

APPENDIX 8.7. POWER CONSUMPTION OF ECM BLOWER MOTORS

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APPENDIX 8.7: POWER CONSUMPTION OF ECM BLOWER MOTORS

8.7.1 INTRODUCTION

For the electronically commutated motor (ECM) design option, the Department calculated power consumption of blower motors as a function of furnace static pressure. The Department developed a series of equations to first calculate the blower speed and shaft power from the furnace static pressure. Using the values for shaft power and blower speed, the Department developed a second series of equations to calculate the blower motor efficiency. Building on the first and second series of equations, the Department then calculated the blower motor power consumption from the efficiency and shaft power.

8.7.2 BLOWER SPEED AND SHAFT POWER

This section explains how the Department determined blower speed and shaft power from the furnace static pressure.

For furnaces with ECM motors and standard forward-curved impellers in the blower, the airflow and static pressure at operating conditions are determined from the intersection of the fan curve of the furnace and the system curve of the ducts. 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 calculated the furnace static pressure at the nominal air flow for each of the virtual model furnaces for a range of blower speeds. (See Appendix 7.4, Furnace Fan Curves, for an explanation of the furnace static pressure equation.)

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

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.

With the calculated static pressures, the Department developed an equation for blower speed as a function of static pressure at the nominal airflows of the generic model furnaces.

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

where:

- N = motor speed (rpm),
- 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 speed as a function of furnace static pressure for generic furnaces with ECM motors and forward-curved impellers are shown in Table 8.7.2.1.

Table 8.7.2.1 Coefficients for Blower Speed Equation

	Q	C ₀	C ₁	C ₂	C ₃
Cooling					
2-ton	800	758.510902	818.311142	-314.27103	88.0707484
3-ton	1200	749.383575	539.726313	-113.76913	32.9063052
4-ton	1600	746.778132	462.47066	-48.570713	0
5-ton	2000	853.498286	446.471489	-43.055706	0
High Fire					
2-ton	640	608.29206	994.40398	-510.6498	173.2131
3-ton	960	600.52032	658.79742	-172.3176	59.047199
4-ton	1280	598.34369	567.4097	-77.75611	0
5-ton	1600	682.74296	558.79107	-85.34107	0
Low Fire					
2-ton	533.3	506.0368	1164.7986	-727.0327	265.41284
3-ton	800.0	505.36184	716.89594	-95.81477	0
4-ton	1066.7	500.31672	662.7684	-106.8632	0
5-ton	1333.3	569.14764	666.9781	-141.5275	0

For the same air flow and speeds that were used to evaluate furnace static pressure, DOE evaluated the blower shaft power using the equation developed in Appendix 7.5 Blower Fan Curves. From this evaluation, the Department developed an equation for blower shaft power as a function of furnace static pressure at the nominal airflows of the generic 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 generic furnaces with ECM motors and forward-curved impellers are shown in Table 8.7.2.2.

Table 8.7.2.2 Coefficients for Blower Shaft Power Equation

	Q	C ₀	C ₁	C ₂	C ₃
Cooling					
2-ton	800	0.0152708	0.050746	0.0257333	-0.005583
3-ton	1200	0.2104571	0.2417293	0.0078857	0.0053584
4-ton	1600	0.323437	0.337503	0.0327196	-0.000428
5-ton	2000	0.5250273	0.4308035	0.0462496	-0.015896
High Fire					
2-ton	640	0.0077478	0.0418898	0.0275575	-0.00666
3-ton	960	0.1078423	0.1919758	0.0143375	0.0067217
4-ton	1280	0.1656094	0.2697001	0.0420681	-0.001972
5-ton	1600	0.2687731	0.3456568	0.0540197	-0.027583
Low Fire					
2-ton	533.3	0.00452	0.0355173	0.0293339	-0.007401
3-ton	800.0	0.0624766	0.1584268	0.0229145	0.0063644
4-ton	1066.7	0.0958492	0.2245117	0.0514025	-0.004302
5-ton	1333.3	0.1555447	0.2907602	0.0517586	-0.034138

8.7.3 DEVELOPMENT OF EFFICIENCY EQUATION

To find motor efficiency from motor speed and shaft power, DOE started with data from a typical ECM motor used regularly by furnace manufacturers, GE ECM 2.3. Figure 8.7.3.1 shows the iso-efficiency lines for the GE ECM 2.3 series motors.¹ This chart was taken from a brochure published by General Electric and manually converted to 250 data points.

