APPENDIX 7-B. SYSTEM CURVE DERIVATION FOR FURNACE FANS

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APPENDIX 7-B. SYSTEM CURVE DERIVATION FOR FURNACE FANS

7-B.1 INTRODUCTION

The system curve of the air-distribution system is a graphical representation of the airflow through the supply and return ducts in a house for different static pressures. The airflow and pressure drop at which the furnace will operate can be determined by the intersection of the system curve of the house and the fan curve of the furnace fan.[1] Figure 7-B.1.1 shows an example of a plot of system curves intersecting a furnace fan curve.

DOE modeled system curves as quadratic curves, which is standard in heating, ventilation, and air conditioning (HVAC) design and fan selection handbooks.[2] 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 = static pressure (in.w.g.), and
α = a constant coefficient.

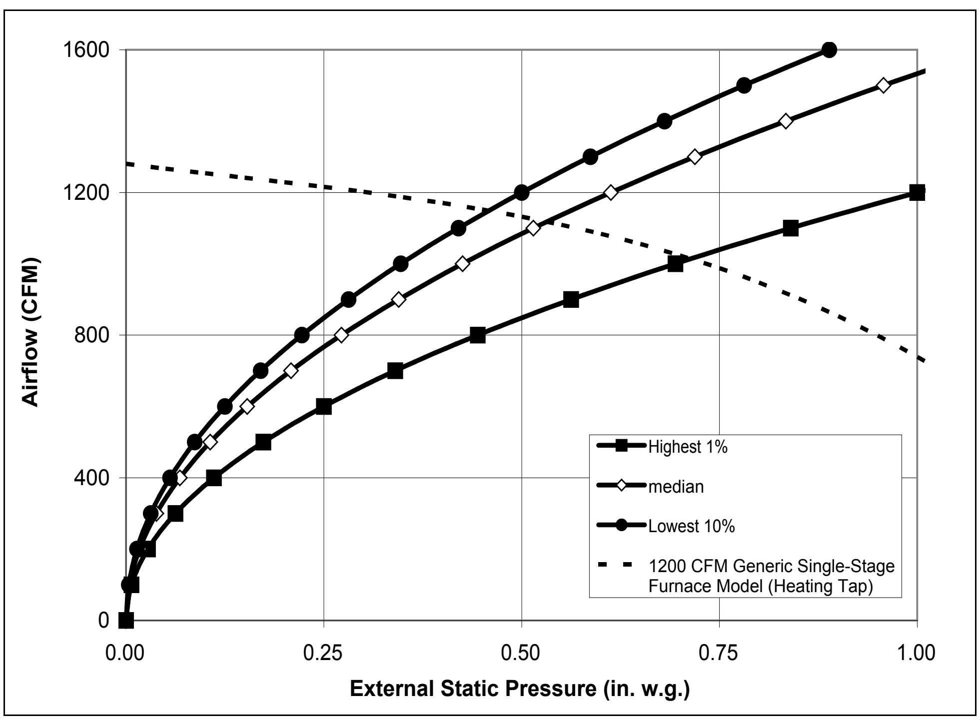

Figure 7-B.1.1 Sample of System Curves with a Typical Fan Curve

7-B.2 FURNACE FANS REFERENCE SYSTEM CURVES

In DOE's proposed furnace fan test procedure, the reference system curve is defined as follows:

$$K_{ref} = \frac{ESP_{ref}}{Q_{max}^{\ 2}}$$

where:

K_{ref} = a constant that characterizes the reference system;
ESP_{ref} = Reference System External Static Pressure (ESP); and
$Q_{max} = a_{max} ESP_{ref}^{\ 2} + b_{max} ESP_{ref} + c_{max}$

The operating point in the maximum airflow-control setting is defined by the reference system criteria: ESP_{ref} and Q_{max}. External static pressure (ESP) is the portion of the fan total pressure that exists by virtue of degree of compression external to the HVAC product in which the furnace fan is contained. ESP does not include the pressure drop across appurtenances internal to the HVAC product. In the field, ESP is measured as the difference in pressure between the HVAC product inlet and outlet points, and includes the ductwork, inlet filter, and coil outside of the unit if applicable.

