CHAPTER 7. ENERGY USE ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 7. **ENERGY USE ANALYSIS**

7.1 INTRODUCTION

The purpose of the energy use analysis is to determine the annual energy consumption of furnace fans in representative U.S. homes and to assess the energy savings potential of increased fan efficiency. In contrast to the DOE test procedure, which uses typical operating conditions in a laboratory setting, the energy use analysis seeks to estimate the range of energy consumption of the products in the field. DOE estimated the annual energy consumption of furnace fans at specified energy efficiency levels across a range of climate zones and household characteristics. The energy use analysis provides estimates of the distribution of annual energy consumption for furnace fans at the efficiency standard levels considered.

DOE developed energy consumption estimates for the key product classes analyzed in the engineering analysis (chapter 5 of the technical support document (TSD)). These are listed in Table 7.1.1.

Table 7.1.1 Furnace Fan Product Classes Analyzed

Non-Weatherized, Non-Condensing Gas Furnace Fan
Non-Weatherized, Condensing Gas Furnace Fan
Weatherized Gas Furnace Fan
Oil Furnace Fan
Electric Furnace / Modular Blower Fan
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan
Manufactured Home Electric Furnace / Modular Blower Fan
Hydronic Air Handler Fan (Heat/Cool)

7.2 GENERAL APPROACH TO THE ENERGY USE ANALYSIS

Estimating annual energy consumption of furnace fans requires calculating the energy use at different operating modes: heating, cooling, constant circulation, and standby. DOE estimated the total annual energy consumption of furnace fans for each household sampled using the following equation:

$$FFEU_{total} = FFOH_{heating} \times FFP_{heating} + FFOH_{cooling} \times FFP_{cooling} + FFOH_{cont\,fan} \times FFP_{cont\,fan} + FFOH_{standby} \times FFP_{standby}$$

Where:

$FFEU_{total}$ = Total annual energy consumption by furnace fan, kW/yr,

$FFOH_{heating}$ = furnace fan operating hours during the heating season, h,

$FFP_{heating}$ = furnace fan power during the heating operation, kW,

$FFOH_{cooling}$ = furnace fan operating hours during the cooling season, h,

$FFP_{cooling}$ = furnace fan power during the cooling operation, kW,

$FFOH_{cont\,fan}$ = furnace fan operating hours during constant circulation fan operation, h,

$FFP_{cont\,fan}$ = furnace fan power during the constant circulation fan operation, kW,

$FFOH_{standby}$ = furnace fan operating hours during standby, h, and

$FFP_{standby}$ = furnace fan power during the standby operation, kW.

7.3 HOUSEHOLD SAMPLE

DOE's calculation of the annual energy use of residential furnace fans relied on data from Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS 2005).[1] 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 furnace fans 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), electricity, or fuel oil;
- heated only one housing unit; and
- had a heating energy consumption greater than zero.

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

The RECS 2005 weighting indicates how commonly each household configuration occurs in the general population in 2005. DOE made some adjustments to EIA's weightings for each RECS 2005 household in order to create a furnace fan population weight for 2018. The first adjustment was to compensate for the fact that the RECS 2005 sample does not distinguish between weatherized and non-weatherized gas furnaces. DOE also took into account the growth in population by region from 2005 to 2018 based on U.S. census population projections. Finally, DOE adjusted the weightings to account for households with multiple furnaces. Appendix 7-A provides further details on these adjustments.

Table 7.3.1 Household Samples for Furnace Fan Products

Product Class	Criteria	No. of Records	RECS 2005	2018 Estimate
			Number of Houses *million*	**Number of Furnaces** *million*
Non-Weatherized, Non-Condensing Gas Furnace Fan	Primary or Secondary Heating Equipment = Gas Furnace[a] Region = South Housing Type = non-mobile home	736	19.6	14.5
Non-Weatherized, Condensing Gas Furnace Fan	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = non-mobile home	1726	45.5	35.6
Weatherized Gas Furnace Fan	Primary or Secondary Heating Equipment = Gas Furnace Region = South Housing Type = non-mobile home Primary or Secondary Cooling Equipment = Central Air Conditioner	576	15.4	17.9
Oil Furnace Fan	Primary or Secondary Heating Equipment = Oil Furnace Housing Type = non-mobile home	150	2.9	3.3
Electric Furnace / Modular Blower Fan	Primary or Secondary Heating Equipment = Electric Furnace Housing Type = non-mobile home	40	1.3	0.8
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	Primary or Secondary Heating Equipment = Gas Furnace Region = South Housing Type = mobile home	565	15.6	3.6
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = mobile home	51	1.2	1.2
Manufactured Home Electric Furnace / Modular Blower Fan	Primary or Secondary Heating Equipment = Electric Furnace Housing Type = mobile home	109	2.5	1.6
Hydronic Air Handler Fan (Heat/Cool)	Primary or Secondary Heating Equipment = Gas Furnace Region = South Housing Type = non-mobile home Primary or Secondary Cooling Equipment = Central Air Conditioner Water Heater Equipment = Gas Water Heater Household Square Footage <2000 sq ft	68	1.9	2.1

---

[a] Natural Gas or LPG Furnace.

7.4 FURNACE FAN POWER CONSUMPTION

The electricity consumption (and overall efficiency) of a furnace fan depends on the speed at which the motor operates, the external static pressure difference across the blower, and the airflow through the blower. The power consumption of the furnace fan is determined using the individual sample housing unit operating conditions (the pressure and airflow) at which a particular furnace fan will operate when performing heating, cooling, and constant circulation functions.

These operating conditions can be graphically displayed as the intersection of a system curve of the air-distribution system in the housing unit (which plots the airflow across the supply and return air ducts as a function of static pressure) with the fan curve of the furnace (which plots the airflow through the furnace as a function of static pressure).[2] The intersection of these two curves is the airflow and the static pressure at which the furnace will operate in that housing unit.

Furnace fan curves, reported as tables of airflow rise versus static pressure through the furnace, are available from manufacturers in the product literature for most furnace models. Some of the manufacturers also supply blower-motor input power as a function of static pressure across the furnace.

Air power is calculated from the air speed through the furnace and the pressure rise across the furnace. The overall air-moving efficiency is air power divided by the electric power to the blower motor.

All of the electric power of the blower motor eventually is converted into heat that contributes heat to the building's interior. DOE takes this into account by increasing the heating load and/or decreasing the cooling load for more efficient furnace fans.

7.4.1 System Curves

DOE modeled system curves as quadratic curves, which is standard in heating, ventilation, and air conditioning (HVAC) design and fan selection handbooks.[3] The curves are based on Bernoulli's equations for fluid flow and are expressed as the following equation:

$$Q = \sqrt{\frac{P}{\alpha}}$$

Where:

Q = airflow (CFM),

P = external static pressure (in.w.g.), and

α = a constant coefficient.

DOE selected the external static pressure (ESP) in the system curve equation for each sample housing unit. DOE identified four installation types with unique ESP considerations: units paired with an evaporator coil; heating-only units or units with an internal evaporator coil; manufactured home units paired with an evaporator coil; and manufactured home heating-only units. To develop distributions of ESP values for each of these types, DOE gathered field data from available studies and research reports to determine an appropriate distribution of ESP values. DOE compiled over 1,300 field ESP measurements from several studies that included furnace fans in single-family and manufactured homes in different regions of the country. The data and sources are described in appendix 7-B. Table 7.4.1 gives the weighted average ESP values for each type. DOE designed each distribution as a normal distribution based on the field studies. DOE randomly sampled a static pressure value at the nominal maximum airflow from one of the four distributions, depending on the type of equipment installed in the housing unit.

Table 7.4.1 Values Used for External Static Pressure

Installation Type	Associated Product Class	Weighted Average ESP (in. w.c.)	Standard Deviation (in. w.c.)
Units paired with an evaporator coil	Furnaces paired with a CAC unit	0.73	0.12
Heating-only units or Units with an internal evaporator coil	Furnaces not paired with a CAC unit or Weatherized gas furnaces	0.52	0.12
Manufactured home paired with an evaporator coil	Manufactured home furnaces paired with a CAC unit	0.37	0.6
Manufactured home heating-only units	Manufactured home furnaces not paired with a CAC unit	0.17	0.6

Figure 7.4.1 shows an example of a plot of system curves intersecting a furnace fan curve.

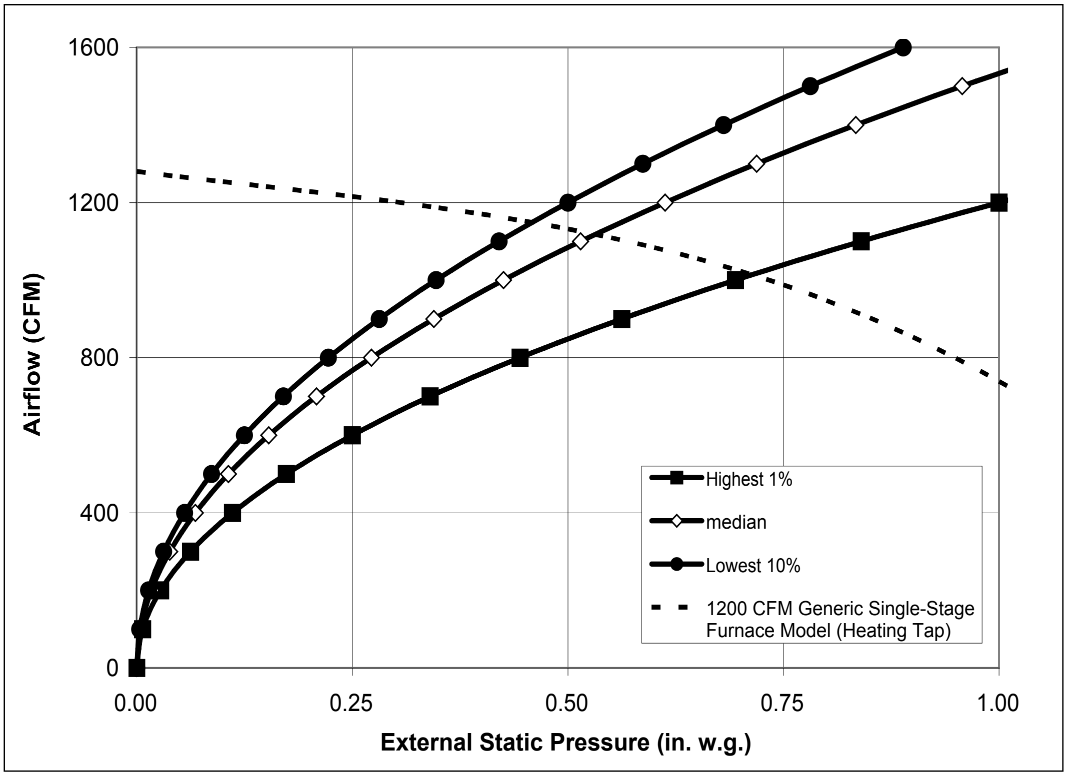

Figure 7.4.1 **Sample of System Curves with a Typical Fan Curve**

7.4.2 Furnace Fan Curves

Depending on the resistance (measured as static pressure) of the supply and return air ducts, a furnace will move more or less air. When these airflow values are plotted graphically against pressure, they are referred to as fan curves.

