APPENDIX D. DETERMINATION OF FURNACE AND BOILER ENERGY USE IN THE ENGINEERING ANALYSIS

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D.1 INTRODUCTION

The DOE test procedure for measuring the energy consumption of furnaces and boilers provides a calculation approach for determining the energy use of furnaces and boilers under test conditions.[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_{SS}) of furnaces and boilers.

The following calculations and summary tables describe the determination of E_F, E_{AE}, and BOH_{SS} for gas- and oil-fired furnaces and boilers.

D.2 CALCULATIONS

D.2.1 Determination of Average Annual Fuel Energy Consumption (E_F)

The Department calculated the average annual fuel consumption in sections 10.2.2 and 10.2.2.1 of the DOE test procedure:[1]

for single-stage furnaces and boilers

$$E_F = \text{BOHss} * (Q_{IN} - Q_P) + 8{,}760 * Q_P \qquad \textbf{Eq. 1}$$

and for two-stage and step modulating furnaces and boilers

$$E_F = E_M + 4{,}600 * Q_P \qquad \textbf{Eq. 2}$$

where:

BOHss	=	National average number of burner operating hours (see section D.2.4 of this appendix for derivation),
Q_{IN}	=	Steady-state nameplate input rate in Btu/h for single-stage furnaces and boilers or steady-state nameplate maximum input rate in Btu/h for two-stage and step modulating furnaces and boilers,
Q_P	=	Pilot flame fuel input rate in Btu/h, and
E_M	=	Average annual energy used during the heating season for two-stage and modulating furnaces.

Q_{IN} is based on the baseline value for each product class. Q_P is zero for all product classes, except for the baseline mobile home gas furnace and gas boiler.

D.2.2 Determination of Average Annual Electrical Energy Consumption (E_{AE})

Using the DOE test procedure,[1] DOE calculated the average annual electrical energy consumption in sections 10.2.3, 10.2.3.1, and 10.2.3.2:

for single-stage furnaces and boilers

$$E_{AE} = BOH_{SS} (y_P * PE + y_{IG} * PE_{IG} + y * BE) \quad \textbf{Eq. 3}$$

and for two-stage and step modulating furnaces and boilers

$$E_{AE} = BOH_R (y_P*PE_R + y_{IG}*PE_{IG} + y*BE_R) + BOH_{HorM} (y_P*PE_H + y_{IG}*PE_{IG} + y*BE_H) \quad \textbf{Eq. 4}$$

where:

$BOHss$	=	See section D.2.3 of this appendix,
BOH_H	=	National average number of burner operating hours at the maximum operating mode (see section D.2.4 of this appendix),
BOH_M	=	National average number of burner operating hours at the modulating operating mode (see section D.2.4 of this appendix),
BOH_R	=	National average number of burner operating hours at the reduced operating mode (see section D.2.4 of this appendix),
y_P	=	Ratio of induced or forced draft blower on-time to average burner on-time,
PE	=	Burner electrical power input at full-load steady-state operation in kW,
PE_R	=	Burner electrical power input at full-load steady-state operation in kW, measured at the reduced fuel input rate,
PE_H	=	Burner 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,
PE_{IG}	=	Electrical input rate to the interrupted ignition device on the burner,
y	=	Ratio of blower or pump on-time to burner on-time,
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 Department calculated the value y_P using t_P (post-purge time in minutes). For this calculation, the Department took t_P to be less than or equal to 30 seconds and therefore set it equal to 0 seconds, according to sections 8.2 and 8.4 of the DOE test procedure.[1] The Department calculated the value y_{IG} using t_{IG} (on-time of the burner interrupted ignition device in minutes), which is set equal to .62 minutes[2] for gas furnaces and boilers, 26 minutes for oil equipment without interrupted ignition[3], and 45 seconds for oil equipment with interrupted ignition[3]. The Department calculated the value y using t^+ (blower or pump on-delay in minutes) and t^- (blower or pump off-delay in minutes). For furnaces, t^+ = 2 min and t^- = 1.5 min and for boilers, t^+ = 0 and t^- = 0, which are default values from the test procedure. *PE* is equal to 0.076 watts for gas furnaces and boilers[4] and equal to 220 watts for oil furances and boiler[3]. The Department corrected the PE_{IG}, t_{IG}, and *BE* values for different design options (see summary tables in section D.4 for more details). For design options which include modulation, the Department set PE_R and PE_H to have the same values as *PE*, since it assumed no inducer modulation. The Department set BE_H equal to *BE*, and set BE_R to be 80 percent of *BE* for furnaces.[5]