In the field there are four distinct reference system ESPs associated with specific equipment:

a) **Units with Cooling Option (Coil Outside of Unit):** This includes non-weatherized gas furnaces and oil-furnaces. Reference system is measured at the maximum default cooling airflow control setting. ESP includes a fraction of units in the field that include the evaporator coil.

b) **Heating only units:** This includes heating-only hydronic air-handlers.[a] Reference system is measured at the default heating airflow control setting. ESP does not include evaporator coil.

b) **Units with Coil inside Unit:** This includes weatherized gas and oil-fired furnaces. Reference system is measured at the maximum default cooling airflow control setting. ESP does not include evaporator coil.

c) **Manufactured Home Units:** This includes manufactured home gas or oil-fired furnaces. Reference system is measured at the cooling airflow control setting for these units. ESP includes a fraction of units in the field that include the evaporator coil.

[a] Units like First Company's FWA series: http://www.firstco.com/products/fwa_hw.asp.

7-B.3 FIELD STUDIES

DOE gathered field data from available studies and research reports to determine an appropriate ESP value to propose for the reference system. DOE compiled over 1300 field ESP measurements from 27 studies that included furnace fans in single family and manufactured homes in different regions of the country. Table 7-B.3.1 summarizes the field data for single family homes at cooling airflow setting. Table 7-B.3.2 summarizes the field data for manufactured homes at cooling airflow setting. The average measured ESP values are the actual values measured in each study. Some studies did not include the evaporator coil or filter in the ESP measurement. To account for this DOE added the filter pressure drop to all adjusted ESP values ("Adj. w/o Coil" and "Adj. w/ Coil"). In addition, DOE subtracted the pressure drop of the evaporator coil for "Adj. w/o Coil" and added the pressure drop of the evaporator coil for "Adj. w/ Coil" when appropriate. See next section for the determination of average filter and evaporator pressure drop values.

Table 7-B.3.1 Single Family Field Data ESP at Cooling Airflow Setting

Study	Sample Size	Average ESP *(in. w.c.)*			Notes
		Measured	Adj. w/o Coil	Adj. w/ Coil	
Blasnik et al. 1995[3]	40	0.41	0.41	0.61	1
Blasnik et al. 1996[4]	28	0.48	0.48	0.68	1
Parker 1997[5]	9	0.55	0.55	0.75	1
Proctor et al. 1995[6]	40	0.53	0.53	0.73	1
Proctor et al. 1996[7]	36	0.51	0.51	0.71	1
Proctor et al. 1998[8]	15	0.45	0.45	0.65	1
Proctor 1998[9]	36	0.42	0.42	0.62	1
Proctor 2005[10]	78	0.48	0.48	0.68	1
Proctor et al. 2007[11]	4	1.01	0.81	1.01	
Proctor 2000[12]	5	0.50	0.50	0.70	1
Proctor 2001[13]	69	0.54	0.54	0.74	1
Proctor 2003[14]	69	0.53	0.53	0.73	1
Proctor 1996a[15]	8	0.45	0.45	0.65	1
Proctor 1996b[16]	92	0.31	0.52	0.73	1,2
Wilcox et. al. 2006[17]	51	0.77	0.57	0.77	
Dickenhoff 1998[18]	13	0.54	0.54	0.74	1
Baylon et al. 2005[19]	148	0.36	0.57	0.78	1,2
Ueno 2010 (2008 Study)[20]	4	0.90	0.70	0.90	
Ueno 2010 (2009 Study)[20]	1	1.12	0.92	1.12	
Pigg 2008 (2007 Study)[21]	76	0.73	0.53	0.73	
Pigg 2008 (2005 Study)[21]	37	0.53	0.53	0.73	1
Pigg 2003[22]	31	0.55	0.55	0.75	1
Weighted Average	890	0.50	0.52	0.73	