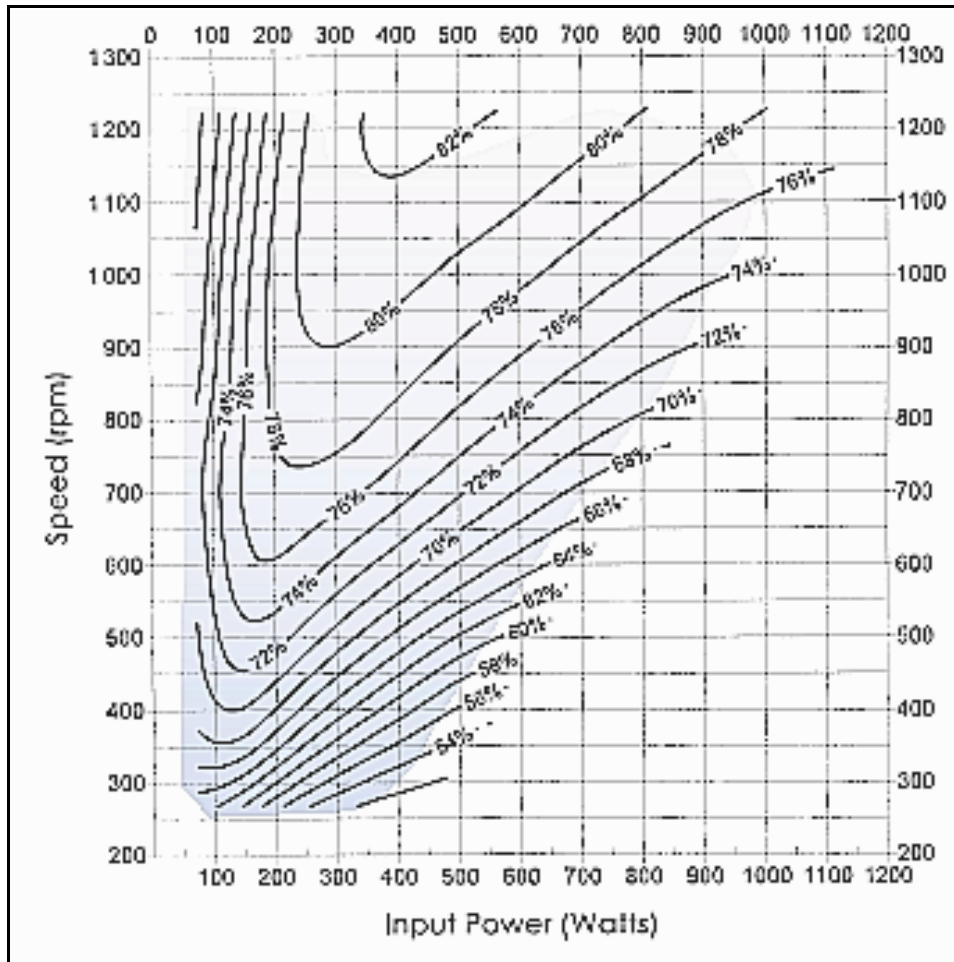


Figure 8.7.3.1 Iso-Efficiency Lines for GE ECM 2.3

Although input power is given as one of the parameters in this chart, once the data are digitized, they can be rearranged and input power can be considered as a function of shaft power and motor efficiency. Shaft power is calculated as a product of input power and motor efficiency:

$$H = BE \times \eta_{motor}$$

where:

- H = shaft power (W),
- BE = input power (W), and
- η_{motor} = motor efficiency.

A plot of transformed iso-efficiency lines in a speed (N) and shaft power (H) plane is shown in Figure 8.7.3.2 below.