DOE developed fan curves for PSC, PSC with controls, X13, and ECM furnace models by fitting airflow and pressure data points from manufacturer product literature and measurements conducted during the engineering analysis to a second-order polynomial. DOE did this separately for each of the four main nominal air handler sizes (2-ton, 3-ton, 4-ton, and 5-ton). The cubic feet per minute (CFM) is given by the following equation:

$$CFM = m_0 + m_1 \times (P) + m_2 \times (P^2)$$

Where:

CFM =airflow in CFM reported by manufacturer,

$m_{0,1,2,and\ 3}$ = coefficients derived from 2nd degree polynomial approximation, and

P = external static pressure (in. w.g.).

Figure 7.4.2 shows an example of a CFM curve for a 3-ton non-condensing PSC gas furnace fitted with the manufacturer's raw data.

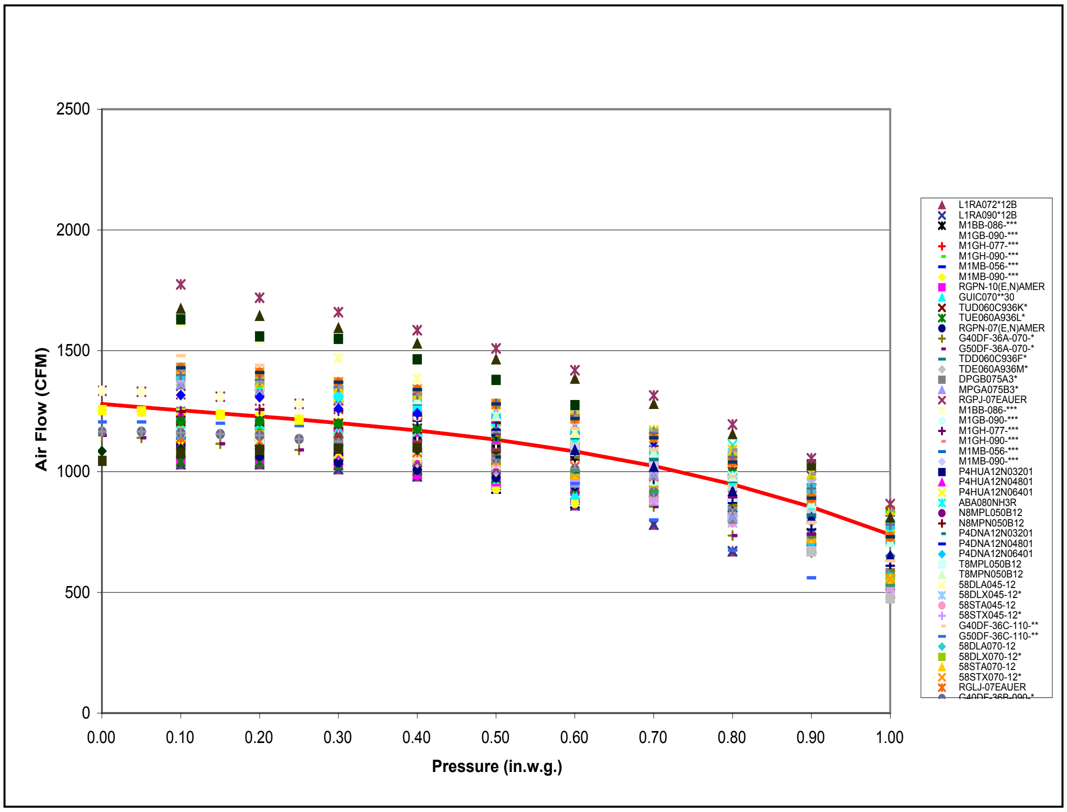

Figure 7.4.2 Example Fit of CFM for 3-Ton PSC Furnace in Heating Mode

7.4.3 Fan Power

Once the operating point of air flow and static pressure is determined, by finding the intersection of the fan performance curve and the system curve, the watts per cubic feet per minute (CFM) of airflow are determined from the equations developed by DOE using manufacturer product literature and measurements conducted during the engineering analysis. The power consumption of the fan at this operating point, BE, is calculated by multiplying the watts/CFM by the CFM at the operating point:

$$BE = \left(\frac{Watts}{CFM}\right) \times Q$$

Where:

BE = circulating air fan electrical energy consumption (watts),

$Watts/CFM$ = blower electricity consumption in watts reported by manufacturer divided by the airflow in CFM at the same static pressure (watts/CFM), and

Q = airflow (CFM).

Some manufacturers of furnace fans report watts across a range of external static pressures. Furthermore, DOE conducted measurements on several furnace fan models during the engineering analysis. For these models, DOE divided watts at these pressures by air flow in CFM at these same pressures. These values of watts per CFM across a range of pressures were fit to a second-order polynomial for the basic furnace models made by the manufacturer. DOE did this separately for each of the four nominal air handler sizes. The watts per CFM is given by the following equation:

$$\frac{Watts}{CFM} = m_0 + m_1 \times (P) + m_2 \times (P^2)$$

Where:

$Watts/CFM$ = blower electricity consumption in watts reported by manufacturer divided by the airflow in CFM at the same static pressure,

$m_{0,1,and\ 2}$ = coefficients derived from second-degree polynomial approximation, and

P = external static pressure (in. w.g.).

Figure 7.4.3 shows the watts per CFM curve for 3-ton condensing single-stage furnace fitted to the manufacturers' data. A similar process of fitting curves to data was done for each nominal blower size.

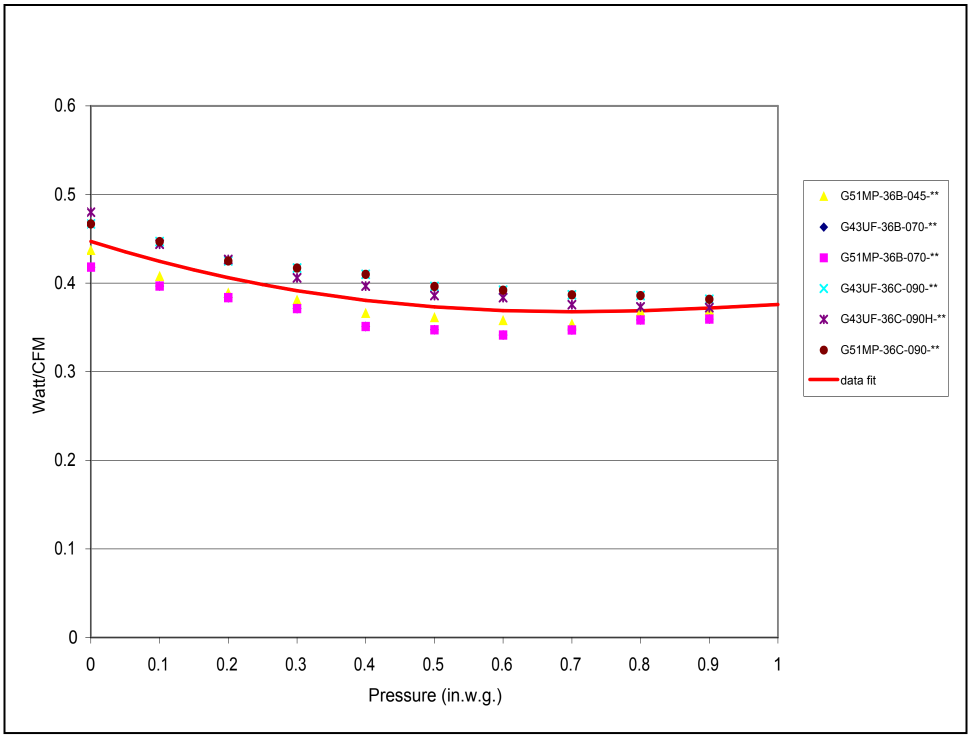

Figure 7.4.3 **Example Fit of Watts/CFM for 3-Ton Single-Stage Furnace**

7.4.4 Determination of Fan Performance by Product Class and Efficiency Level

In order to generate the fan performance data used in the analysis DOE applied the following procedure (the 3-ton baseline PSC motor for non-weatherized, non-condensing gas furnaces is used as an example):

STEP 1: Using the airflow and power curves at each airflow speed (heating, cooling, and constant circulation), DOE found the airflow and power at DOE's proposed furnace fan test procedure conditions. For example, DOE's reference system curve external static pressure is 0.65 in. wc at the maximum cooling airflow speed for non-weatherized gas furnaces. For the 3-ton baseline PSC motor for non-weatherized (non-condensing) gas furnaces the maximum airflow CFM was calculated to be 1158 cubic feet per minute.