1 ESP measurement includes Coil
2 ESP measurement includes Filter

Table 7-B.3.2 Manufactured Home Field Data

Study	Sample Size	Average ESP *(in. w.c.)*			Notes
		Measured	Adj. w/o Coil	Adj. w/ Coil	
Baylon et al. 1995[23]	164	0.18	0.18	0.38	1
Davis et al. 2000[24]	36	0.23	0.23	0.43	1
Davis et al. 2004[25]	100	0.12	0.12	0.32	1
Ecotope 2006[26]	69	0.23	0.23	0.43	1
Baylon et al. 2009[27]	89	0.12	0.12	0.32	1
Weighted Average	458	0.17	0.17	0.37	

1 *ESP measurement does not include Coil*
2 *ESP measurement does not include Filter*

7-B.4 DETERMINATION OF REFERENCE SYSTEM CURVES FOR DOE FURNACE FAN TEST PROCEDURE

Using field data from 3 studies, DOE estimated average filter and coil pressures in order to adjust field data that did not include the filter or coil. On average, the pressure drop measured for the evaporator coil was 0.20 in w.c. (as shown in Table 7-B.4.1) and the pressure drop for the filter was 0.21 in w.c. (as shown in Table 7-B.4.2).

Table 7-B.4.1 Evaporator Coil Pressure Data

Study	Sample Size	Average Pressure Drop *(in. w.c.)*
Pigg 2008 (2007 Study)[21]	75	0.20
Pigg 2008 (2005 Study)[21]	19	0.19
Wilcox et. al. 2006[17]	51	0.21
Weighted Average	145	0.20

Table 7-B.4.2 Filter Pressure Data

Study	Sample Size	Average Pressure Drop *(in. w.c.)*
Pigg 2008 (2007 Study)[21]	76	0.25
Pigg 2008 (2005 Study)[21]	37	0.21
Wilcox et. al. 2006[17]	46	0.16
Weighted Average	159	0.21

Using EIA's RECS 2005 data, DOE estimated the fraction of furnace installations with and without a coil in the ESP. For units with a cooling option (coil outside unit), DOE looked at all households with either a gas or oil-fired furnace and determined that 72.9% of these households had central air-conditioners.[b] For manufactured home units DOE looked at all manufactured home households with either a gas or oil-fired furnace and determined that 50.2% of these households had central air-conditioners. DOE estimated that these two fractions would represent the fraction of installations with evaporator coil in the ESP. Table 7-B.4.3 data shows the results for each of the distinct reference systems. None of the heating only units or units with coil inside are assumed to have an evaporator coil in the ESP.

Table 7-B.4.3 Fraction of Installations with Evaporator Coil in ESP

Product Description	Fraction of Installations with Evaporator Coil in ESP
Units with Cooling Option (Coil Outside Unit)	72.9%
Heating only units	0%
Units with Coil inside	0%
Manufacture Home	50.2%

Table 7-B.4.4 presents the final results of this analysis for each distinct reference system curve used in DOE's NOPR furnace fan test procedure. The results take into account the fraction of units with the coil included in the ESP.

Table 7-B.4.4 Summary of Weighted Average Reference System ESP Values

Product Description	Airflow Control Setting	Weighted Average ESP *(in. w.c.)*
Units with Cooling Option (Coil Outside Unit)	Cooling	0.65
Heating only units	Heating	0.50
Units with Coil inside	Cooling	0.50
Manufacture Home[c]	Cooling	0.30

(All Values Rounded)

The results are determined as follows:

1) for units with cooling option (coil outside unit), 72% of the furnace fans are installed with CAC (see Table 7-B.4.3), so 72% * 0.73 in. w.c. + 28% * 0.52 in. w.c., which is rounded to 0.65 in w.c.;
2) for manufactured homes furnace fans, 50% of the furnaces are installed with CAC (see Table 7-B.4.3), so 50% * 0.17 in. w.c. + 50% * 0.37 in. w.c., which is rounded to 0.30 in w.c.;
3) for heating only units and units with coil inside the weighted average ESP is rounded from 0.52 in. w.c. to 0.50 in w.c.

