APPENDIX 8.8. POWER CONSUMPTION OF BC/ECM+ BLOWER MOTORS

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8.8.1 INTRODUCTION

General Electric Industrial Systems (GE) has developed a prototype backward-inclined blower impellor for use in residential furnace and air handlers.[1] Backward-inclined blowers have significantly wider blades and must rotate at higher speeds to provide the same static pressure rise as forward-curved blowers of the same size. As part of this project, GE also developed a new, smaller diameter, motor, ECM 4.0, which is able to drive the new blower at higher speeds.

The Department developed the equations to predict blower motor electrical power consumption for the BC/ECM+ design option based on this prototype.

From a plot of efficiencies and pressures versus airflow of the GE prototype, DOE developed equations for shaft power and static pressure as functions of airflow. These equations, combined with the fan laws, allowed the Department to determine shaft power and static pressure for any speed and airflow for this prototype blower. The Department developed modifications of these equations to estimate the performance of blowers of other sizes to cover virtual model furnaces of other nominal maximum airflow capacities.

The GE prototype is designed to provide airflow for a furnace built to accommodate a 3-ton air conditioner. The Department assumed it would be matched to a furnace designed to have a system effect factor (SEF) giving a static pressure rise across the furnace of 0.5 in.w.g. at an airflow of 1200 cfm. The ratio of the SEF for other size furnaces to the SEF of this furnace was assumed to follow the pattern seen in furnaces with forward-curved blowers.

Furnaces with these backward-inclined blowers are intended to operate at constant airflow, regardless of the static pressure. Once the equations based on airflow were developed, the Department applied them to determine the blower speeds required to provide nominal airflow across a range of static pressures. Shaft power was determined at these same operating points to fit equations of blower speed and shaft power as polynomial functions of furnace static pressure.

GE reported the efficiency of the ECM 4.0 at two operating conditions. The two points had almost identical efficiencies. The points roughly span the intended operating range of the motor in a furnace with a nominal airflow capacity of 1200 cfm. Based on this, the Department assumed the new motor would operate at constant efficiency. The shaft power of the BC/ECM+ blower in generic model furnaces divided by this efficiency gives the blower motor electrical power consumption.

The following sections in this appendix provide the details of these calculations and assumptions.

8.8.2 SHAFT POWER AND STATIC PRESSURE AT CONSTANT SPEED

The GE topical report on the development of the prototype blower and motor includes a plot of efficiencies and pressures versus airflow at a constant speed.[1] The Department measured the values from one and a half dozen points on the curves on this plot. It then converted the values of these points to units of cfm for airflow and in.w.g. for pressure using a guide for SI units from ASTM.[2] See Figure 8.8.2.1.