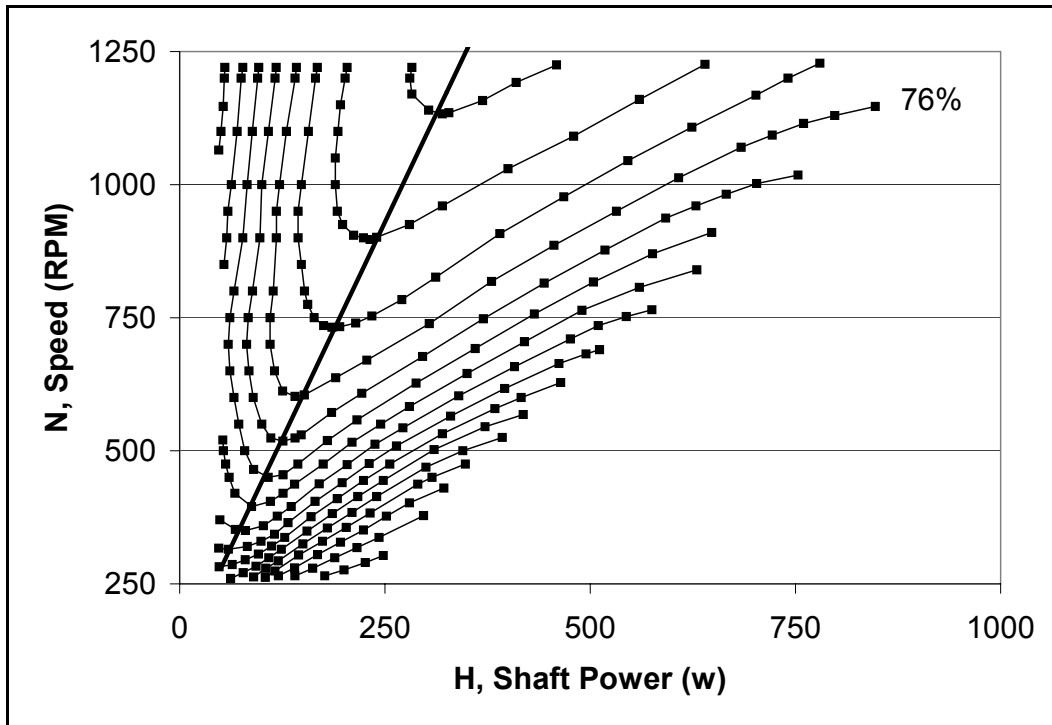


Figure 8.7.3.2 Plot of Iso-Efficiency Lines Against Speed and Shaft Power

The Department fit a straight line through the minimum speed points of all iso-efficiency lines. The Department rotated the axes so that the fit line was vertical by applying the following transformation to every point on the iso-efficiency lines in the plot. The new axes of this plot (X and Y) do not have any physical meaning, but are used in the intermediate calculations to calculate efficiency. After this rotation, an equation can be fit to the data to give an equation of Y as a function of X (see Figure 8.7.3.3).

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} H \\ N \end{bmatrix} \times \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix}$$

where:

- H = shaft power (W),
- N = motor speed (rpm), and
- θ = 17.09° , the angle of rotation.

The angle of rotation is the difference in degrees between vertical and the slope of the line fit through the minimum speed points on the iso-efficiency lines.