[b] For simplicity, electric furnaces are excluded since they are mostly associated with heat pumps. Also, RECS does not provide information to distinguish which households have hydronic air-handlers. Adding electric furnaces and hydronic equipment will increase the fraction of households with central air-conditioners, since this equipment tends to be located in warmer climates.

[c] Manufactured home external static pressure is much smaller due to the fact there is no return air ductwork in manufactured homes. Also HUD requirements stipulate that the ductwork for cooling should be set at 0.3 in. w.c.

7-B.4.2 Other reference system curves

Manufacturers Rating for Cooling – 0.5 in.w.c. at cooling airflow setting [manufacturer product literature]
DOE test procedure for Cooling - 0.1 to 0.2 in.w.c. for conventional split systems [Subpart B Appendix M of Title 10 Part 430 of the Code of Federal Regulations (CFR)]
DOE test procedure for Furnaces – 0.12 – 0.58 in.w.c. minimum static pressure values depend on equipment type as follows [Subpart B Appendix N of Title 10 Part 430 of the Code of Federal Regulations (CFR), which references ANSI/ASHRAE 103, table 4 and 5]:

a) Gas furnaces and Oil furnaces (w/ temp rise greater than 65 deg) - 0.18 to 0.33 in. w.c. (depending on input capacity)
b) Oil furnace (w/ temp rise less than or equal to 65 deg) – 0.38 - 0.58 in w.c. (depending on input capacity)
c) Electric furnaces - 0.12 to 0.25 in.w.c. (dependant on Standard Air Quantity (SCFM))

Canadian Furnace Fan Standard – 0.3 inches WC (Recommended practice) and 0.6 inches WC (Common Practice) at heating airflow setting [CSA. C823-11: Performance of air handlers in residential space conditioning systems. May 2011.]
HUD for Manufactured Home with comfort cooling certificate – 0.3 inches WC at cooling airflow setting [Title 24 of the HUD code PART 3280--Manufactured Home Construction and Safety Standards, Part 3280.715 (a) (3) (ll)]

7-B.5 DISRIBUTION OF SYSTEM CURVES USED IN LCC ANALYSIS

For the LCC analysis, DOE used the field data above to generate normal distributions for the various equipment installation variations as shown in Table 7-B.5.1. Figure 7-B.5.1 to Figure 7-B.5.4 show the external static pressure distributions used in the analysis.

Table 7-B.5.1 Reference System ESP Distribution Parameters Values by Product Class

Product Classes	Household Has Central AC	Average ESP *(in. w.c.)*	Standard Deviation *(in. w.c.)*
Non-Weatherized Gas Furnace Fan; Oil Furnace Fan; Electric Furnace / Modular Blower Fan; Hydronic Air Handler Fan (Heat/Cool)	Yes	0.73	0.12
	No	0.52	0.12
Weatherized Gas Furnace Fan	Yes	0.52	0.12
Manufactured Home Non-Weatherized Gas Furnace Fans; Manufactured Home Electric Furnace / Modular Blower Fan	Yes	0.37	0.06
	No	0.17	0.06