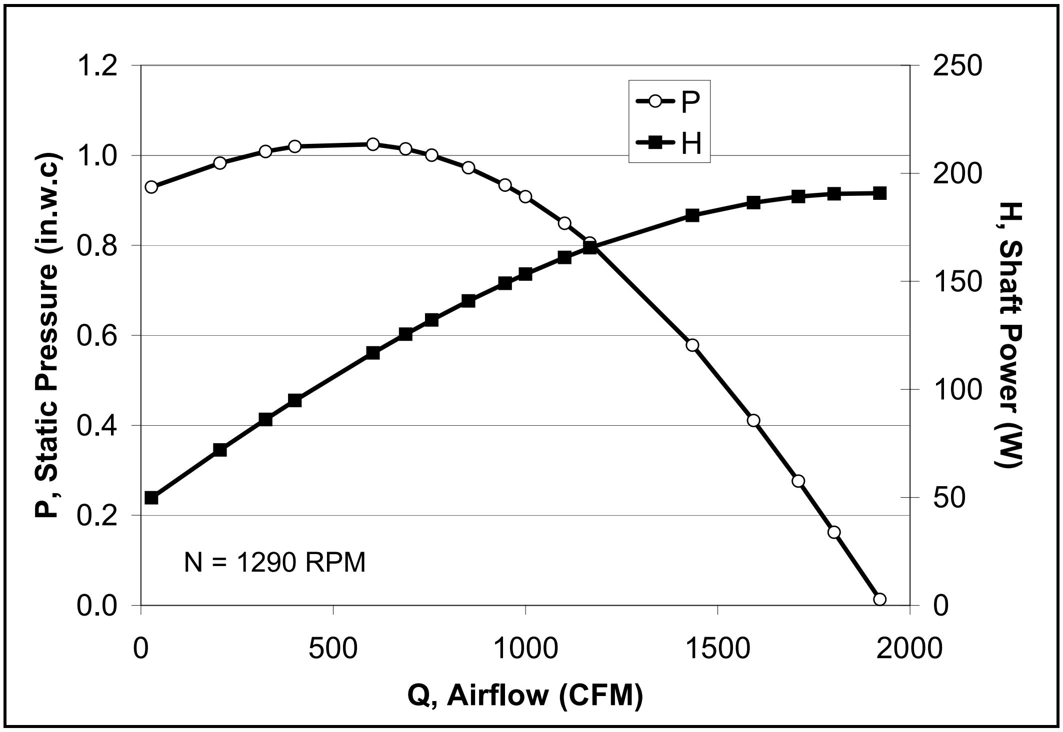

Figure 8.8.2.1 Pressure and Shaft Power versus Airflow at Constant Speed

The Department fit these points to equations for shaft power and static pressure at constant blower speed as polynomial functions of airflow. The equations are:

$$P(Q) = C0 + C1 \times \left(\frac{Q}{1000}\right) + C2 \times \left(\frac{Q}{1000}\right)^2 + C3 \times \left(\frac{Q}{1000}\right)^3 + C4 \times \left(\frac{Q}{1000}\right)^4$$

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

where:

P	=	static pressure rise across blower (in.w.g.),
Q	=	airflow (cfm),
H	=	blower shaft power (W), and

$C_0, C_1, C_2, C_3, C_4 =$ empirical coefficients from curve fitting.

The coefficients for these equations are shown in Table 8.8.2.1.

Table 8.8.2.1 Coefficients for Shaft Power and Static Pressure at Constant Speed

	Static Pressure (P)	Shaft Power (H)
C_0	0.91982	46.32071
C_1	0.34136	127.57380
C_2	-0.11357	-13.27624
C_3	-0.32487	-7.27523
C_4	0.08524	

8.8.3 BLOWER AT OTHER SPEEDS AND AIRFLOWS

These equations, combined with the fan laws, allowed the Department to determine shaft power and static pressure for any speed and airflow for this prototype blower. To do this requires finding the equivalent airflow at the test speed, and then scaling the pressure to new speed.[3] The equations for this are:

$$Q_{equiv} = Q \times \frac{N_{test}}{N}$$

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

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

where:

P = static pressure rise across blower (in.w.g.),
N = blower speed (rpm),
N_{test} = blower speed during test (rpm),
Q_{equiv} = equivalent airflow at test speed (cfm),
P_{test} = static pressure rise across blower at test speed (in.w.g.),
H = shaft power of blower (W), and
H_{test} = shaft power of blower at test speed (W).

8.8.4 OTHER SIZE BLOWERS

The prototype blower developed by GE was thought to be designed for only one size furnace, with a nominal airflow of 1200 cfm. Wider blowers provide more airflow and require more shaft power to develop the same static pressure. The Department examined the airflow for four forward-curved blowers of the same diameter with different widths (Lau Industries blowers DD10-7A, DD10-8A, DD10-9A, and DD10-10A) when operating at 1075 rpm, the nominal speed for PSC motors they are usually driven with.[4] The ratio of average airflows for these blowers across a representative range of pressures, roughly scaled as the ratio of widths raised to a power of 0.795. The Department assumed that the shaft power and airflow wider backward-inclined blowers would scale with width at this same rate. The assumed width ratios and resulting scalars for airflow and shaft power for the backward-inclined blowers for the four airflow capacities of the generic model furnaces are shown in Table 8.8.4.1.

Table 8.8.4.1 Scalars for Airflow and Shaft Power for the Backward-Inclined Blowers

nominal airflow (cfm)	**800**	**1200**	**1600**	**2000**
generic model forward-curved blower size	9×8	10×8	10×10	11×10
width ratio	0.875	1	1.25	1.5
scalar	0.89932	1	1.19402	1.38018

Using these assumptions, finding the pressure for a given airflow for a different width blower means finding the equivalent airflow to calculate the pressure for the prototype blower at the test speed. This is a modification of the techniques used in section 8.8.3, Blower at Other Speeds and Airflows. The equations to find the equivalent airflow and scaled shaft power are:

$$Qequiv = Q_W \times \frac{Ntest}{N} \times \frac{1}{W}$$

$$HW(N,Q) = H_{test}(Q_{equiv}) \times \left(\frac{N}{N_{test}}\right)^3 \times \frac{1}{W}$$

where:

- N = blower speed (rpm),
- N_{test} = blower speed during test (rpm),
- Q_W = airflow of wider blower (cfm),
- Q_{equiv} = equivalent airflow at test speed (cfm),
- H_W = shaft power of wider blower (W), and
- H_{test} = shaft power of blower at test speed(W).