STEP 2: DOE used the equation above to calculate the BE at each airflow speed (heating, cooling, and constant circulation) with DOE's proposed furnace fan test procedure conditions. For example, for the 3-ton baseline PSC motor for non-weatherized (non-condensing) gas furnaces *BE* was calculated to be 382 watts at heating, 495 watts at cooling, and 382 watts at constant circulation.

STEP 3: Using the calculated maximum airflow CFM and BE values at the external static pressure prescribed by DOE's reference system curve, Furnace Efficiency Rating

(FER) values were evaluated. For example, for the 3-ton baseline PSC motor for non-weatherized (non-condensing) gas furnaces FER was calculated to be 363.

STEP 4: The constant curve fit parameter m_0, that is derived from plotting the watts/CFM vs. the ESP, is then used to adjust the airflow and power curve in order to match the FER values derived from the engineering analysis (for all product classes and efficiency levels). For example, for the 3-ton baseline PSC motor for non-weatherized (non-condensing) gas furnaces the FER value derived in the engineering analysis was 380, so the adjustment multiplier to convert the FER value calculated in step 3 was calculated to be 1.04.

Table 7.4.2 shows the airflow (CFM) vs. pressure coefficients determined for non-weatherized (non-condensing) gas furnaces (3-ton) at each efficiency level (EL). Figure 7.4.4 to Figure 7.4.6 shows the resulting curves at various pressures and operating modes. See appendix 7-C for further details.

Table 7.4.2 Coefficients for CFM equation for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton

EL	Heating			Cooling			Constant Circulation		
	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2
0	1158	-12	-507	1523	-280	-432	1158	-12	-507
1	1158	-12	-507	1523	-280	-432	931	99	-527
2	1059	269	-405	1277	198	-516	667	-117	-44
3	1139	-403	-62	1427	-323	-15	1001	-880	214
4	1043	24	-101	1203	8	-26	679	3	-64
5	1043	24	-101	1203	8	-26	679	3	-64

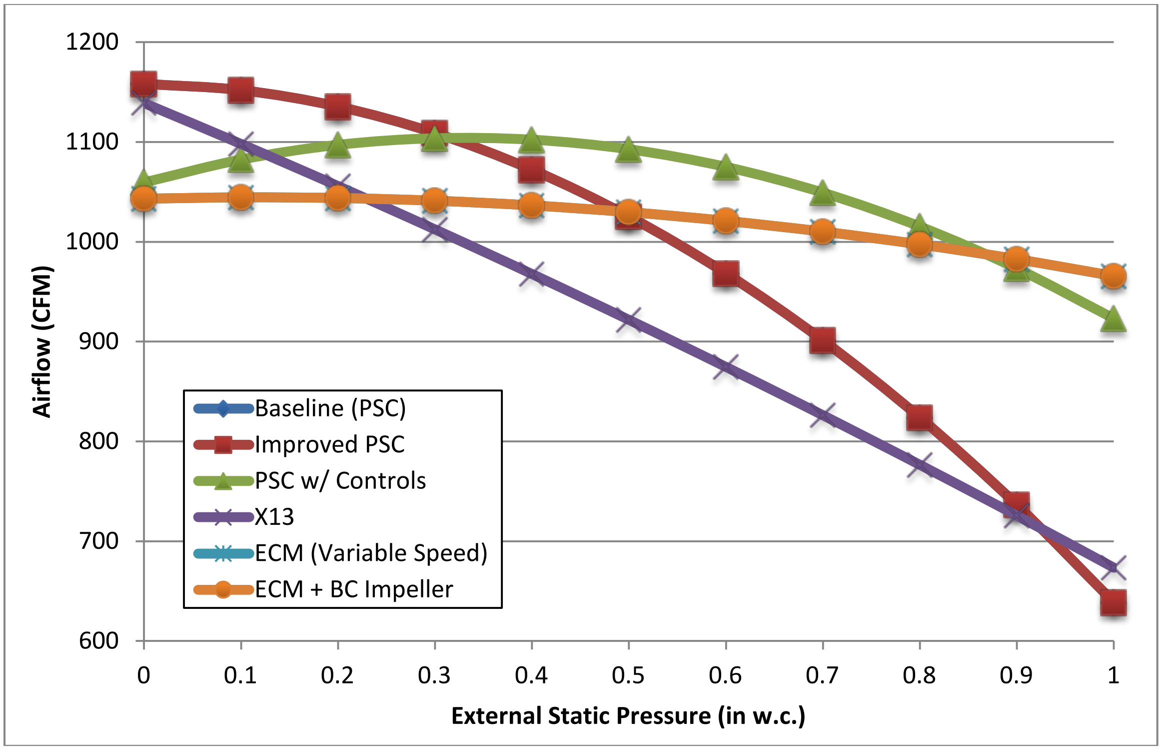

Figure 7.4.4 CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Heating Mode)

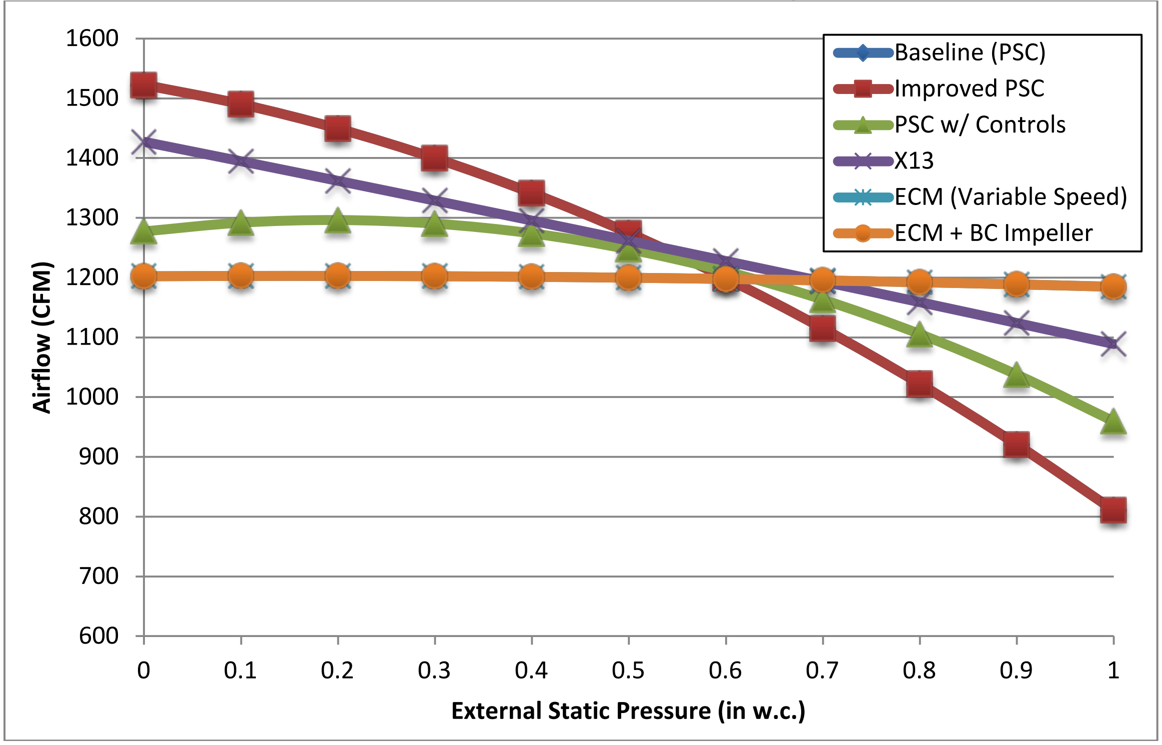

Figure 7.4.5 CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Cooling Mode)

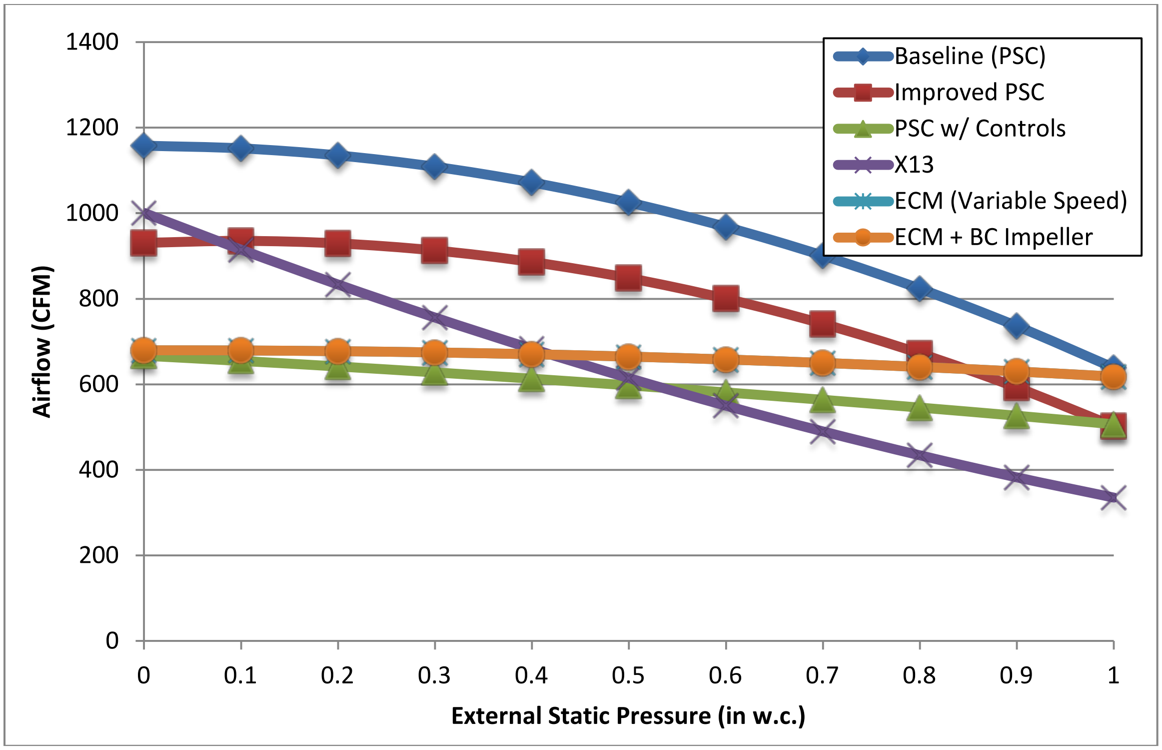

Figure 7.4.6 CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Constant Circulation Mode)

Table 7.4.3 shows the watts/CFM vs. pressure curves coefficients determined for non-weatherized (non-condensing) gas furnaces (3-ton) at each efficiency level. Figure 7.4.7 to Figure 7.4.9 shows the resulting curves at various pressures. Figure 7.4.10 to Figure 7.4.12 show the resulting Watts vs. pressure curves. See appendix 7-C for further details.