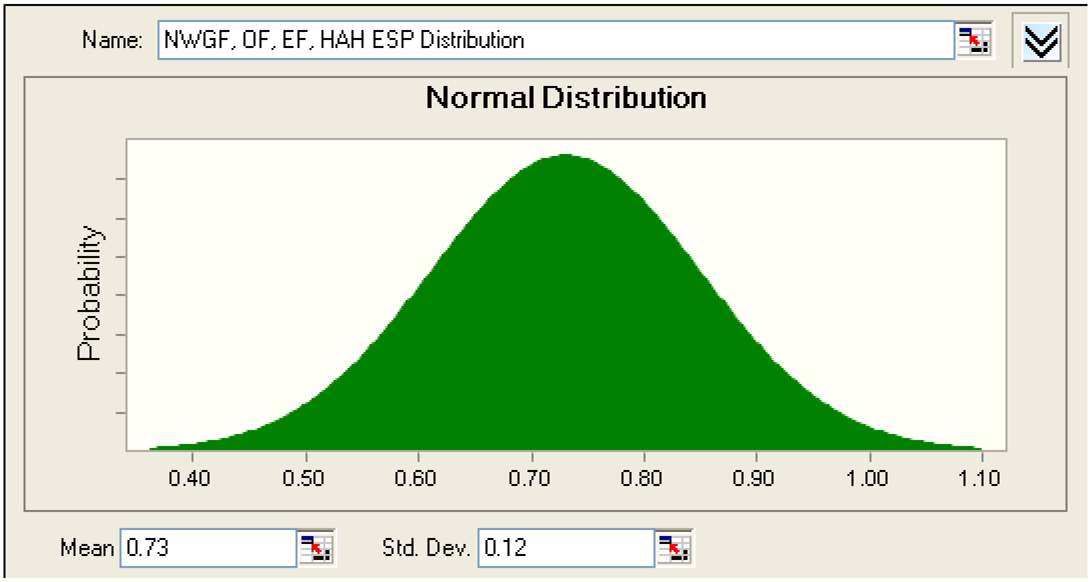

Figure 7-B.5.1 External Static Pressure Distribution for Non-Weatherized Gas Furnace Fan; Oil Furnace Fan; Electric Furnace / Modular Blower Fan; Hydronic Air Handler Fan (Heat/Cool) with Central Air Conditioning

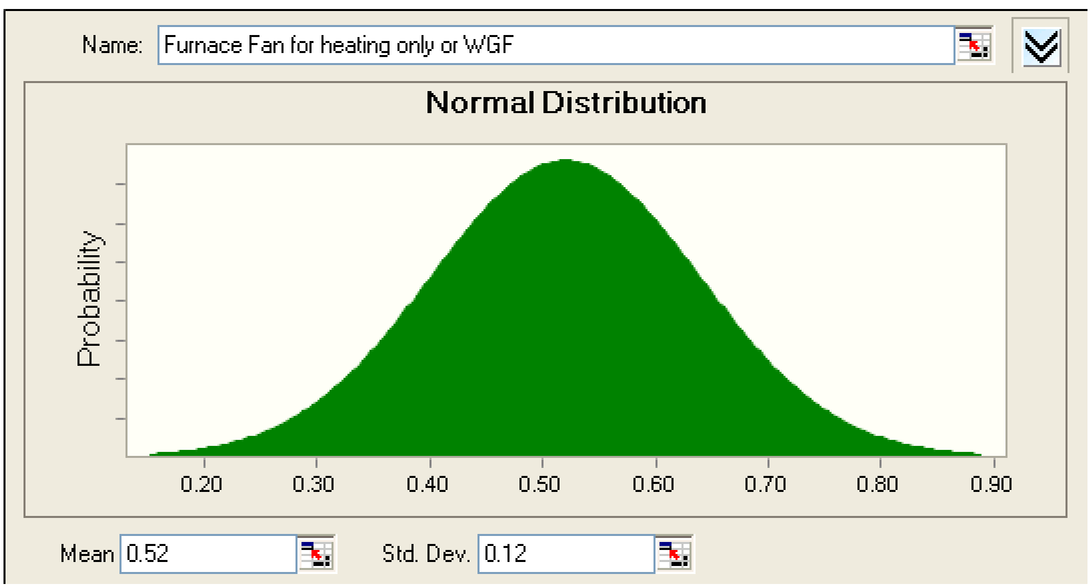

Figure 7-B.5.2 External Static Pressure Distribution for Non-Weatherized Gas Furnace Fan; Oil Furnace Fan; Electric Furnace / Modular Blower Fan; Hydronic Air Handler Fan (Heat/Cool) without Central Air Conditioning or Weatherized Gas Furnace Fan