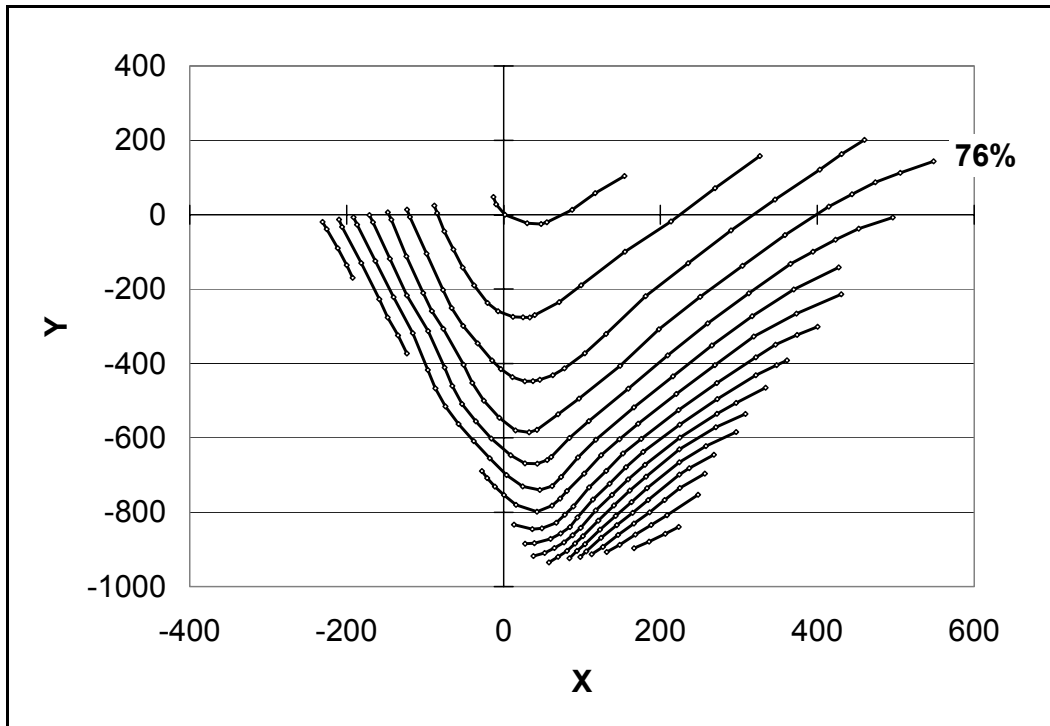


Figure 8.7.3.3 Plot of Rotated Iso-Efficiency Lines

The Department fit an equation to the iso-efficiency line at an efficiency of 76 percent because this line had the most data points. The form of the equation is:

$$Y_{76} = \left(C_0 \times \sqrt{X'^2 + C_1^2} \right) - e^{\left(C_2 + \frac{X'}{C_3} \right)}$$

where:

$$\begin{aligned} Y_{76} &= Y @ \eta_{\text{motor}} = 76\%, \\ Y' &= Y - Y_{\text{trans}}, \text{ and} \\ X' &= X - X_{\text{trans}}. \end{aligned}$$

where:

$$\begin{aligned} Y_{76} &= \text{translated Y value for 76\% motor efficiency line,} \\ Y_{\text{trans}} &= \text{amount Y value was translated,} \\ X_{\text{trans}} &= \text{amount X value was translated, and} \\ C_0, C_1, C_2, C_3 &= \text{empirical coefficients from curve fitting.} \end{aligned}$$

This equation has two main parts. The first part is a hyperbola that is used to fit the left side of the curve. The second part is an exponential curve that has the effect of pulling down the

right side of the hyperbola to match the data points. All the coefficients and the translation along the X and Y axes were selected to give the best possible fit to the data. They are listed in Table 8.7.3.1.

Table 8.7.3.1 Coefficients for Equation of Y at 76 Percent Efficiency as a Function of X

X_{trans}	281.305
Y_{trans}	1170.78
C_0	4.066465
C_1	69.497914
C_2	6.732347
C_3	594.895937

The differences in Y between the line at 76 percent efficiency and the other iso-efficiency lines is nearly constant for all values of X (See Figure 8.7.3.4.) The plot shows all the points, with the Y value for the 76 percent efficiency subtracted.

The efficiency for data points off the 76 percent iso-efficiency line can now be calculated as a function of the differences in Y from the 76 percent iso-efficiency line. Before doing this, the Department applied a logistic transform to the efficiency values. Because efficiency is limited by definition to between 0 percent and 100 percent, polynomial fits of efficiency are often done more accurately on a logistic transformation. The equation the Department used for the logistic transform is:

$$T = \ln\left(\frac{1}{\eta_{motor}} - 1\right)$$

where:

T = logistic transform of motor efficiency, and
 η_{motor} = motor efficiency.

And the difference in Y from the 76 percent iso-efficiency line is calculated as:

$$Y_{76R} = Y' - Y_{76}$$

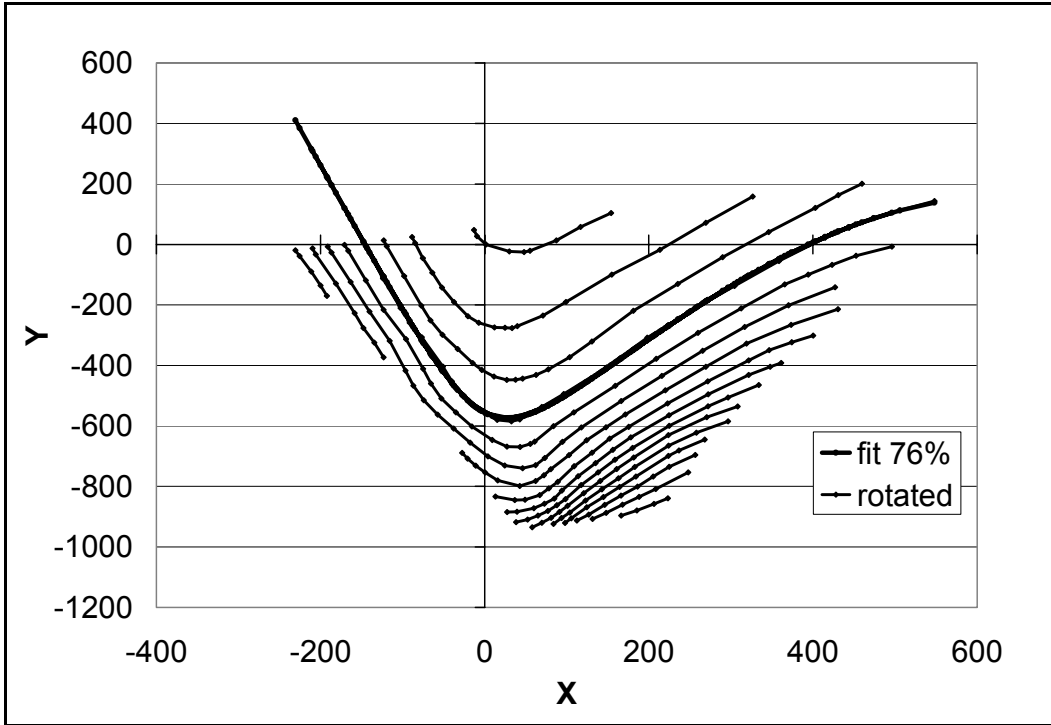


Figure 8.7.3.4 Residuals of Y After Subtracting Predicted 76 percent Efficiency Y Values

where:

- Y_{76} = translated Y value for 76 percent motor efficiency line, and
- Y' = translated Y value.

The Department fit a polynomial equation of the difference between Y and the Y of the 76 percent efficiency line to the logistic transform of the efficiency (shown in Figure 8.7.3.5).

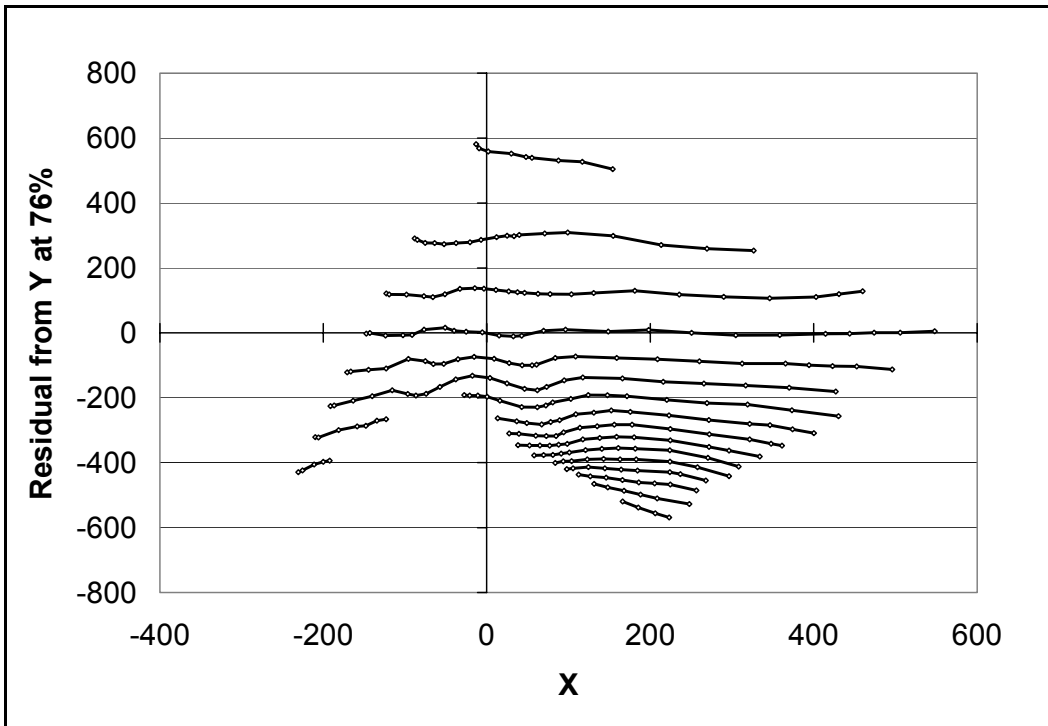


Figure 8.7.3.5 Fit of Transformed Efficiency to Difference between Y and 76 percent Efficiency Y Values

The equation for this fit is:

$$T = C_0 + C_1 \times Y_{76R} + C_2 \times Y_{76R}^2 + C_3 \times Y_{76R}^3$$

where:

- T = logistic transform of motor efficiency,
- Y_{76R} = difference between Y' and Y' for the 76 percent efficiency line, and
- C_0, C_1, C_2, C_3 = empirical coefficients from curve fitting.

