APPENDIX 7.4. FURNACE FAN CURVES

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 7.4. FURNACE FAN CURVES

Furnace energy consumption includes motor electricity from the motor of the indoor air blower. The furnace blower electricity use depends on air flow through the furnace and the pressure rise across the furnace. A fan curve is a graphical representation of the pressure rise, called static pressure, compared to the airflow through the fan or blower.

A furnace fan has three operational modes: cooling (when central air conditioning is present), normal heating, and low-fire heating. This appendix describes the Department's methods for determining the generic model furnace fan curves for the cooling operation mode. For the normal heating or low-fire heating operation, DOE fit the basic model fan curves directly to develop equations of static pressure versus air flow across the furnace.

Blower manufacturers provide blower fan curves for both static pressure and shaft power as functions of airflow. The furnace fan curve shows the static pressure compared to airflow through the furnace. The Department combined the blower fan curves with assumptions about the furnace airflow and motor performance to derive furnace fan curves for generic model furnaces.

7.4.1 GENERAL AIR SPEED AND AIRFLOW RELATIONSHIP

Blowers are the component inside the furnace that moves the air through the furnace. All the air that moves through the furnace also goes through the blower.

Many furnace components, such as the heat exchangers, the inlet and outlet openings, and the geometry of the enclosure, partially obstruct or restrict the airflow. The decrease in the pressure rise due to putting a blower into the furnace enclosure is called the system effect factor (SEF). SEF is a pressure loss which represents the effect of fan inlet restrictions, fan outlet restrictions, or other conditions influencing fan performance when installed in the system.[1] The difference between the blower pressure and the external static pressure across the furnace at the same airflow is due to the SEF. The SEF varies as the square of the air velocity.

For any given furnace model, the air velocity at the blower is directly proportional to airflow through the furnace. Thus, the pressure across the furnace can be calculated as:

$$P_{furn}(Q) = P_{blower}(Q, N) - SEF \times Q^2$$

where:

P_{furn} = furnace static pressure (in.w.g.),
P_{blower} = static pressure across blower alone (in.w.g.),
Q = airflow (cfm),
N = motor speed (rpm), and
SEF = system effect factor.

7.4.2 BLOWER FAN CURVES

The Department chose four blowers from Lau Industries, a manufacturer that supplies blowers to the furnace industry, to match with four virtual model furnace blowers[2] (see Chapter 7, section 7.2, for a discussion of virtual model furnaces). The Department first determined equations for the blower fan curves. The Department fit third- and fourth-order polynomial equations of air flow to the pressure and shaft power curves of these blowers. (See Appendix 7.5, Blower Fan Curves, for more details.)

$$P(Q, N_{test}) = c_{p0} + c_{p1} \times \left(\frac{Q}{1000}\right) + c_{p2} \times \left(\frac{Q}{1000}\right)^2 + c_{p3} \times \left(\frac{Q}{1000}\right)^3 + c_{p4} \times \left(\frac{Q}{1000}\right)^4$$

where:

P = static pressure (in.w.g.),
N_{test} = motor speed at the test speed (rpm), and
$c_{p0}, c_{p1}, c_{p2}, c_{p3}, c_{p4}$ = empirical coefficients.

The Department also determined shaft power for the blower as:

$$H(Q, N_{test}) = c_{h0} + c_{h1} \times \left(\frac{Q}{1000}\right) + c_{h2} \times \left(\frac{Q}{1000}\right)^2 + c_{h3} \times \left(\frac{Q}{1000}\right)^3 + c_{h4} \times \left(\frac{Q}{1000}\right)^4$$

where:

H = shaft power (W), and
$c_{h0}, c_{h1}, c_{h2}, c_{h3}, c_{h4}$ = empirical coefficients.

7.4.2.1 Fan Laws

Using the relationships between blower speed, airflow, static pressure, and shaft power, DOE determined[1] the equation for the fan curves for speeds other than those at which they were tested. These relationships are known as fan laws and can be written as:

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} \quad \left(\frac{N_1}{N_2}\right)^2 = \frac{P_1}{P_2} \quad \left(\frac{N_1}{N_2}\right)^3 = \frac{H_1}{H_2}$$

Using the blower equations and the fan laws, the blower pressure and shaft power can be determined for any speed and airflow.

$$P(Q,N) = P\left(Q, \frac{N\ test}{N}\right) \times \left(\frac{N}{N_{test}}\right)^2$$

$$H(Q,N) = H\left(Q, \frac{N\ test}{N}\right) \times \left(\frac{N}{N_{test}}\right)^3$$

7.4.2.2 Motor Speed

The permanent split capacitor (PSC) motors used in the baseline furnaces do not operate at constant speed. The difference between actual operating speed and the synchronous speed of an induction motor is referred to as slip. For six-pole induction motors, the synchronous speed is 1200 rpm. At the rated speed of these motors of 1075 rpm, so the slip is 125 rpm.

$$S = N_{sync} - N$$

where:

S	=	motor slip (rpm),
N_{sync}	=	synchronous blower speed (rpm), and
N	=	motor speed (rpm).