The equation to calculate pressure is the then same as in section 7.8.3 with the new *Qequiv*.

8.8.5 SYSTEM EFFECT FACTOR (SEF) OF BLOWERS IN FURNACES

The SEF is the reduction in pressure from the blower operating by itself compared to when the blower is operating in a furnace. The SEF accounts for the effect of obstructions to the airflow and the inlet and outlet geometry of the blower enclosure of the furnace. The Department made the assumption that the fractional change in SEF for every 400 cfm change of nominal airflow in the virtual model furnaces would also apply for the BC-ECM+ blowers in the virtual model furnaces.

The Department fit the SEF of the virtual model furnaces to an exponential function of nominal airflow. Figure 8.8.5.1, shows values and the fit equation for forward-curved blowers and PSC motors. The equation for SEF as a function of nominal airflow is:

$$SEF = b \times m^{Q_{nom}}$$

where

SEF	=	system effect factor,
b	=	1.227249×10^{6},
m	=	0.999039, and
Q_{nom}	=	nominal airflow of blower(cfm).

The SEF was calculated independently for the BC-ECM+ at a nominal airflow of 1200 cfm. The equation is:

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

where

SEF	=	system effect factor,
P_{blower}	=	static pressure of blower, 0.781 (in.w.g.), calculated at 1290, rpm and 1200 cfm,
P_{furn}	=	static pressure of furnace, 0.5 (in.w.g.), and
Q_{nom}	=	nominal airflow of blower, 1200 (cfm).

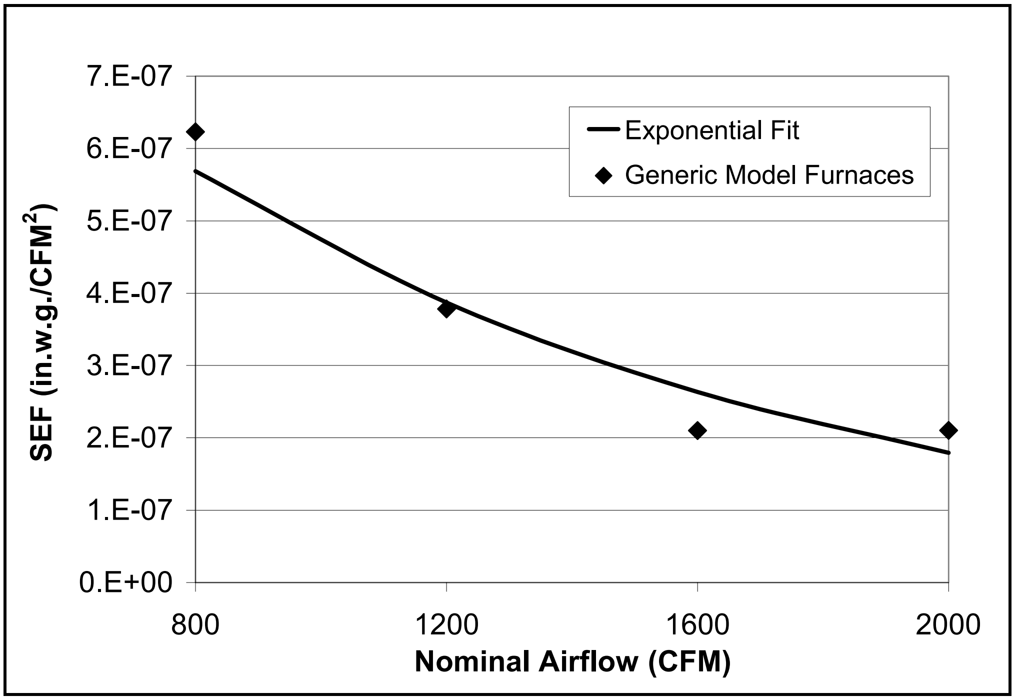

Figure 8.8.5.1 SEF Versus Nominal Airflow for Virtual Model Furnaces

To get the SEF for the other virtual model furnaces with BC/ECM+ blowers, DOE calculated the ratio of SEF for the other nominal maximum airflow virtual furnaces to the SEF for this furnace. This was done using the exponential function of SEF versus nominal maximum airflow of the virtual model furnaces. The resulting ratios are shown in Table 8.8.5.1.