D.2.3 Determination of National Average Number of Burner Operating Hours (BOH_{SS})

From the test procedure, DOE calculated the national average number of burner operating hours in section 10.2.1[1]:

$$BOH_{SS} = 2080 * 0.77 * A * DHR - 2080 * B \qquad \textbf{Eq. 5}$$

where:

A	=	as defined in sections 10.2.1 and 10.2.1.1,
B	=	as defined in sections 10.2.1, and
DHR	=	typical design heating requirements as listed in Table 8,[6] using the proper value of Q_{OUT}.

To calculate factors *A* and *B*, the Department calculated y_P, *PE*, y_{IG}, PE_{IG}, *y*, *BE*, Q_{IN}, and Q_P as described in section D.2.2 of this appendix. To calculate *A*, the Department assumed the burner motor efficiency Eff_{motor} = 0.5 (as defined in section 10.2.1[1]), except for oil furnaces and boilers with fan-atomized burners—where Eff_{motor} = 0.8. The Department calculated $Effy_{HS}$, heating seasonal efficiency, as defined in section 10.2.1[1]. For Q_P = 0, $Effy_{HS}$ is equal to the annual fuel utilization efficiency (AFUE). The factor *R*, used in calculating *A*, the Department defined in section 10.2.1.1[1]. For factor *B*, if Q_P = 0, then *B* = 0, which is true for all cases except for the baseline mobile home gas furnace and baseline gas boiler. To calculate factor A for weatherized furnaces, the Department used the equation for induced-draft unit isolated combustion systems (ICS), because the intention is to account for the heat from the motor, which always goes into the air distribution system.

The Department used Q_{OUT} (heating capacity for single-stage furnaces and boilers, or maximum heat capacity for two-stage and step modulating furnaces and boilers) to calculate design heating rate (*DHR*) for the considered efficiency levels and design options. Furthermore, to calculate Q_{OUT} (see eqn. 8 defined in section D.2.5 of this appendix), DOE used Q_{IN} (defined in section D.2.1 of this appendix), $Effy_{SS}$ (defined in section D.2.5 of this appendix), *K* (factor that adjusts the jacket losses, where *K* = 1.7 for non-weatherized furnaces, 3.3 for weatherized furnaces, and 1 for boilers), and *Lj* (jacket loss, where *Lj* = 1 is the default value).

In the current test procedure *DHR* is a step function of furnace output capacity ranges

(Table 8[6]). DOE observed that small changes in Q_{OUT} may assign an efficiency level to a different *DHR* range, which could cause significant variations of BOH_{SS} (in some cases up to 20-30 percent). For example, the non-weatherized gas furnace at 81 percent AFUE and at 75 kBtu/h capacity has a Q_{OUT} which calls for a *DHR* value of 30, while the same capacity furnace at 82 percent AFUE require a *DHR* value of 40. As a result, an AFUE change of 1 percent (from 81 percent to 82 percent AFUE) represents a 24 percent increase in energy consumption for the 82 percent AFUE furnace as compared to the 81 percent AFUE furnace. It results in higher energy consumption for a more efficient furnace (82 percent AFUE vs 81 percent AFUE) and as a result the payback for 82 percent AFUE becomes negative. This test procedure feature impacts several efficiency levels in the engineering analysis for non-weatherized gas furnaces, mobile home furnaces and gas and oil-fired boilers.

Note: The ASHRAE committee in charge of the furnace/boiler test procedure (SPC 103) is taking steps to correct this anomaly in the current proposed test procedure: BSR/ASHRAE SPC 103R "Method of testing for Annual Fuel Efficiency of Residential Furnaces & Boilers".[7] The approach by SPC 103R is to eliminate the *DHR* parameter from the formula for calculating BOH_{SS} and replace it with a parameter containing Q_{OUT} and an oversized factor, which has a constant value of 0.7. DOE used this new proposed test procedure in the LCC analysis (see Appendix L).