Table 7.4.3 Coefficients for Watts/CFM Equation for Non-Weatherized (Non-Condensing) Gas Furnaces, 3-Ton

EL	Heating			Cooling			Constant Circulation		
	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2
0	0.45	-0.21	0.19	0.46	-0.12	0.15	0.45	-0.21	0.19
1	0.45	-0.21	0.19	0.46	-0.12	0.15	0.44	-0.20	0.21
2	0.30	0.16	0.02	0.35	0.16	-0.03	0.22	0.15	0.14
3	0.15	0.10	0.10	0.24	0.12	0.04	0.13	0.01	0.42
4	0.12	0.24	-0.03	0.13	0.29	-0.04	0.07	0.24	0.00
5	0.09	0.24	-0.03	0.10	0.29	-0.04	0.06	0.24	0.00

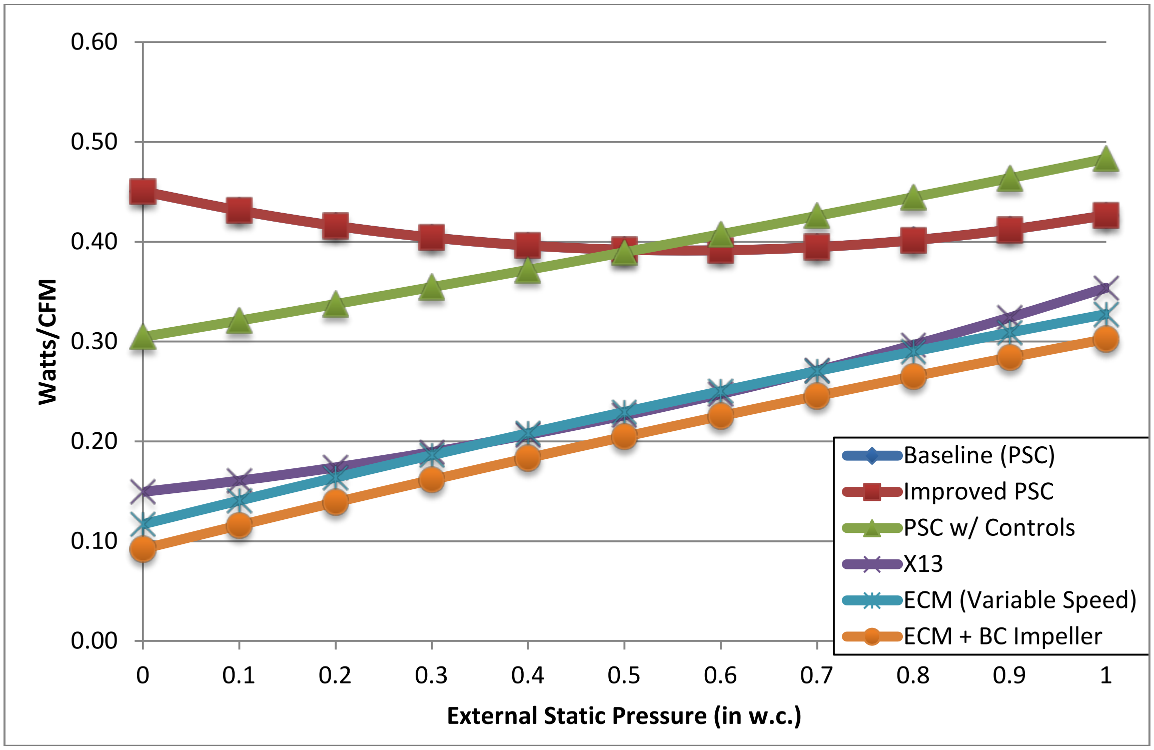

Figure 7.4.7 Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Heating Mode)

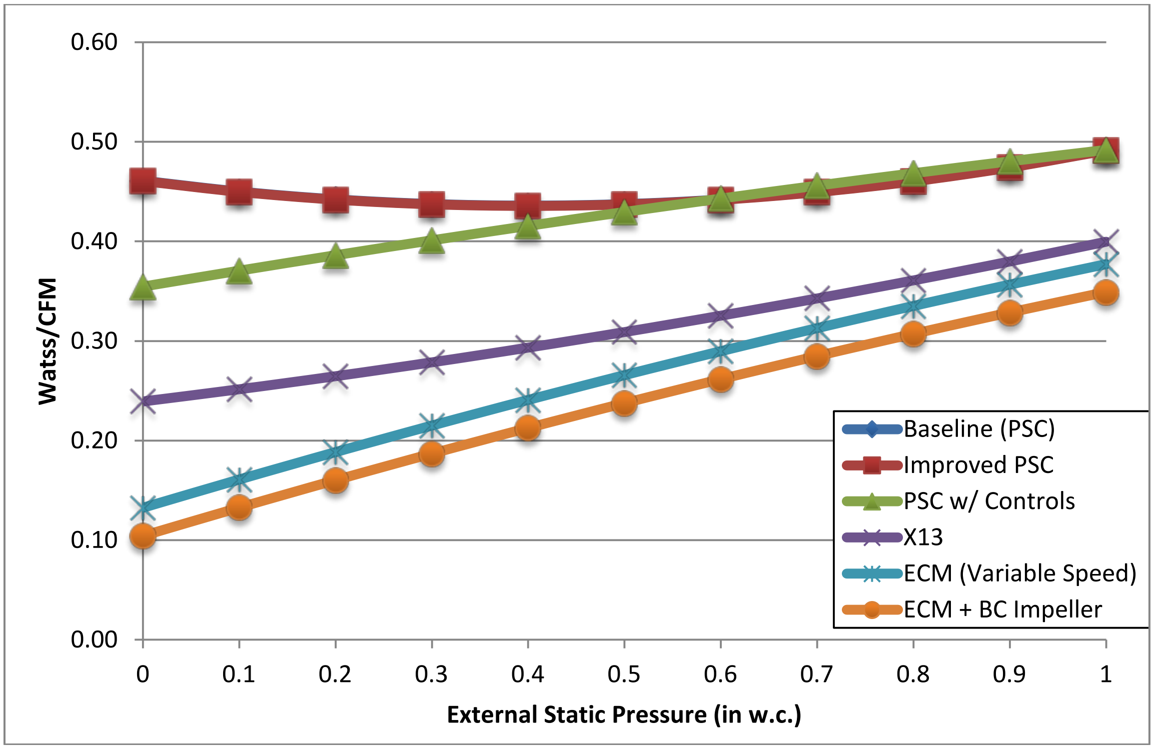

Figure 7.4.8 Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Cooling Mode)

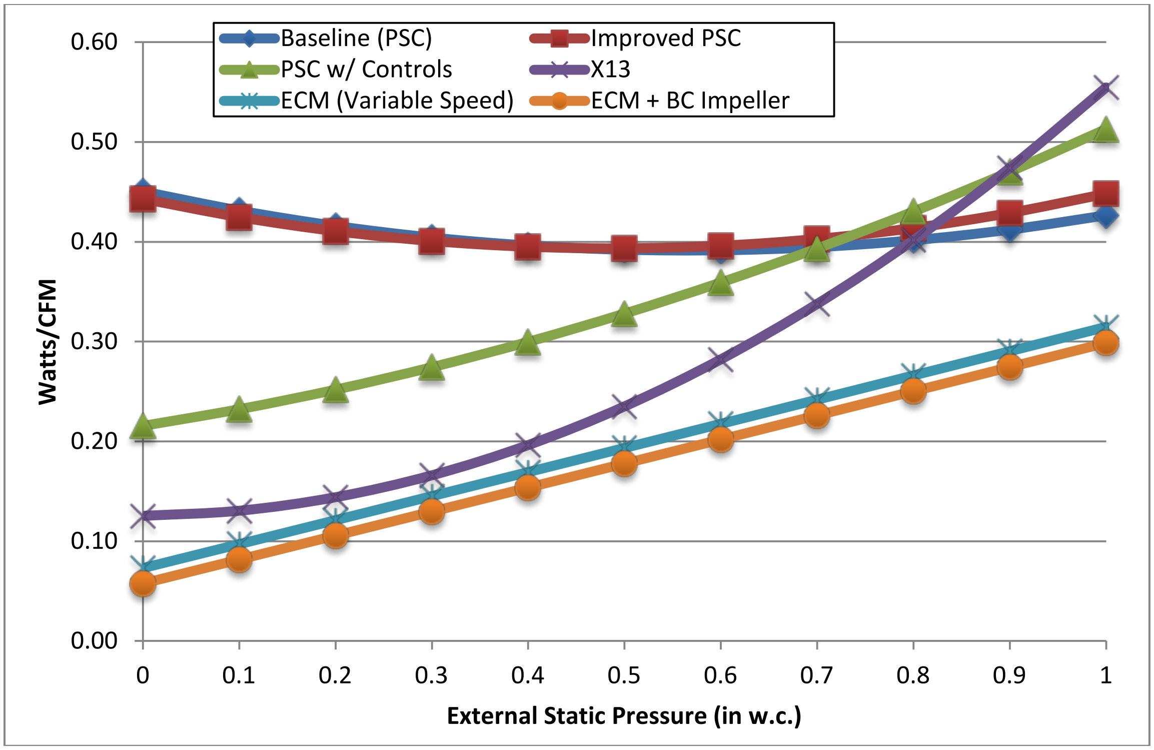

Figure 7.4.9 Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Constant Circulation Mode)

