developed a scaling factor to be applied to the home cooling square footage and equal to:

$$SF_{design,c} = (T_{design,\,c} - 65) / (95 - 65)$$

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-E.6.2shows the distribution of airflow ratings for the representative product classes listed above, based on AHRI shipment data. [5]

Table 7-E.6.2 Distribution of Airflow for Furnaces

Airflow Rating *cfm*	2007-2011 AHRI Shipments %	Cumulative Fraction %
600	9.5	9.5
800	19.6	29.1
1000	16.5	45.6
1200	22.5	68.0
1400	8.7	76.8
1600	12.5	89.2
2000	10.8	100.0

7-E.6.3AFUE of Existing Equipment

DOE 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, DOE randomly assigned a percentile value and extracted the furnace age information from RECS. Using the extracted furnace age, DOE assigned an installation year from the installation year range for the applicable RECS equipment age bin (see Table 7-E.6.3).

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. 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 (See Table 7-E.6.4). See the LCC spreadsheet, worksheet "Furnace & AC Spec" for the distributions of input capacities for other product classes.

Table 7-E.6.3 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-E.6.4 Historical Fraction of Regional Non-Weatherized 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	0.0%	70.2%	27.4%	0.0%	86.8%	10.2%
1992	2.4%	59.3%	34.0%	3.0%	80.2%	10.7%
1991	6.7%	23.9%	29.7%	9.1%	30.9%	9.3%
1990	46.3%	22.3%	25.3%	59.8%	27.4%	7.9%
1989	52.4%	17.4%	24.3%	64.6%	21.2%	7.6%
1988	58.3%	19.6%	25.7%	71.2%	24.2%	8.1%
1987	54.8%	18.3%	23.7%	67.8%	22.2%	7.4%
1986	58.0%	18.7%	10.2%	70.4%	20.1%	3.2%
1985	71.1%	17.3%	16.2%	76.7%	19.6%	5.1%
1984	66.5%	18.2%	17.8%	75.3%	20.9%	5.6%
1983	64.0%	7.8%	22.9%	73.5%	9.4%	7.2%
1982	69.3%	8.2%	19.2%	83.4%	9.6%	6.0%
1981	72.6%	8.6%	15.6%	84.4%	9.7%	4.9%
1980	75.9%	9.0%	11.9%	85.4%	9.8%	3.7%
1979	79.1%	3.9%	5.9%	86.5%	4.1%	1.9%
1978	90.2%	1.4%	0.0%	94.1%	1.4%	0.0%
1977	98.6%	0.9%	0.0%	98.6%	0.9%	0.0%
1976	99.1%	0.5%	0.0%	99.1%	0.5%	0.0%
1975	99.5%	0.0%	0.0%	99.5%	0.0%	0.0%
1966 to 1974	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%

7-E.6.3.2 AFUE of New Equipment

DOE assigned the AFUE of new furnaces based on distribution of AFUE of furnaces equipment and the RECS household location standards in 2018 for furnaces (e.g. minimum efficiency of 90% AFUE for northern region households with a non-weatherized gas furnace). Table 7-E.6.5 shows the distribution of AFUE for the most commonly available AFUE bins for non-weatherized gas furnaces based on the 2012 AHRI Residential Furnace Directory.[2] See the LCC spreadsheet, worksheet “Furnace & AC Spec” for the distributions of AFUE for other product classes.

Table 7-E.6.5 Distribution of AFUE for Non-Weatherized Gas Furnaces

	Non-Condensing		Condensing	
AFUE *%*	**2012 AHRI Directory Fraction of Models** *%*	**Cumulative Fraction of Models** *%*	**2012 AHRI Directory Fraction of Models** *%*	**Cumulative Fraction of Models** *%*
80	99.8	99.8	0.0	0.0
81	0.0	99.8	0.0	0.0
82	0.0	99.8	0.0	0.0
83	0.2	100.0	0.0	0.0
90	0.0	100.0	1.8	1.8
91	0.0	100.0	2.4	4.2
92	0.0	100.0	18.2	22.4
93	0.0	100.0	6.4	28.7
94	0.0	100.0	2.7	31.5
95	0.0	100.0	33.5	64.9
96	0.0	100.0	21.1	86.0
97	0.0	100.0	10.7	96.7
98	0.0	100.0	3.3	100.0

REFERENCES

1. American Society of Heating Refrigerating and Air-Conditioning Engineers Inc., *ASHRAE Standard: Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers*, 2007. Report No. ANSI/ASHRAE 103-2007.

2. Air Conditioning Heating and Refrigeration Institute, *Consumer's Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment (AHRI Directory March 2012),* 2012. (Last accessed March, 2012.) <http://www.ahridirectory.org/ahridirectory/pages/home.aspx>

3. U.S. Department of Energy-Office of Energy Efficiency and Renewable Energy, *Title 10, Code of Federal Regulations, Chapter II Part 430 Appendix N, Subpart B-Uniform Test Method for Measuring the Energy Consumption of Furnaces,* January 1, 2012.

4. Department Of Energy, 10 CFR Part 430 Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers; Final Rule. *Federal Register*, 2007. 72 No.222: pp. 65132-65170

5. Air-Conditioning Heating and Refrigeration Institute, *AHRI Shipments Data for Air Conditioners by Capacity* 2007-2011. <http://www.ahrinet.org/monthly+shipments.aspx>