D.2.4 Determination of National Average Number of Burner Operating Hours for Two-Stage and Step Modulating Furnaces and Boilers

From the test procedure, DOE calcuated the national average number of burner operating hours in sections 10.2.1.2, 10.2.1.3, and 10.2.1.4[1]:

at the reduced operating mode, and

$$BOH_R = X_R * E_M / Q_{IN,R}, \qquad \textbf{Eq. 6}$$

at the maximum operating mode, and

$$BOH_H = X_H * E_M / Q_{IN}, \qquad \textbf{Eq. 7}$$

at the modulating operating mode

$$BOH_M = X_H * E_M / Q_{IN,M} \qquad \textbf{Eq. 8}$$

where:

X_R	=	fraction of heating load at the reduced fuel input operating mode, Table 10,[6]
X_H	=	fraction of heating load at the reduced fuel input operating mode, Table 10,[6]
E_M	=	average annual energy used during the heating season for two-stage and modulating furnaces,

Q_{IN}	=	as defined in section D.2.1 of this appendix,
$Q_{IN,R}$	=	steady-state reduced-fuel input rate, and
$Q_{IN,M}$	=	steady-state modulating fuel input rate.

The Department calculated X_R and X_H using T_C (balance-point temparature), α (the oversize factor), $Q_{OUT,R}$ (reduced fuel input rate heating capacity), $Effy_{SS,M}$ (steady-state efficiency at the modulating fuel input rate), $Effy_{SS,R}$ (steady-state efficiency at the reduced fuel input rate), $T_{OA,H}$ (average outdoor temperature at the modulating or maximum fuel input operating mode), and $Q_{OUT,M}$ (modulating fuel input rate heating capacity), which DOE defined in section 11.4 of DOE test procedure.[6] The Department determined Q_{OUT}, as defined in section D.2.3 of this appendix. To calculate E_M, the Department used BOH_{SS}, Q_{IN}, and Q_P as defined in section D.2.1 of this appendix. The Department set $Q_{IN,R}$ to be 68 percent of Q_{IN}, where this value represents the average ratio $Q_{IN}/Q_{IN,R}$ as derived using manufacturer product literature and Gas Appliance Manufacturers Association (GAMA) April 2004 Directory data for all listed two-stage furnace models.[Gas Appliance Manufacturers Association, April 2002 #3045] From section 11.4.8.6 or 11.5.8.6,[6] $Q_{IN,M}$ is calculated using Q_{OUT} and $Effy_{SS,M}$ (as defined in section 11.4.8.8 or 11.5.8.8)[6].

D.2.5 Determination of Heating Seasonal Efficiency ($\mathbf{Effy_{SS}}$)

The Department needed $Effy_{SS}$ to calculate Q_{OUT}, the heating capacity, and to determine *AFUE*, the annual fuel utilization efficiency for heating equipment with pilot lights. DOE chose the approach which requires determining the average ($Effy_{SS}$ - *AFUE*) difference for each product class.

From Section 11.2.8.1 of ANSI/ASHRAE 103-1993[6]:

$$Q_{OUT} = Q_{IN}*[Effy_{SS} - (K)(Lj)]/100 \qquad \textbf{Eq. 9}$$

The Department calculated ($Effy_{SS}$ -AFUE) values by solving Equation 9 for $\mathrm{Effy_{SS}}$ and subtracting AFUE from both sides:

$$Effy_{SS}\ \text{-AFUE} = 100*[(Q_{OUT}/Q_{IN}) + (K)(Lj)] - AFUE \qquad \textbf{Eq. 10}$$

The Department used the available model information (Q_{IN}, Q_{OUT}, and *AFUE*) from the GAMA directory to determine average ($Effy_{SS}$ -*AFUE*) values for each product class.[Gas Appliance Manufacturers Association, October 2002 #3069] DOE listed the average ($Effy_{SS}$ - *AFUE*) values in the look-up table, which is a part of the engineering spreadsheet (see "SSE Analysis.xls" spreadsheet).