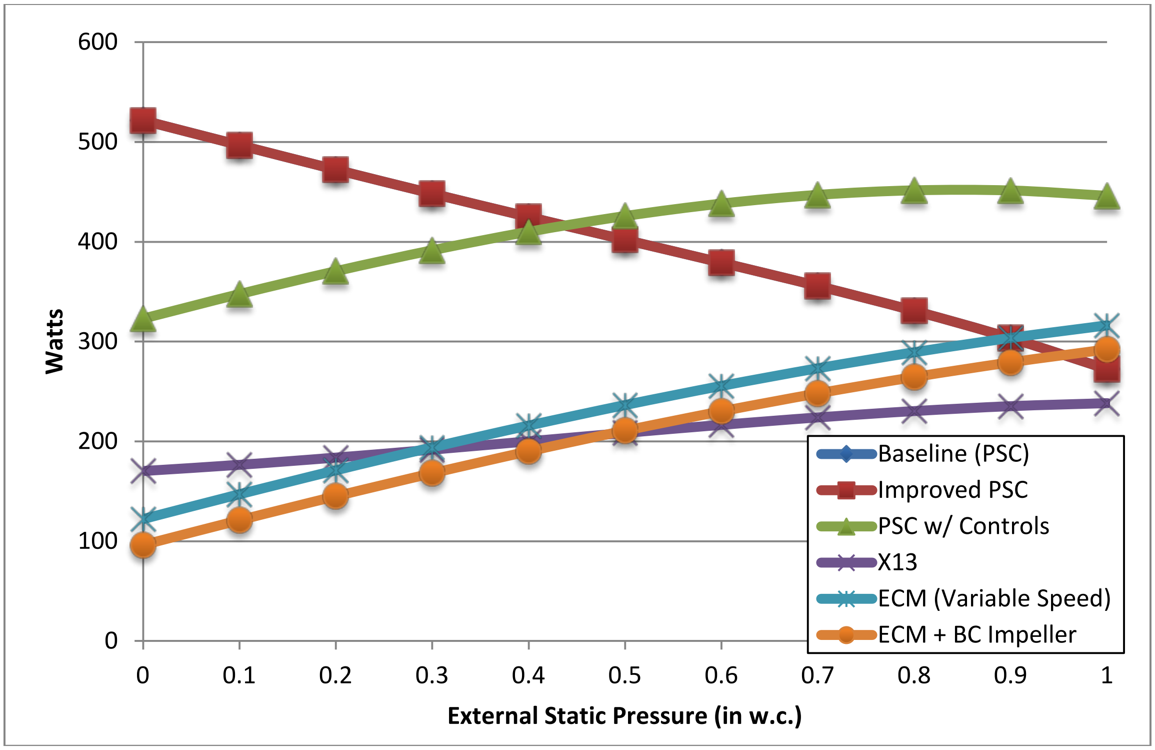

Figure 7.4.10 **Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Heating Mode)**

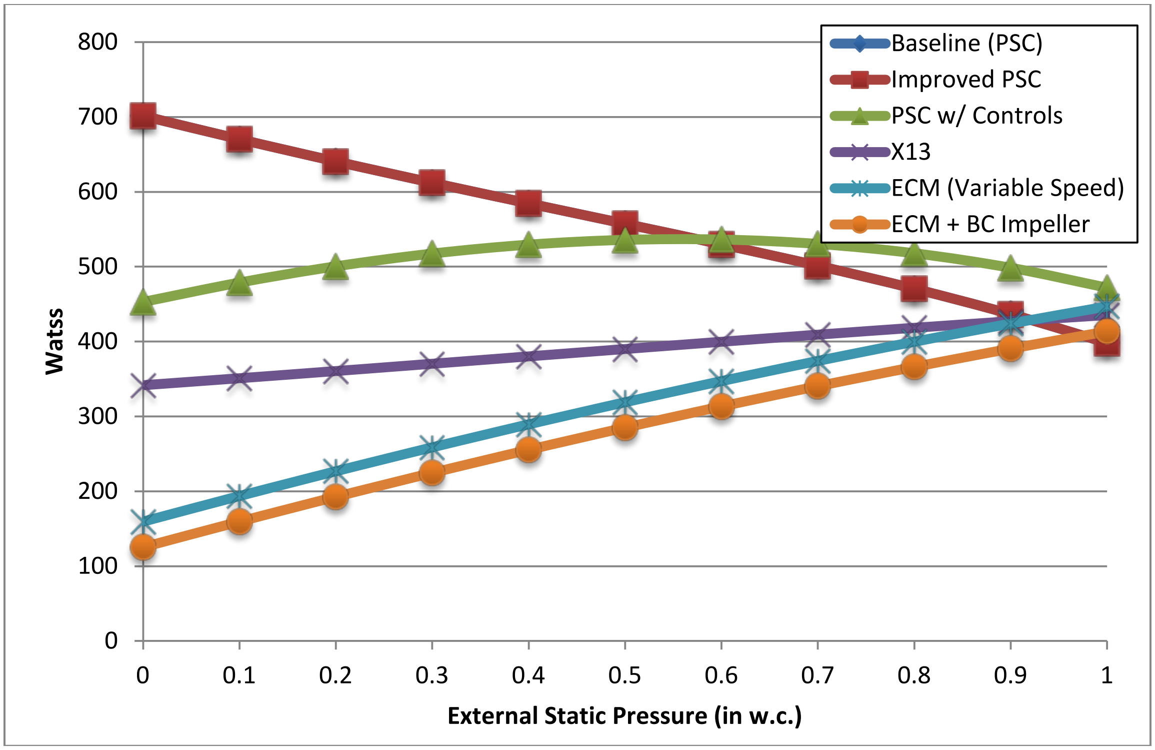

Figure 7.4.11 **Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Cooling Mode)**

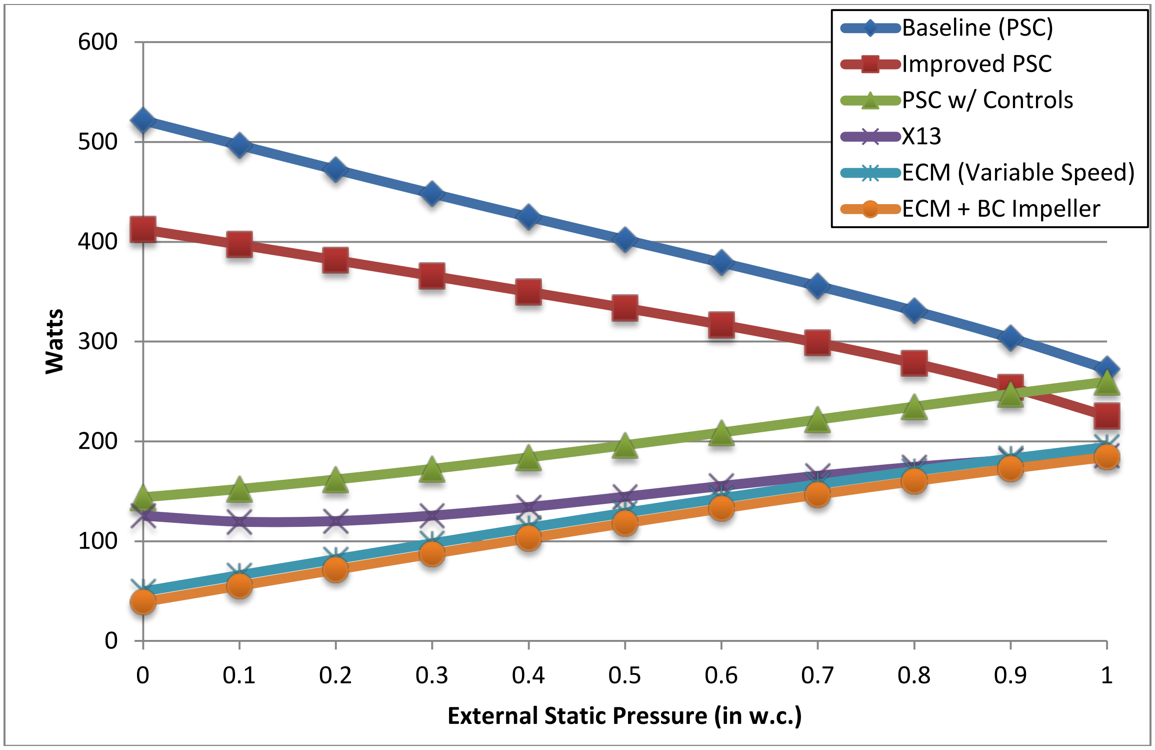

Figure 7.4.12 Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Constant Circulation Mode)

7.5 OPERATING HOURS

The DOE test procedures for furnaces and air conditioners were used to estimate heating and cooling mode operating hours for the furnace fan.

7.5.1 Heating Mode

DOE used the furnace test procedure[4] to determine furnace fan operating hours[b] during the heating season using the following formula:

$FFOH_{heating} = y \times BOH$, for single stage furnaces.

Where:

$FFOH_{heating}$ = furnace fan operating hours during the heating season, h,

y = ratio of blower on-time to average burner on-time, and

BOH = burner operating hours, h.