Table 8.8.5.1 SEF for BC/ECM+ Blowers in Virtual Model Furnaces

Nominal Airflow (CFM)	**800**	**1200**	**1600**	**2000**
SEF ratio	1.468938	1	0.680764	0.463439
SEF (in.w.g./CFM^2)	2.86931E-07	1.953E-07	1.32975E-07	9.05245E-08

8.8.6 BLOWER SPEED AND SHAFT POWER AS FUNCTION OF FURNACE STATIC PRESSURE

For furnaces with improved ECM motors and backward-inclined impellors in the blower, the Department determined the airflow and static pressure at the operating conditions from the intersection of the fan curve of the furnace and the system curve of the ducts. This is done in the same way as for standard PSC motors. However, furnaces with these motors are programmed to provide a constant airflow regardless of static pressure. Thus, the fan curves for these furnaces are a vertical line of constant airflow.

The Department evaluated the furnace static pressure at the nominal air flow for each of the virtual model furnaces with BC/ECM+ blowers for a range of blower speeds.

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

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 as explained in Appendix 7.4, Furnace Fan Curves, section 7.4.1, General Air Speed and Airflow Relationship.

From these static pressures, the Department developed an equation for blower speed as a function of static pressure at the nominal airflows of the virtual model furnaces.

$$N\left(P_{furn}\right) = C_0 + C_1 \times P_{furn} + C_2 \times P_{furn}^2$$

where

N	=	motor speed (rpm),
P_{furn}	=	furnace static pressure (in.w.g.), and
C_0, C_1, C_2	=	empirical coefficients from curve fitting.

The coefficients for the equations of blower speed as a function of furnace static pressure for virtual furnaces with improved ECM motors and forward-curved impellors is shown in Table 8.8.6.1.

Table 8.8.6.1 Coefficients for Blower Speed Equation

	Q	C_0	C_1	C_2
Cooling				
2 ton	800	771.297930225	779.26756805	-139.008728615
3 ton	1200	1004.4257405	612.718105072	-82.3858179298
4 ton	1600	1115.11438648	556.374528078	-66.4367804917
5 ton	2000	1186.32793032	524.106011654	-58.6030844866
High Fire				
2 ton	640.0	620.504604012	933.280077841	-205.025304436
3 ton	960.0	805.339732049	744.862082929	-126.832574748
4 ton	1280.0	893.475264237	679.413794851	-103.848338196
5 ton	1600.0	950.264980926	641.197789459	-91.9907933216
Low Fire				
2 ton	533.3	521.413603686	1068.28226839	-271.834021254
3 ton	1200	673.447604033	866.36860443	-175.654364949
4 ton	1066.7	746.403441995	793.875638502	-145.692110892
5 ton	1333.3	793.449632938	751.002693796	-129.8241

For the same air flow and speeds that were used to evaluate furnace static pressure, DOE evaluated the blower shaft power using the equations explained earlier in this appendix. From these results, the Department developed an equation for blower shaft power as a function of static pressure at the nominal airflows of the virtual model furnaces.

$$H(P_{furn}) = C_0 + C_1 \times P_{furn} + C_2 \times P_{furn}^2 + C_3 \times P_{furn}^3$$

where

H	=	blower shaft power (which is also the motor output power) (W),
P_{furn}	=	furnace static pressure (in.w.g.), and
C_0, C_1, C_2, C_3	=	empirical coefficients from curve fitting.

The coefficients for the equations of blower shaft power as a function of furnace static pressure for virtual furnaces with ECM motors and forward-curved impellors is shown in Table 8.8.6.2.