D.3 PARAMETERS TO DETERMINE THE ENERGY USE OF MODULATING

FURNACES

DOE based the furnace energy use calculations on the current DOE test procedure for determining the AFUE of residential furnaces and boilers,[1] which for the most part references the industry test standard ANSI/ASHRAE 103/1993 of the American Society of Heating, Refrigerating, and Air Conditioning (ASHRAE).[2] In the case of single stage and two-stage furnaces rated at one and the same AFUE level, the analysis points to a significant difference in the energy use between both designs. This introduces an inconsistency, because with a ratio of reduced to maximum input of about 70 percent the test procedure shows that the furnace would supply almost 95 percent of the annual heating load at the reduced input. Therefore a two stage furnace operates almost all of the time as a single-stage furnace at a reduced input rate. However, as pointed out above, the calculations based on the current test procedure indicate much more efficient operation.

This section outlines the parameters involved in the calculations and provides an additional basis upon which the stakeholders can comment on this part of the analysis.

D.3.1 Parameters to Determine Average Annual Fuel Energy Consumption

The average annual fuel energy consumption for both single-stage and two-stage furnaces (as calculated using CFR Appendix N, Subpart B of Part 430, *Uniform Test Method for Measuring the Energy Consumption of Furnaces and Boilers*, sections 10.2.2 and 10.2.2.1[1]) is:

$$E_F = BOH_{SS} * (Q_{IN} - Q_P) + 8{,}760 * Q_P \qquad \textbf{Eq. 11}$$

E_F (for single and two-stage furnaces) differs due to the different approach used to calculate the national average number of burner operating hours - BOH_{SS}:

$$BOH_{SS} = 2080 * 0.77 * A * DHR - 2080 * B \qquad \textbf{Eq. 12}$$

where for single-stage furnaces

$$A = 100{,}000 / [341{,}300 * (y_{IG} * PE_{IG} + y * BE) + (Q_{IN} - Q_P) * Effy_{HS}], \qquad \textbf{Eq. 13}$$

and for two-stage and step modulating furnaces

$$A = 100{,}000 / [341{,}300 * (y_{IG} * PE_{IG} + y * BE)*R + (Q_{IN} - Q_P) * Effy_{HS}] \qquad \textbf{Eq. 14}$$

where the term $(y_{IG} * PE_{IG} + y * BE)$ in the formula for two-stage furnaces is increased by the factor R=2.3.

Kweller[8] described the derivation of R-values for single and two-stage furnaces as follows: Burner on-time for single-stage furnace is assigned values in the DOE test procedure of 3.8 minutes on and 13.3 minutes off. The corresponding values for two-stage modulating furnaces are 10 minutes and 10 minutes. The ratio of percent time-on for a single-stage furnace is 3.8/(3.8+13.3)=0.22 and for a two-stage furnace is 10/(10+10)=0.50. Using these on-time fractions, the ratio "*R*" of on-time for the two-stage furnace vs the single-stage furnace is 0.50/0.22=2.27. In other words the amount of electrical energy required for the two stage furnaces is 227 percent (or *R*=2.3) of the single-stage furnace.

The different value of *R* is the cause for the reduced energy consumption for modulating furnaces compared to single-stage at the same efficiency level. In this case, the increased electrical energy use for two-stage furnaces is credited in reducing the house heating load.

D.3.2 Parameters to Determine Annual Fuel Utilization Efficiency

The *AFUE* equals the heating seasonal efficiency ($Effy_{HS}$) when no pilot light is present. The detailed test procedure approach to determine $Effy_{HS}$ requires specific information on heat-up and cool down temperatures as measured during an actual test. When test results are not available, DOE made an assumption for the value of the *AFUE*.

From Section 11.2.12 and 11.4.12 of ANSI/ASHRAE 103-1993[6] (DOE furnace/boiler test procedure refers to this standard):

$$AFUE = Effy_{HS} \text{ (when no pilot light is present)} \qquad \textbf{Eq. 15}$$

$Effy_{HS}$ for two-stage furnaces is a function of X_H and $X_R = 1 - X_H$, ratios representing the fraction of heating load at maximum and reduced input rate.