---

[b] Approach described for single stage operation only; see Appendix 7-E for multistage details

Using DOE's furnace test procedure, the ratio of blower on-time to average burner on-time (y) is calculated using the following formula:

$$y = 1 + \frac{t^{+} - t^{-}}{t_{ON}}$$

Where:

t^{+} = off-period (blower off delay) between burner shutdown and blower shutdown in minutes,

t^{-} = on-period (blower on delay) between burner shutdown and blower shutdown in minutes, and

t_{ON} = average burner on-time in minutes.

The blower off-delay (t^{+}) and blower on-delay (t^{-}) values are derived from manufacturer default blower delay settings for non-weatherized gas furnace models in the 2007 Furnace Database from DOE's 2007 Furnace and Boiler Final Rule.[5] The median values using these data are 120 seconds (or 2 minutes) for blower off-delay (t^{+}) and 30 seconds (or 0.5 minutes) for blower on-delay (t^{-}). The average burner on-time (t_{ON}) is equal to 3.87 minutes for single-stage furnaces with a fan delay based on DOE's furnace test procedure. Therefore, the ratio of blower on-time to average burner on-time (y) is estimated to be 1.39 using the median values.

The burner operating hours are calculated using the following formula[c]:

$$BOH = A * HHL, \text{ for single-stage furnaces.}$$

Where:

$A = 100{,}000 / [341300(y_P * PE + y_{IG} * PE_{IG} + y * BE) + Q_{IN} * Effy_{HS}]$,

y_P = ratio of induced or forced draft blower on-time to average burner on-time,

PE = burner (or draft inducer) electrical power input at full-load steady-state operation in kW,

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 = furnace fan electrical energy input rate in kW,

Q_{IN} = steady-state nameplate input rate in Btu/h,

---

[c] Approach described for single stage operation and a furnace without pilot ignition only; see Appendix 7-E for multistage operation details and derivation of the formula.

$Effy_{HS}$ = ratio of the average length of the heating season in hours to the average heating load hours,

HHL = house heating load in MMBtu/h.

Details about the calculation of the parameters used to calculate the value A (such as y_P, PE, y_{IG}, PE_{IG}, y, BE, Q_{IN}, and $Effy_{HS}$) are provided in appendix 7-E.

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. DOE 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:

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

Where:

$Q_{YR,RECS}$ = annual fuel consumption for heating based on RECS 2005 (kBtu/yr),

$AFUE_{ex}$ = AFUE of the existing furnace (see appendix 7-E),

3.412 = constant to convert kW to kBtu/hr,

BE_{ex} = power consumption of the blower motor of the existing furnace (kW),

BOH_{ex} = burner operating hours of existing household (hr/yr),

N = number of cycles per hour (set equal to 5 for furnaces),

t^{+} = off delay (seconds),

t^{-} = on delay (seconds), and

Adj_Factor = adjustment factors (discussed below).

DOE calculated BOH_{ex} for the existing furnace as:

$$BOH_{ex} = \frac{Q_{YR,RECS}}{Q_{IN,ex}}$$

Where:

BOH_{ex} = burner operating hours of existing household (hr/yr),

$Q_{YR,RECS}$ = as defined above (kBtu/yr), and

$Q_{IN,ex}$ = input capacity of the existing furnace (see appendix 7-E) (kBtu/hr).

DOE made adjustments to the house heating load to reflect the expectation that newly built housing units in 2018 will have a somewhat different house 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 National Energy Modeling System (NEMS) simulation performed for EIA's *AEO 2012*.[6] 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 2018 is 0.86 for replacements and 0.87 for new construction, which means that the average new home in 2018 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 7.5.1 shows the 2002-2011 average heating degree days (HDD) as well as the 2005 average HDD for the 29 geographical areas. The adjustment factors are calculated using the equation below.

$$Adj\_Factor_{average\_climate} = \frac{HDD_{10\_yr\_avg}}{HDD_{res\_stock\_2005}}$$

Where:

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

$HDD_{10\_yr\_avg}$ = 10-year average HDD (2002–2011) based on NOAA data[7] for the specific region where the housing unit is located.[d]

---

[d] The last 10-year average is used to normalize the HDD values, which is similar to what is done in AEO 2012.

Table 7.5.1 Heating Degree-Day Adjustment Factors

Geographical Area		Average HDD		Adjustment Factor
		2002-2011	2005	
1	CT, ME, NH, RI, VT	6576	6746	0.97
2	MA	6184	6467	0.96
3	NY	5770	5912	0.98
4	NJ	5105	5311	0.96
5	PA	5656	5806	0.97
6	IL	6047	5800	1.04
7	IN, OH	5687	5759	0.99
8	MI	6655	6608	1.01
9	WI	7365	6975	1.06
10	IA, MN, ND, SD	7857	7326	1.07
11	KS, NE	5455	4988	1.09
12	MO	4943	4622	1.07
13	VA	4224	4328	0.98
14	DE, DC, MD, WV	4500	4621	0.97
15	GA	2807	2709	1.04
16	NC, SC	3171	3180	1.00
17	FL	692	647	1.07
18	AL, KY, MS	3251	3153	1.03
19	TN	3757	3625	1.04
20	AR, LA, OK	2727	2434	1.12
21	TX	1855	1686	1.10
22	CO	7109	6949	1.02
23	ID, MT, UT, WY	6964	6744	1.03
24	AZ	1946	1788	1.09
25	NV, NM	3908	3581	1.09
26	CA	2575	2450	1.05
27	OR, WA	5267	5132	1.03
28	AK	NA	NA	1.03
29	HI	NA	NA	1.05

Note: Data for Alaska and Hawaii was not available. The region 27 adjustment factor was used for Alaska, while region 26 adjustment factor was used for Hawaii.

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 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 it was determined that a household had multiple furnaces, the house heating load was divided by the number of furnaces. Details are presented in appendix 7-D.

Table 7.5.2 shows the results for the range in adjusted heating load among sample households.

Table 7.5.2 Range of Adjusted Heating Load for Each Furnace Fan Product Class, million Btu/h

Product Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.31	143.44	20.25	3.99	9.40	16.29	26.78	49.08
Non-Weatherized, Condensing Gas Furnace Fan	0.36	215.43	37.94	9.57	23.21	34.74	48.37	77.91
Weatherized Gas Furnace Fan	0.36	156.88	20.34	3.85	9.50	16.42	26.55	49.57
Oil Furnace Fan	2.37	140.24	55.49	24.19	35.86	56.14	71.50	94.55
Electric Furnace / Modular Blower Fan	0.29	31.08	6.61	1.73	3.54	5.86	8.46	14.27
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	3.89	78.73	22.82	6.38	12.68	21.37	28.03	47.98
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	3.65	101.59	33.15	9.86	21.51	31.58	42.58	66.16
Manufactured Home Electric Furnace / Modular Blower Fan	0.30	29.41	7.90	1.80	4.10	6.77	10.51	19.17
Hydronic Air Handler Fan (Heat/Cool)	0.62	69.61	12.60	2.50	3.74	9.11	16.10	35.70

Table 7.5.3 shows the results for the baseline heating furnace fan operating hours among sample households.

Table 7.5.3 Range of Baseline Furnace Fan Heating Operating Hours for Each Furnace Fan Product Class, hours

Product Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	8	4826	434	93	207	355	560	1040
Non-Weatherized, Condensing Gas Furnace Fan	9	3749	591	159	336	508	746	1313
Weatherized Gas Furnace Fan	9	4835	393	87	188	321	505	916
Oil Furnace Fan	24	2448	716	230	438	680	945	1336
Electric Furnace / Modular Blower Fan	8	3322	274	68	138	211	336	696
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	100	2478	661	183	371	613	816	1396
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	77	2644	797	263	486	734	1018	1593
Manufactured Home Electric Furnace / Modular Blower Fan	9	1545	370	69	205	316	478	892
Hydronic Air Handler Fan (Heat/Cool)	15	2252	339	70	112	254	405	913

7.5.2 Cooling Mode

Furnace fan operating hours during the cooling season are calculated using the following formula:

$$FFOH_{cooling} = y_C \times COH$$

Where:

$FFOH_{cooling}$ = furnace fan operating hours during the cooling season;

y_C = ratio of blower on-time to average compressor on-time; and

COH = cooling operating hours.

Some furnace fans come with a cooling blower off delay feature. To account for this DOE estimated the ratio of blower on-time to average compressor on-time (y_C) using the following formula:

$$y_C = 1 + \frac{t_C^+ - t_C^-}{t_{ON,C}}$$

Where:

t_C^+ = off-period (blower off delay in cooling mode) between compressor shutdown and blower shutdown in minutes,

t_C^- = on-period (blower on delay in cooling mode) between compressor start-up and blower start-up in minutes, and

$t_{ON,C}$ = average compressor on-time in minutes.

The blower off-delay (t_C^+) and blower on-delay (t_C^-) values are derived from manufacturer default blower delay settings. The median values using these data are 45 seconds for blower off-delay (t_C^+) and 2 seconds for blower on-delay (t_C^-). The average burner on-time ($t_{ON,C}$) is equal to 6 minutes for single-stage central air conditioners based on DOE's central air conditioner test procedure. Using these assumptions, the ratio of blower on-time to average burner on-time (y_C) is estimated to be 1.12.

The cooling operating hours are calculated using the following formula:

$$COH = \frac{HCL}{CoolingCapacity} \times Adj\_Factor_{motor}$$

Where:

COH = cooling operating hours, hour/year,

HCL = house cooling load, MMBtu/year,

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h (see appendix 7-F), and

Adj_Factor_{motor} = adjustment factor to account for impact of motor heat on cooling operating hours.

The house cooling load (HCL) assumes that the household has a default furnace fan motor power output of 365 watts per 1000 CFM (used in the CAC test procedure). To properly account for increased or decreased cooling operating hours due to the higher or lower motor power output for different furnace fan efficiencies, DOE used the following equation to determine the adjustment factor:

$$Adj\_Factor_{motor} = \frac{1}{(1 + 3.412 \times \frac{\frac{365}{1000} * CFM - FFPcooling}{CoolingCapacity})}$$

Where:

$\frac{365}{1000} * CFM$ = default central air conditioner blower output used for calculating SEER, watts,

CFM = nominal cooling load CFM measured at 400 CFM per AC ton, cu. ft. per min,

$FFP_{cooling}$ = furnace fan power during the cooling operation, kW, and

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h.