Table 8.8.6.2 Coefficients for Blower Shaft Power Equation

	Q	C_0	C_1	C_2	C_3
Cooling					
2 ton	800	34.7637865629	101.257496416	30.819237206	-4.393198813
3 ton	1200	86.8964114725	149.648658529	24.686091998	-1.351144007
4 ton	1600	142.379224744	199.258007379	25.830716411	-0.75624128
5 ton	2000	199.168681228	247.410917528	26.886578305	-0.163068387
High Fire					
2 ton	640	17.7814395418	81.4599546929	36.760753941	-6.820695201
3 ton	960	44.4918524165	119.54001273	31.765403864	-3.666136066
4 ton	1280	72.9202558294	159.014401208	33.753367048	-2.927933696
5 ton	1600	101.991203084	197.482373726	35.406395106	-2.130855013
Low Fire					
2 ton	533.3	10.2554469313	68.6525919364	41.182715094	-8.986586445
3 ton	800	25.7529563782	99.6988982718	37.766224552	-6.017676309
4 ton	1066.7	42.197172414	132.467356467	40.800818335	-5.419757563
5 ton	1333.3	59.0319912122	164.29823146	43.598086888	-4.793958254

8.8.7 ECM 4.0 MOTOR EFFICIENCY

The GE topical report listed the efficiency of the prototype ECM 4.0 motor at two operating conditions.[1] The two points, which roughly span the intended operating range of the prototype motor, are at the target operating condition and at the maximum operating conditions. The motor efficiencies at these two operating conditions were 86.0% and 84.7%, respectively. Figure 8.8.7.1, shows these data points against the targeted operating range of the motor. Based on this, the Department assumed the new motor would operate at constant efficiency of 85%.

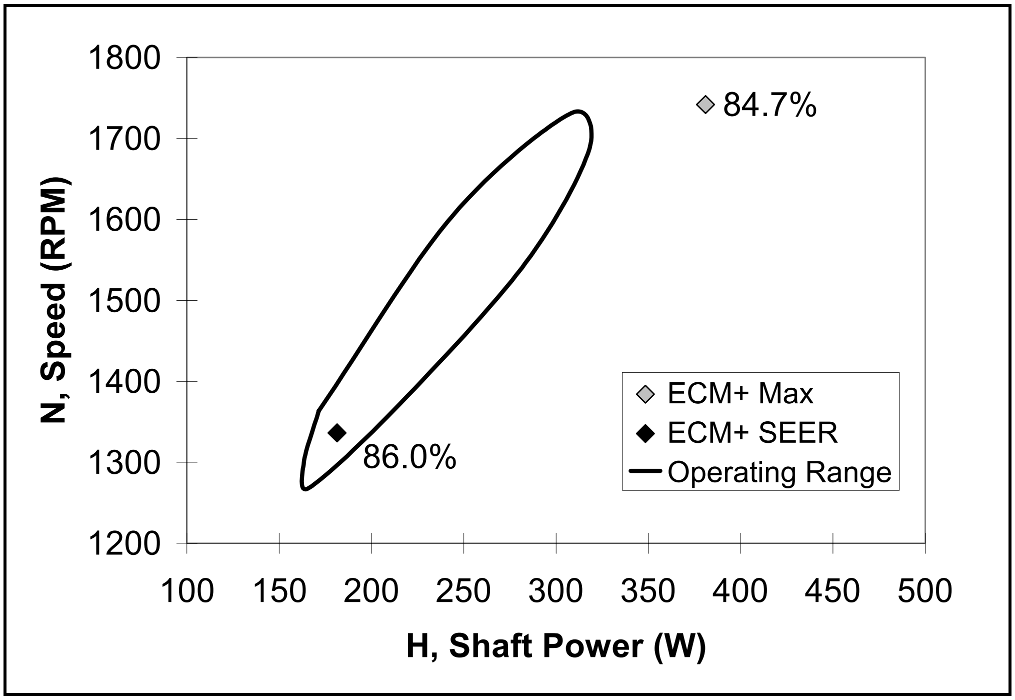

Figure 8.8.7.1 Efficiencies and Operating Range of Prototype Motor

8.8.8 BC/ECM+ BLOWER MOTOR ELECTRICITY CONSUMPTION

The shaft power of the BC/ECM+ blower in virtual model furnaces divided by efficiency gives the blower motor electrical power consumption.

$$BE = \frac{Hw(N, Q_W)}{\eta_{motor}}$$

where

N	=	blower speed at operating static pressure of furnace (rpm),
Q_W	=	airflow of wider blower at operating static pressure of furnace (cfm),
H_W	=	shaft power of wider blower (W), and
η_{motor}	=	motor efficiency.

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