X_H is a function of the steady-state efficiency at maximum ($Effy_{SS}$) and reduced ($Effy_{SS,R}$) fuel input rate capacities. From several actual modulating furnace tests described in Liu[Liu, 2002 #3082] DOE found that the values for $Effy_{SS,R}$ are sometimes higher and sometimes lower than the $Effy_{SS}$ values. Therefore, based on these tests it is possible to assume that $Effy_{SS,R} = Effy_{SS}$. DOE confirmed this assumption in the above cited reference,[8] where the furnace steady-state efficiency at maximum ($Effy_{SS}$) and reduced ($Effy_{SS,R}$) fuel input rate capacities are assumed the same. Once confirmed, it is straightforward to calculate the reduced fuel input heating capacity $Q_{OUT,R} = Q_{OUT} * Q_{IN,R} / Q_{IN}$ and the balance-point temperature T_C. Knowing T_C allows one to determine X_H and X_R from Table 10.[6]

DOE did not use the above approach to determine $Effy_{HS}$. The Department examined 8 families of furnace models at 80 percent *AFUE* from six manufacturers, and compared pairs of models which are essentially identical with the exception of the modulating component. (See Table D.3.1) The comparison showed that the reported *AFUE* for each pair is identical. This finding indicates that $Effy_{HS}$ is the same for single-stage and two-stage furnaces, which are otherwise identical and therefore *AFUE* value may be used as proxy for $Effy_{HS}$ in the equation 13 and 14.

Table D.3.1 AFUE for Similar Single-Stage and Two-Stage Furnace Models Series

Manufacturer	Single-Stage Series	Two-Stage Series	AFUE
Amana	GUIC	GUIS	80%
Carrier	58DLA	58CTA	80%
Lennox	G50 (UH/DF)	G60 (UH/DF)	80%
Rheem[1]	RGLJ/RGPH	RGLK/RGPK	80%
Trane	TDD-C/TUD-C	TDD-R/TUD-R	80%
York	PDN/PHU	PDD/PDU	80%

D.3.3 Conclusions

DOE determined the fuel consumption difference between single-stage and modulating furnaces by:

1) the value of the parameter *R*, and

2) the value of X_R and X_H, (ratios representing the fraction of heating load at maximum and reduced input rate), where they are functions of the steady-state efficiency at maximum and reduced fuel input rate capacities as determined by test procedure measured quantities.

To bring the energy use of single-stage and two-stage furnaces in line with the actually observed field performance it may be necessary to correct at least the above parameters. This may require assuming different values for the furnace time on/off and also changing the oversizing factor. There may be other factors in the test procedure which should be examined.

D.4 SUMMARY TABLES

The summary tables below include single-stage and two-stage modulation tables referenced in Chapter 6 (section 6.7.2) of the TSD. Tables D.4.1 through D.4.6 in this appendix contain data about the furnaces and boilers with single-stage controls, Tables D.4.7 through D.4.11 present data about two-stage modulation furnace and boiler designs, and Table D.4.12 contains data about step modulation furnace design options.

[1] Some models in this series have AFUE of 80% or 81%.

Table D.4.1 Single-Stage Non-Weatherized Gas Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	PE	BE	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	E_{AE}	E_F
Gas Furnace, 78% w/time delays, w/o pilot	75,000	57,809	0	78	0.076	0.50	0.4	0.62	30	792	558	59.42
Gas Furnace, 80% w/time delays, w/o pilot	75,000	59,309	0	80	0.076	0.50	0.4	0.62	30	773	545	57.99
Gas Furnace, 81% w/time delays, w/o pilot	75,000	60,059	0	81	0.076	0.50	0.4	0.62	40	1019	718	76.39
Gas Furnace, 90% w/time delays, w/o pilot	75,000	66,809	0	90	0.076	0.50	0.4	0.62	40	920	648	68.99
Gas Furnace, 92% w/time delays, w/o pilot	75,000	68,309	0	92	0.076	0.50	0.4	0.62	40	900	635	67.53