For a broad operating range, the slip on induction motors is proportional to the load. For blower motors the load is the shaft power of the blower.[3]

$$\frac{S_1}{S_2} = \frac{H_1}{H_2}$$

where:

H = shaft power (hp or W).

7.4.2.3 Shaft Power

The shaft power to turn the blower must equal the shaft power produced by the motor, so the previous equation can be written as:

$$H_{blower}(Q,N) = H_{motor\_rated} \times \frac{(N_{sync} - N)}{(S_{rated})}$$

where:

H_{motor_rated} = is the rated motor output, and
S_{rated} = the motor slip at its' rated output power.

For any airflow, the speed can be adjusted iteratively until the equation is solved.

7.4.2.4 System Effect Factor

The Department assumed that furnaces are designed so the blower motors operate at rated power at the nominal maximum air flow with 0.5 in.w.g. static pressure. Following this assumption, the Department adjusted the speed until the shaft power of the blower (at the nominal maximum airflow) matched the rated power output of the motor.

Once DOE found the motor speed necessary to produce the nominal maximum airflow through the furnace at 0.5 in.w.g. external static pressure (Q_{nom}), the *SEF* was determined as:

$$SEF = \frac{P_{blower}(Q_{nom}, N) - P_{furn}(Q_{nom})}{(Q_{nom})^2}$$

7.4.3 FAN CURVES FOR GENERIC MODEL FURNACES

For each airflow, across the full range of airflows for each virtual model furnace, the speed was then iteratively adjusted until the blower shaft power matched the motor shaft power.

Once the speed was known for each airflow, the external static pressure across the furnace was calculated as:

$$P_{furn}(Q) = P_{blower}(Q, N) - SEF \times Q^2$$

For each of the four airflow capacities of virtual model furnaces, the Department repeated this process for several values of airflow to determine motor speed and external static pressures during cooling operation. The Department fit a polynomial equation of P as a function of Q through these points to get the fan curve for each airflow capacity of virtual model furnaces. The form of the equations is:

$$P_{furn}(Q) = C0 + C1 \times \left(\frac{Q}{1000}\right) + C2 \times \left(\frac{Q}{1000}\right)^2 + C3 \times \left(\frac{Q}{1000}\right)^3$$

To develop equations of static pressure across the furnace for normal heating or low-fire heating operation modes, DOE fit the pressure from the basic model fan curves directly to air flow. Table 7.4.1 presents the coefficients for static pressure as a function of airflow for the virtual furnace models.

Table 7.4.1 Coefficients for Static Pressure as a Function of Airflow

	C_0	C_1	C_2	C_3
Cooling				
5ton	1.916151	-0.87805	0.317813	-0.11646
4ton	0.631601	1.183158	-0.90841	0.073442
3ton	0.259783	2.2545	-2.11025	0.332181
2ton	1.452571	-1.26789	0.41408	-0.39707
Single-stage heating or high fire 2-stage heating				
5ton	1.6533	-1.5622	1.6788	-0.7274
4ton	2.7447	-6.1898	7.4999	-3.1809
3ton	0.0778	2.8833	-2.5288	0
2ton	0.9753	1.0443	-2.9451	0
Low-fire heating				
5ton	0.511338	1.356782	-1.0186	0
4ton	-0.08841	3.268466	-2.57168	0
3ton	-0.56392	5.35246	-5.04481	0
2ton	0.861904	1.106394	-3.14531	0

REFERENCES

1. Air Movement and Control Association International Inc., *Fans and Systems*, in *AMCA Publication 201-90*. 1990: Arlington Heights, IL.

2. Lau Industries Inc., e-mail from Michael J. Neely, Research and Development Engineer, to Jim Lutz, *personal communication.* August 29, 2002.

3. Nadel, S., M. Shepard, S. Greenberg, G. Katz, and A. T. d. Almeida, *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*. In *Series on Energy Conservation and Energy Policy*, C. Blumstein, Editor. 1992, American Council for an Energy-Efficient Economy: Washington, DC. p. 76-77.