The house cooling load is derived using the EIA's RECS 2005[8] cooling energy use data for the sample households as follows:

$$HCL = \frac{CoolingEnergyUseRECS \times SEER_{ex}}{CoolingCapacity_{ex}} \times Adj\_Factor$$

Where:

HCL = house cooling load, MMbtu/year,

$CoolingEnergyUseRECS$ = annual electricity consumption for cooling based on RECS 2005 (kBtu/yr),

$SEER_{ex}$ = SEER of the existing central air conditioner (see appendix 7-F),

$CoolingCapacity$ = cooling capacity of existing central air conditioner, Btu/h (see appendix 7-F), and

Adj_Factor = adjustment factors (discussed below).

DOE made adjustments to the house cooling load to reflect the expectation that newly built housing units in 2018 will have a somewhat different house cooling load than the housing units in the RECS 2005 sub-sample. Similar to furnace fan energy use calculation above, the building shell efficiency index sets the cooling load value at 1.00 for an average home in 2005 (by type) in each census division. DOE developed adjustment factors to represent the change in cooling 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 2018 is 0.94 for replacements and 1.01 for new construction. To add variability, the factor is varied by plus or minus 15 percent.

DOE also made adjustments to the HCL calculated using RECS 2005 data to reflect historical average climate conditions. Table 7.5.4 shows the 2002-2011 average heating degree days (HDD) as well as the 2005 average CDD for the 29 geographical areas. The adjustment factors are calculated using the equation below.

$$Adj\_Factor_{average\_climate} = \frac{CDD_{10\_yr\_avg}}{CDD_{res\_stock\_2005}}$$

Where:

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

$CDD_{10\_yr\_avg}$ = 10-year average CDD (2002–2011) based on NOAA data[7] for the specific region where the housing unit is located.

Table 7.5.4 Cooling Degree Day Adjustment Factors

Geographical Areas		Average CDD		Adjustment Factor
		2002-2011	2005	
1	CT, ME, NH, RI, VT	485	562	0.86
2	MA	522	576	0.91
3	NY	737	943	0.78
4	NJ	932	1121	0.83
5	PA	765	901	0.85
6	IL	924	1151	0.80
7	IN, OH	879	1027	0.86
8	MI	622	828	0.75
9	WI	552	747	0.74
10	IA, MN, ND, SD	637	792	0.81
11	KS, NE	1327	1491	0.89
12	MO	1325	1534	0.86
13	VA	1206	1250	0.97
14	DE, DC, MD, WV	1004	1034	0.97
15	GA	1832	1804	1.02
16	NC, SC	1654	1644	1.01
17	FL	3558	3436	1.04
18	AL, KY, MS	1813	1832	0.99
19	TN	1517	1576	0.96
20	AR, LA, OK	2266	2392	0.95
21	TX	2841	2908	0.98
22	CO	352	345	1.02
23	ID, MT, UT, WY	575	533	1.08
24	AZ	3171	3130	1.01
25	NV, NM	1753	1740	1.01
26	CA	923	837	1.10
27	OR, WA	235	227	1.04
28	AK	NA	NA	1.04
29	HI	NA	NA	1.10

Note: Data for Alaska and Hawaii was not available. The region 27 adjustment factor was used for Alaska, while region 26 adjustment factor was used for Hawaii.

DOE is calculating multi-stage cooling the same way as single-stage equipment (i.e., at the highest cooling mode only) and therefore used the same number of operating hours, since:

1) Multi-stage heating is not necessarily associated with multi-stage cooling equipment (e.g. multi-stage cooling is much less common than multi-stage furnace equipment); and
2) SEER already captures cases when multi-stage heating and cooling equipment are matched.

For households in which it is clear that the electricity use for cooling is associated solely with the use of central air conditioning equipment, DOE used the annual electricity consumption for cooling the household from RECS 2005. DOE adjusted the house cooling load for households that used both a central air conditioner and a room air conditioner. RECS 2005 reports the percentage of cooling energy consumption attributable to room air conditioners. DOE derived the house cooling load applicable to the central air conditioner by subtracting the estimated amount of cooling provided by the other cooling system.

Table 7.5.5 shows the range in cooling load among sample households for each furnace fan product class. The table also provides the fraction of households that have central air conditioning.

Table 7.5.5 Range of Annual Cooling Load for Each Furnace Fan Product Class, million Btu/h

Product Class	**Fraction with Central AC**	**Min**	**Max**	**Avg.**	**Percentiles**				
					5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	76.0%	0.11	107.34	14.55	1.97	6.31	11.84	18.94	37.02
Non-Weatherized, Condensing Gas Furnace Fan	72.1%	0.25	107.34	8.49	1.51	3.81	6.37	10.61	21.91
Weatherized Gas Furnace Fan	100.0%	0.11	107.34	14.16	1.97	5.95	11.61	18.77	34.63
Oil Furnace Fan	34.0%	1.30	15.57	7.60	2.23	3.76	6.32	11.43	15.57
Electric Furnace / Modular Blower Fan	85.1%	0.76	101.14	14.41	2.72	7.03	12.42	19.42	31.97
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	54.5%	1.27	22.87	9.72	1.90	4.62	8.40	15.63	21.88
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	41.1%	0.24	22.87	5.74	2.16	3.28	4.29	5.73	15.80
Manufactured Home Electric Furnace / Modular Blower Fan	78.3%	1.22	29.17	13.33	2.86	9.23	12.87	18.30	26.27
Hydronic Air Handler Fan (Heat/Cool)	100.0%	0.78	31.14	9.87	0.78	3.31	6.31	17.15	24.66

Table 7.5.6 shows the results for the baseline furnace fan cooling operating hours among sample households.

Table 7.5.6 Range of Baseline Furnace Fan Cooling Operating Hours for Each Furnace Fan Product Class, hours

Product Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	0	7879	902	0	136	729	1332	2563
Non-Weatherized, Condensing Gas Furnace Fan	0	7127	420	0	0	290	591	1379
Weatherized Gas Furnace Fan	0	8240	1162	174	552	970	1532	2877
Oil Furnace Fan	0	1035	139	0	0	0	214	663
Electric Furnace / Modular Blower Fan	0	8760	1240	0	455	1100	1760	3178
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	0	3633	625	0	0	302	1052	2331
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	0	3506	240	0	0	0	359	1078
Manufactured Home Electric Furnace / Modular Blower Fan	0	4330	1323	0	322	1367	2017	3028
Hydronic Air Handler Fan (Heat/Cool)	0	5885	1157	0	423	962	1527	3113

7.5.3 Constant Circulation Mode

The amount of constant-circulation hours are based on data from surveys. One survey was conducted by researchers in Wisconsin in 2003.[9] The second survey was conducted by the Center for Energy and the Environment (CEE) in Minnesota, the results of which were provided by CEE in a written comment that is included in the docket for the furnace fan test procedure.[e] DOE combined both studies and derived average annual furnace fan constant-circulation operating hours for each survey, as shown in Table 7.5.5.

DOE assumed a value for average number of fan constant-circulation hours for each survey response. For “no constant circulation” responses, DOE assumed zero constant-circulation hours. For “year-round” responses, DOE assumed 100 percent of non-heating or cooling furnace fan operating hours, which DOE calculated by subtracting furnace fan heating and cooling operating hours from the total annual hours (8,760). For “during heating season”

---

[e] Docket Number EERE-2010-BT-STD-0011. (CEE, No. 22 at pp. 1-3)

responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For "during cooling season" responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For other or "some constant circulation" responses, DOE assumed 5 percent of non-heating or cooling furnace fan operating hours.

DOE did not use these data directly, because it believes they are not representative of consumer practices for the U.S. as a whole. In Wisconsin and Minnesota, many homes have low air infiltration, and there is a high awareness of indoor air quality issues, which leads to significant use of constant circulation. To account for this, DOE developed separate regional fractions that took into account information from manufacturer product literature and regional climate conditions. Furnace fan manufacturer literature states that constant circulation fan operation is not recommended for humid climates. Therefore, DOE assumed that the fraction using constant circulation would only be 10 percent in the South Hot Humid region[f] of what was reported in the Wisconsin and Minnesota studies (i.e. 3.1 percent compared to 31 percent in the studies). For the rest of the country (North and South Hot Dry regions), DOE assumed that the fraction using constant circulation would be 50 percent of what was reported in the Wisconsin and Minnesota studies (i.e. 15.5 percent compared to 31 percent in the studies).

Table 7.5.7 Results from Constant-Circulation Use Studies and Estimated National Constant-Circulation Hours

How Often is Constant Circulation Fan Used?	Combined Data from Studies		Estimated North and South-Hot Dry Region Fractions for LCC Analysis	Estimated South-Hot Humid Region Fractions for LCC Analysis
	Number of Households	Percentage (%)		
No constant fan	69	68%	84%	97%
Year-round	14	14%	7%	1%
During heating season	4	4%	2%	0.4%
During cooling season	4	4%	2%	0.4%
Other (some constant fan)	10	10%	5%	1%
Total	101	100%	100%	100%

Table 7.5.8 shows the results for the average baseline constant circulation furnace fan operating hours among sample households.