Table D.4.2 Single-Stage Weatherized Gas Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	PE	BE	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	E_{AE}	EF
Gas Furnace, 78% w/time delays, w/o pilot	75,000	56,004	0	78.0	0.076	0.50	0.4	0.62	30	792	558	59.42
Gas Furnace, 80% w/time delays, w/o pilot	75,000	57,504	0	80.0	0.076	0.50	0.4	0.62	30	773	545	57.99
80%AFUE - Improved Insulation	75,000	57,616	0	80.2	0.076	0.50	0.4	0.62	30	772	544	57.88
Gas Furnace, 81% w/time delays, w/o pilot	75,000	58,254	0	81.0	0.076	0.50	0.4	0.62	30	764	538	57.29
81%AFUE - Improved Insulation	75,000	58,366	0	81.2	0.076	0.50	0.4	0.62	30	763	537	57.19
Gas Furnace, 82% w/time delays, w/o pilot	75,000	59,004	0	82.0	0.076	0.50	0.4	0.62	30	755	532	56.62
82%AFUE - Improved Insulation	75,000	59,116	0	82.2	0.076	0.50	0.4	0.62	30	754	531	56.52
Gas Furnace, 82.5% w/time delays, w/o pilot	75,000	59,379	0	83.0	0.076	0.50	0.4	0.62	30	751	529	56.29
82.5%AFUE - Improved Insulation	75,000	59,866	0	83.2	0.076	0.50	0.4	0.62	30	745	525	55.86

Table D.4.3 Single-Stage Mobile Home Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	PE	BE	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	E_{AE}	EF
MH Gas Furnace, 75% w/time delays, w/ pilot	75,000	55,992	500	77	0.076	0.50	0	0.00	30	781	500	62.57
MH Gas Furnace, 80% w/time delays, w/o pilot	75,000	59,742	0	80	0.076	0.50	0.4	0.62	30	773	545	57.99
MH Gas Furnace, 81% w/time delays, w/o pilot	75,000	60,492	0	81	0.076	0.50	0.4	0.62	40	1019	718	76.39
MH Gas Furnace, 82% w/time delays, w/o pilot	75,000	61,242	0	82	0.076	0.50	0.4	0.62	40	1007	709	75.49
MH Gas Furnace, 90% w/time delays, w/o pilot	75,000	67,242	0	90	0.076	0.50	0.4	0.62	40	920	648	68.99

Table D.4.4 Single-Stage Oil-Fired Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	PE	BE	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	E_{AE}	E_F
Oil Furnace, 78% w/time delays, w/o pilot	105,000	80,689	0	78	0.22	0.50	0.045	26.00	50	944	1026	99.09
Oil Furnace, 80% w/time delays, w/o pilot	105,000	82,789	0	80	0.22	0.50	0.045	26.00	50	921	1001	96.69
Oil Furnace, 81% w/time delays, w/o pilot	105,000	83,839	0	81	0.22	0.50	0.045	26.00	50	910	981	95.54
81%AFUE Interrupted Ignition	105,000	83,839	0	81	0.22	0.50	0.025	0.75	50	921	727	96.66
Oil Furnace, 82% w/time delays, w/o pilot	105,000	84,889	0	82	0.22	0.50	0.045	26.00	50	899	977	94.41
82%AFUE Interrupted Ignition	105,000	84,889	0	82	0.22	0.50	0.025	0.75	50	910	718	95.50
Oil Furnace, 83% w/time delays, w/o pilot	105,000	85,939	0	83	0.22	0.50	0.045	26.00	50	889	966	93.31
83%AFUE Interrupted Ignition	105,000	85,939	0	83	0.22	0.50	0.025	0.75	50	899	710	94.38
Oil Furnace, 84% w/time delays, w/o pilot	105,000	86,989	0	84	0.22	0.50	0.045	26.00	50	878	955	92.24
84%AFUE Interrupted Ignition	105,000	86,989	0	84	0.22	0.50	0.025	0.75	50	888	701	93.28
Oil Furnace, 85% w/time delays, w/o pilot	105,000	88,039	0	85	0.22	0.50	0.045	26.00	50	868	944	91.19
85%AFUE Interrupted Ignition	105,000	88,039	0	85	0.22	0.50	0.025	0.75	50	878	693	92.20