The coefficients were selected to give the best possible fit to the data. They are listed in Table 8.7.3.2.

Table 8.7.3.2 Coefficients for Equation of Logistic Transform of Motor Efficiency

C_0	-1.156317102
C_1	-1.075425258
C_2	1.278606109
C_3	-0.947312475.

At this point, the efficiency of the motor can be calculated from the transformed efficiency as:

$$\eta_{motor} = \frac{1}{(1 + e^T)}$$

where:

η_{motor} = motor efficiency, and
 T = logistic transform of motor efficiency.

8.7.4 BLOWER MOTOR POWER CONSUMPTION

The electrical power consumption of the ECM blower motor is calculated as:

$$BE = \frac{H(P_{furn})}{\eta_{motor}(H(P_{furn}), N(P_{furn}))}$$

where:

BE = blower motor electrical input power (W),
 H = shaft power (W),
 η_{motor} = motor efficiency,
 N = motor speed (rpm),
 P_{furn} = furnace static pressure (in.w.g.), and
 T = logistic transform of motor efficiency.

A check shows close correlation between the reported and calculated values for BE as seen in Figure 8.7.4.1. The plot compares the motor input power to the motor input power calculated from blower shaft power and motor speed from the digitized data used to develop the equations listed above.

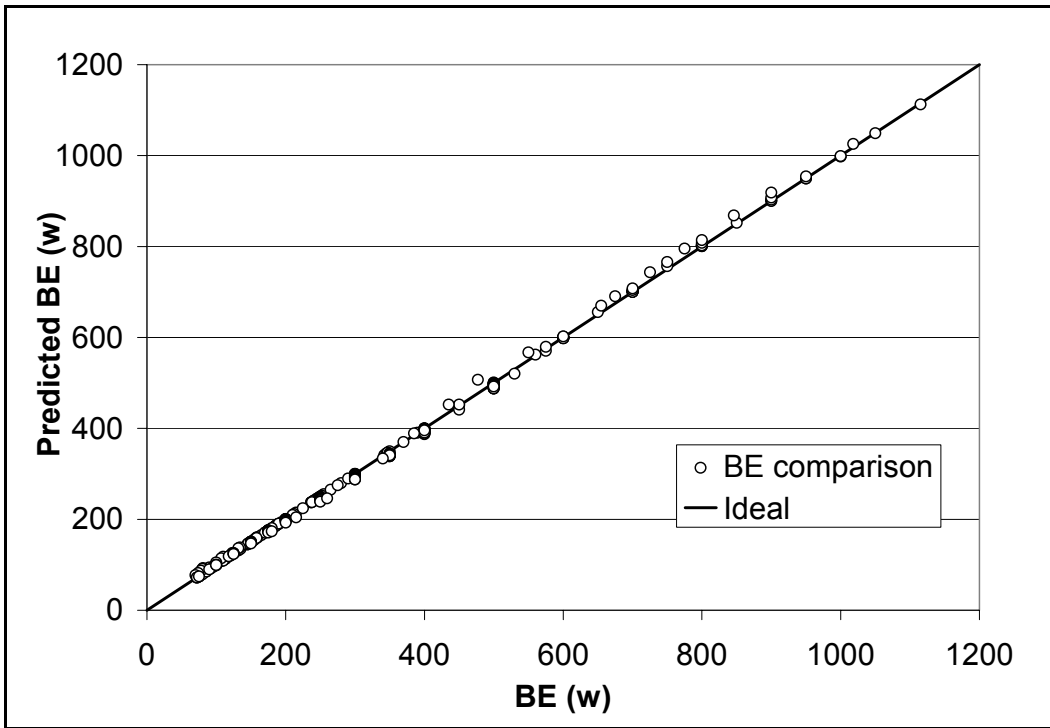


Figure 8.7.4.1 Comparison of Reported to Estimated Blower Motor Input Power

REFERENCES

1. General Electric Company, *General Electric Brochure*, (Last accessed August 28, 2002).
<<http://www.geindustrial.com/products/brochures/GET-8068.pdf>>