---

[f] Regions as defined in the Furnace and Central Air Conditioner Final Rule.[10]

Table 7.5.8 Average Baseline Constant Circulation Furnace Fan Operating Hours for Each Furnace Fan Product Class, hours

Product Class	Average
Non-Weatherized, Non-Condensing Gas Furnace Fan	316
Non-Weatherized, Condensing Gas Furnace Fan	558
Weatherized Gas Furnace Fan	249
Oil Furnace Fan	552
Electric Furnace / Modular Blower Fan	257
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	342
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	567
Manufactured Home Electric Furnace / Modular Blower Fan	213
Hydronic Air Handler Fan (Heat/Cool)	412

7.6 FURNACE FAN STANDBY ENERGY USE

Furnaces with higher efficiency furnace fans tend to have higher standby energy use. To account for this effect, for all products other than hydronic air handlers, DOE first estimated the difference in power consumption between the baseline efficiency level (EL 0) and the higher furnace fan efficiencies.[g] This difference in power consumption was estimated to be 0 watts for EL1 and EL2 and 3 watts for EL3 and above, based on test data from the 2011 Furnace rulemaking.[10] The power consumption is then multiplied by the standby hours calculated for each sampled household.

Hydronic air handlers are the only product in this rulemaking that have no standby and off-mode power included in existing test procedures. The proposed furnace fan test procedure incorporates test methods to measure the standby mode and off mode energy of hydronic air handlers. In this rulemaking, an integrated metric was developed that combines the steady-state standby mode and off mode electrical energy consumption measurements for hydronic air handlers with the active mode energy use for this product (see chapter 5 for additional details). The LCC analysis uses the integrated metric for hydronic air handlers and thus accounts for the standby use associated with this product.

---

[g] EISA 2007 requires that standby energy consumption be considered in energy consumption unless the test procedure already accounts for standby mode and off mode energy use. Furnace fans are integrated in the electrical systems of the HVAC products in which they are used and controlled by the main control board. Therefore, there is no standby mode and off mode energy use associated with furnace fans used in these products that would not already be measured by the established test procedures.

7.7 CHANGES IN HEATING AND AIR-CONDITIONING ENERGY USE WITH MORE-EFFICIENT FURNACE FANS

DOE accounted for the effect of improved furnace fan efficiency on the heating and cooling load of the sample homes. With improved furnace fan efficiency there is less heat from the motor, which means that the heating system needs to operate more and the cooling system needs to operate less.

7.7.1 Impact on Furnace Fuel 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[h]:

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

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

Recall from section 7.5.1 that BOH is calculated using BE (furnace fan electrical energy input rate), which is equal to the $FFP_{heating}$ (furnace fan power during the heating operation) variable calculated for each furnace fan efficiency level. The differential in fuel use between the baseline equipment (EL 0) and more efficient design options (EL 1 and above) for each efficiency level is shown in the results tables in section 7.8.

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:

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

Where:

BOH = as defined above,

---

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

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

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).

The differential in non-furnace fan furnace electricity consumption between the baseline equipment (EL 0) and more efficient design options (EL 1 and above) for each efficiency level is included in the total electricity use shown in the results tables in section 7.8.

The details for calculating furnace energy consumption at each considered fan efficiency level appear in appendix 7-E.

7.7.2 Impact on Central Air Conditioner 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 less cooling operation by the central air conditioner. Since the cooling load of each sample housing unit is known, it is possible to estimate what the air conditioner energy consumption would be if more efficient fan equipment, rather than the baseline equipment, were used in each housing unit.

DOE calculated the non-furnace fan cooling energy using the following formula:

$$CoolingEnergyUse_{non-furnace\_fan} = COH \times Power_{non-furnace\_fan}$$

Where:

COH = as defined above in section 7.5.2,

$Power_{non\text{-}furnace\_fan}$ = power consumption of all non-furnace fan components of the central air conditioner (kW).

DOE calculated the non-furnace fan cooling power consumption as follows:

$$Power_{non-furnace\_fan} = (\frac{CoolingCapacity}{SEER} - \frac{365}{1000} * CFM)$$

Where:

$\frac{365}{1000} * CFM$ = default central air conditioner blower output, watts,

CFM = nominal cooling load CFM measured at 400 CFM per AC ton, CFM,

$SEER$ = SEER of central air conditioner, Btu/(W.h), and

CoolingCapacity = cooling capacity of air conditioner, Btu/h.

The differential in non-furnace fan furnace electricity consumption between the baseline equipment (EL 0) and more efficient design options (EL 1 and above) for each efficiency level is included in the total electricity use shown in the results tables in section 7.8.

The details for calculating the central air conditioner energy consumption at each considered fan efficiency level appear in appendix 7-F.

7.8 SUMMARY OF ENERGY USE 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 fan product class. For the efficiency levels above the baseline the electricity use includes the difference from the baseline in the non-furnace fan cooling energy use, non-furnace fan furnace electricity consumption, and furnace standby energy use. Thus, the electricity savings account for these indirect impacts on the higher furnace fan efficiency levels.

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

Table 7.8.1 Average Annual Energy Consumption and Savings for Furnace Fans Used in Non-Weatherized Gas Furnaces

Efficiency Level	**Non- Condensing Furnace**			**Condensing Furnace**		
	Annual Electricity Use (kWh)	**Electricity Use Savings (kWh)**	**Additional Fuel Use (MMBtu)**	**Annual Electricity Use (kWh)**	**Electricity Use Savings (kWh)**	**Additional Fuel Use (MMBtu)**
Baseline (PSC)	798	NA	NA	768	NA	NA
Improved PSC	784	13	0.00	736	32	0.00
PSC w/ Controls	779	19	-0.04	643	125	-0.03
X13	508	290	0.28	421	347	0.39
ECM + Multi-Stage	532	265	0.33	410	357	0.44
ECM + Backward-curved Impeller	478	319	0.36	372	396	0.48

Table 7.8.2 Average Annual Energy Consumption and Savings for Furnace Fans Used in Weatherized Gas Furnace Fans and Oil-Fired Furnaces

Efficiency Level	**Weatherized Gas Furnace**			**Oil-Fired Furnace**		
	Annual Electricity Use (kWh)	**Electricity Use Savings (kWh)**	**Additional Fuel Use (MMBtu)**	**Annual Electricity Use (kWh)**	**Electricity Use Savings (kWh)**	**Additional Fuel Use (MMBtu)**
Baseline (PSC)	886	NA	NA	639	NA	NA
Improved PSC	879	7	0.00	606	32	-0.01
PSC w/ Controls	833	54	0.03	471	168	0.07
X13	516	370	0.29	310	329	0.56
ECM + Multi-Stage	476	411	0.34	282	357	0.65
ECM + Backward-curved Impeller	420	466	0.37	255	384	0.71

Table 7.8.3 Average Annual Energy Consumption and Savings for Furnace Fans Used in Manufactured Home Gas Furnaces

Efficiency Level	**Non- Condensing Furnace**			**Condensing Furnace**		
	Annual Electricity Use (kWh)	**Electricity Use Savings (kWh)**	**Additional Fuel Use (MMBtu)**	**Annual Electricity Use (kWh)**	**Electricity Use Savings (kWh)**	**Additional Fuel Use (MMBtu)**
Baseline (PSC)	545	NA	NA	572	NA	NA
Improved PSC	533	12	0.00	545	27	-0.01
PSC w/ Controls	431	114	0.15	399	172	0.22
X13	297	247	0.46	267	304	0.61
ECM + Multi-Stage	236	309	0.50	211	360	0.68
ECM + Backward-curved Impeller	211	333	0.53	192	380	0.71

Table 7.8.4 Average Annual Energy Consumption and Savings for Furnace Fans Used in Electric Furnaces and Manufactured Home Electric Furnaces

Efficiency Level	Electric Furnace		Manufactured Home Electric Furnace	
	Annual Electricity Use (kWh)	Net Electricity Use Savings* (kWh)	Annual Electricity Use (kWh)	Net Electricity Use Savings* (kWh)
Baseline (PSC)	594	NA	529	NA
Improved PSC	585	9	526	4
PSC w/ Controls	591	2	446	83
X13	440	154	365	164
ECM + Multi-Stage	455	139	295	234
ECM + Backward-curved Impeller	416	178	268	261

* Accounts for additional energy used for heating.

Table 7.8.5 Average Annual Energy Consumption and Savings for Furnace Fans Used in Hydronic Air Handlers

Efficiency Level	Annual Electricity Use (kWh)	Net Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)
Baseline (PSC)	838	NA	NA
Improved PSC	827	11	0.00
PSC w/ Controls	844	-6	-0.04
X13	533	305	0.25
ECM + Multi-Stage	367	471	0.31
ECM + Backward-curved Impeller	329	509	0.32
Switching Mode Power Supply	309	529	0.32
Toroidal Transformer	296	543	0.32

REFERENCES

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

2. Michael R. Lindeburg, P., *Fans and Ductwork.* In *Mechanical Engineering Reference Manual for the PE Exam*, P. Michael R. Lindeburg, Editor. Tenth ed. 1997. Professional Publications, Inc.: Belmont, CA. p. 20-1, 20-26

3. American Society of Heating Refrigeration and Air-Conditioning Engineers, *ASHRAE 1997 Handbook - Fundamentals*. 1997. Atlanta, GA.p. 3.12.

4. 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.

5. U.S. Department of Energy - Energy Efficiency & Renewable Energy, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Furnaces and Boilers*, 2007. Washington, DC.

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

7. National Oceanic and Atmospheric Administration, *NNDC Climate Data Online,* (Last accessed February 2009.) <www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp>

8. U.S. Department of Energy: Energy Information Administration, *Residential Energy Consumption Survey (RECS),* 2005. (Last accessed September, 2011.) Public use data files. <http://www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html>

9. Pigg, S., *Electricity Use by New Furnaces: A Wisconsin Field Study,* October, 2003. Energy Center of Wisconsin. Madison. Report No. 230-1. prepared for Focus on Energy. <http://www.ecw.org/ecw/productdetail.jsp?productId=499&numPerPage=1000&sortAttribute=initiative.title&sortOrder=ASC>

10. U.S. Department of Energy - Energy Efficiency & Renewable Energy, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Furnaces, Central Air Conditioners, and Heat Pumps*, 2011. Washington, DC.