Table D.4.5 Single-Stage Hot-Water Gas Boilers

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	PE	BE	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	E_{AE}	E_F
Gas Boiler, 80% w/time delays, w/ pilot	105,000	84,754	500	81	0.076	0.07	0	0.00	50	916	134	100.06
Gas Boiler, 81% w/time delays, w/o pilot	105,000	85,804	0	81	0.076	0.07	0.4	0.62	50	937	161	98.34
Gas Boiler, 82% w/time delays, w/o pilot	105,000	86,854	0	82	0.076	0.07	0.4	0.62	50	925	159	97.14
Gas Boiler, 83% w/time delays, w/o pilot	105,000	87,904	0	83	0.076	0.07	0.4	0.62	50	914	157	95.98
Gas Boiler, 84% w/time delays, w/o pilot	105,000	88,954	0	84	0.076	0.07	0.4	0.62	50	903	155	94.84
Gas Boiler, 85% w/time delays, w/o pilot	105,000	90,004	0	86	0.076	0.07	0.4	0.62	50	893	153	93.73
Gas Boiler, 86% w/time delays, w/o pilot	105,000	93,154	0	88	0.076	0.07	0.4	0.62	50	882	151	92.65
Gas Boiler, 91% w/time delays, w/o pilot	105,000	96,304	0	91	0.076	0.07	0.4	0.62	60	1001	172	105.10
Gas Boiler, 99% w/time delays, w/o pilot	105,000	104,704	0	99	0.076	0.07	0.4	0.62	60	920	158	96.64

Table D.4.6 Single-Stage Hot-Water Oil Boilers

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	PE	BE	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	E_{AE}	E_F
Oil Boiler, 80% w/time delays	140,000	113,413	0	80	0.22	0.07	0.045	26.00	70	992	408	138.87
Oil Boiler, 81% w/time delays	140,000	114,813	0	81	0.22	0.07	0.045	26.00	70	980	403	137.17
~~81%AFUE Interrupted Ignition~~	140,000	114,813	0	81	0.22	0.07	0.025	0.75	70	983	287	137.66
Oil Boiler, 82% w/time delays	140,000	116,213	0	82	0.22	0.07	0.045	26.00	70	968	398	135.51
~~82%AFUE Interrupted Ignition~~	140,000	116,213	0	82	0.22	0.07	0.025	0.75	70	971	284	135.99
Oil Boiler, 83% w/time delays	140,000	117,613	0	83	0.22	0.07	0.045	26.00	70	956	393	133.89
~~83%AFUE Interrupted Ignition~~	140,000	117,613	0	83	0.22	0.07	0.025	0.75	70	960	280	134.36
Oil Boiler, 84% w/time delays	140,000	119,013	0	84	0.22	0.07	0.045	26.00	70	945	388	132.31
~~84%AFUE Interrupted Ignition~~	140,000	119,013	0	84	0.22	0.07	0.025	0.75	70	948	277	132.77
Oil Boiler, 85% w/time delays	140,000	120,413	0	85	0.22	0.07	0.045	26.00	70	934	384	130.77
~~85%AFUE Interrupted Ignition~~	140,000	120,413	0	85	0.22	0.07	0.025	0.75	70	937	274	131.21
Oil Boiler, 86% w/time delays	140,000	121,813	0	86	0.22	0.07	0.045	26.00	70	923	379	129.26
~~86%AFUE Interrupted Ignition~~	140,000	121,813	0	86	0.22	0.07	0.025	0.75	70	926	270	129.69
Oil Boiler, 90% w/time delays	140,000	127,413	0	90	0.22	0.07	0.045	26.00	70	883	363	123.56
Oil Boiler, 95% w/time delays	140,000	134,413	0	95	0.22	0.07	0.045	26.00	80	956	393	133.84

Table D.4.7 Two-Stage Non-Weatherized Gas Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	BE_H	BE_R	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	BOH_R	E_{AE}	E_F
80% AFUE w/ Two-stage Modulation + ECM	75,000	59,309	0	80	0.398	0.318	0.4	0.62	30	757	1113	484	56.77
81% AFUE w/ Two-stage Modulation + ECM	75,000	60,059	0	81	0.398	0.318	0.4	0.62	40	997	1467	638	74.81
92% AFUE w/ Two-stage Modulation + ECM	75,000	68,309	0	92	0.398	0.318	0.4	0.62	40	866	1273	554	64.94