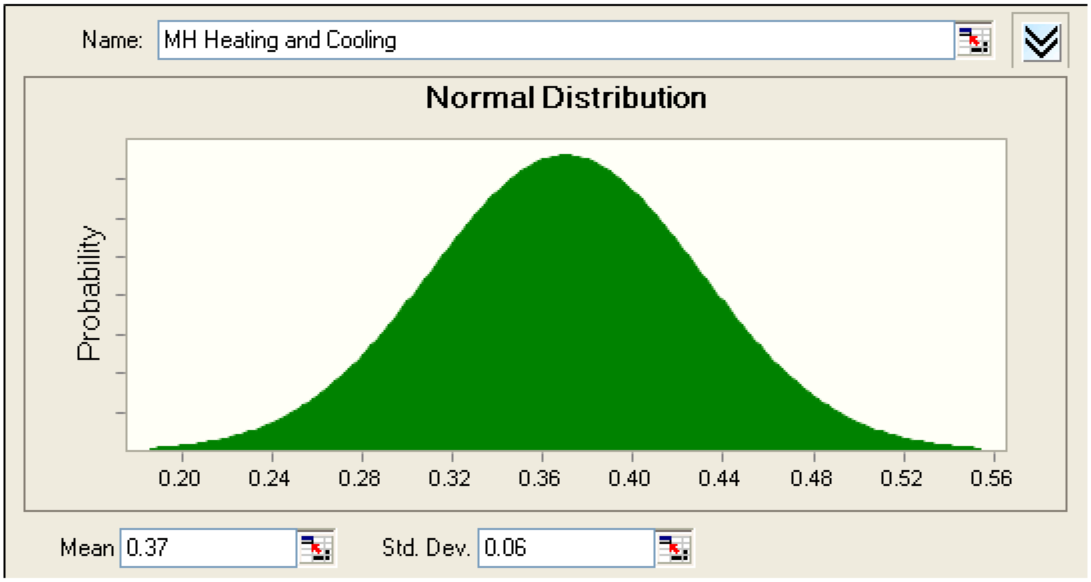

Figure 7-B.5.3 External Static Pressure Distribution for Manufactured Home Non-Weatherized Gas Furnace Fans; Manufactured Home Electric Furnace / Modular Blower Fan with Central Air Conditioning

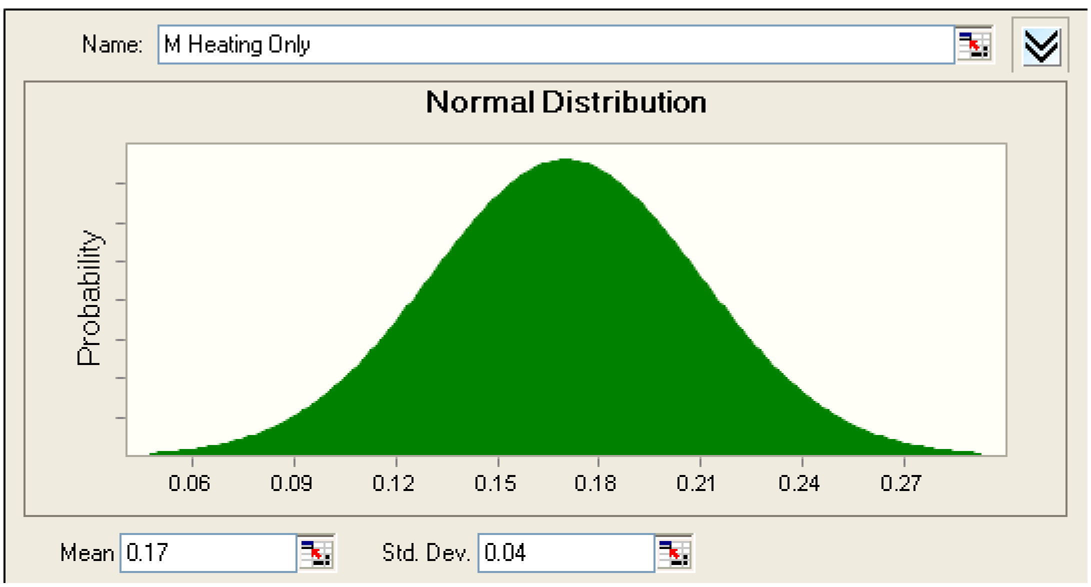

Figure 7-B.5.4 External Static Pressure Distribution for Manufactured Home Non-Weatherized Gas Furnace Fans; Manufactured Home Electric Furnace / Modular Blower Fan without Central Air Conditioning

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