Table D.4.8 Two-Stage Mobile Home Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	BE_H	BE_R	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	BOH_R	E_{AE}	E_F
80% AFUE w/ Two-stage Modulation + ECM	75,000	59,742	0	80	0.398	0.318	0.4	0.62	30	757	1113	484	56.77
81% AFUE w/ Two-stage Modulation + ECM	75,000	60,492	0	81	0.398	0.318	0.4	0.62	40	997	1467	638	74.81
82% AFUE w/ Two-stage Modulation + ECM	75,000	61,242	0	82	0.398	0.318	0.4	0.62	40	986	1450	631	73.95

Table D.4.9 Two-Stage Hot-Water Oil Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	BE_H	BE_R	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	BOH_R	E_{AE}	E_F
81%AFUE Fan Atomized Burner w/ Two-stage Modulation	105,000	83,839	0	81	0.398	0.318	0.045	26.00	50	897	1319	886	94.12
82%AFUE Fan Atomized Burner w/ Two-stage Modulation	105,000	84,889	0	82	0.398	0.318	0.045	26.00	50	887	1304	876	93.12
83%AFUE Fan Atomized Burner w/ Two-stage Modulation	105,000	85,939	0	83	0.398	0.318	0.045	26.00	50	877	1289	866	92.05
84%AFUE Fan Atomized Burner w/ Two-stage Modulation	105,000	86,989	0	84	0.398	0.318	0.045	26.00	50	867	1275	856	91.00
85%AFUE Fan Atomized Burner w/ Two-stage Modulation	105,000	88,039	0	85	0.398	0.318	0.045	26.00	50	857	1260	846	89.98

Table D.4.10 Two-Stage Hot-Water Gas Boilers

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	BE_H	BE_R	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	BOH_R	E_{AE}	E_F
Gas Boiler, 81% w/ Two-stage Modulation	105,000	85,804	0	81	0.070	0.030	0.076	0.62	50	931	1369	168	97.74
Gas Boiler, 82% w/ Two-stage Modulation	105,000	86,854	0	82	0.070	0.030	0.076	0.62	50	920	1352	166	96.56
Gas Boiler, 83% w/ Two-stage Modulation	105,000	87,904	0	83	0.070	0.030	0.076	0.62	50	909	1336	164	95.41
Gas Boiler, 84% w/ Two-stage Modulation	105,000	88,954	0	84	0.070	0.030	0.076	0.62	50	898	1321	162	94.29
Gas Boiler, 84% w/ Two-stage Modulation	105,000	90,004	0	85	0.070	0.030	0.076	0.62	50	888	1305	160	93.19

Table D.4.11 Two-Stage Hot-Water Oil Boilers

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	BE_H	BE_R	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	BOH_R	E_{AE}	E_F
Oil Boiler, 82% Fan Atomized Burner w/ Two-stage Modulation	140,000	116,213	0	82	0.070	0.030	0.045	26.00	70	964	1417	465	134.91
Oil Boiler, 83% Fan Atomized Burner w/ Two-stage Modulation	140,000	117,613	0	83	0.070	0.030	0.045	26.00	70	952	1400	459	133.31
Oil Boiler, 84% Fan Atomized Burner w/ Two-stage Modulation	140,000	119,013	0	84	0.070	0.030	0.045	26.00	70	941	1384	454	131.74
Oil Boiler, 85% Fan Atomized Burner w/ Two-stage Modulation	140,000	120,413	0	85	0.070	0.030	0.045	26.00	70	930	1368	449	130.21
Oil Boiler, 86% Fan Atomized Burner w/ Two-stage Modulation	140,000	121,813	0	86	0.070	0.030	0.045	26.00	70	919	1352	443	128.71

Table D.4.12 Step Modulation Non-Weatherized Gas Furnaces

Description	Q_{IN}	Q_{OUT}	Q_P	$EFFy_{HS}$	BE_H	BE_R	PE_{IG}	T_{IG}	RDHR	BOH_{SS}	BOH_R	E_{AE}	E_F
92% AFUE w/ Step Modulation	75,000	68,309	0	92	0.398	0.318	0.4	0.62	40	884	1300	566	66.30
96% AFUE w/ Step Modulation	75,000	71,309	0	96	0.398	0.318	0.4	0.62	40	849	1248	543	63.66

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