ECM EFFICIENCY

Better (and Worse) Than You Think

BY KOHTA UENO

The two technologies used in furnace and air handler blower motors are permanent split-capacitor (PSC) or induction motors and, more recently, electronically commutated motors (ECMs), which are also known as brushless DC motors. ECMs can offer gains in efficiency, especially when their variable-speed capacity is utilized (for example, with a continuous low-speed fan for circulation and destratification, low-speed heating mode). These ECMs are widely used in higher-end furnaces and air handlers (typically referred to as variable-speed units); they are used especially in efficiency-focused work and high-end residences.

A full background on the use of ECMs in air handlers is not the focus of this article. The subject has been discussed at length in previous issues of *Home Energy* (see "The Electric Side of Gas Furnaces," *HE* Nov/Dec '03, p. 24; and "Motors Matter," *HE* July/Aug '00, p. 31). This article focuses instead on air handler energy use and fan efficiency. It is based on a study conducted in 2009 by the Building Science Corporation (BSC), where I work, for the Building America Program. It includes a survey of previous research, and it discusses the results of field measurements. Note that this study is by no means a large-scale survey. However, this research for this study was a matter of particular interest to BSC, given the push toward higher- and higher-performance houses in the Building America program. As enclosure improvements reduce heating and cooling loads, the smaller electrical loads—including the parasitic loads of the air handler motor—become more significant, and thus worth measuring.

BACKGROUND... AND A PLEA FOR SANITY

I began my research by conducting a survey of previous work on this topic. Having done so, I have to send out a plea for sanity: There are a lot of air handler efficiency metrics out there, all of them measuring the same thing. They include CFM/watt, watt/CFM, watts/1,000 CFM, and kW/CFM. I personally prefer metrics of efficiency that are of the form output divided by input. This type of metric increases with improved efficiency, much like such common examples as miles per gallon (mpg), annual fuel utilization efficiency (AFUE), seasonal energy efficiency ratio (SEER), and heating seasonal performance factor (HSPF)—which are efficiency metrics for cars and trucks, furnaces and boilers, air conditioners, and heat pumps, respectively. However, it appears that the majority of the industry leans toward watt/CFM (W/CFM). As a compromise, this article will use the first two metrics.

My survey of previous work on this topic was taken from many sources, including standards and test procedures, simulation assumptions, laboratory measurements, and field surveys (see Table 1). Some of the numbers and what they mean are described in detail below.

Table 1. Survey Data

Source	ECM/Non-ECM	CFM/Watt	Watt/CFM	"Static pressure IWC (Pascals)"
Standards				
DOE Test Procedure Default	n/a	2.7	0.37	n/a
Proposed Revised Default (Sachs)	n/a	2	0.5	n/a
Simulations				
Energy Gauge USA	ECM	2.5	0.4	n/a
Laboratory Testing				
Wilcox 2006 (0.5 IWC)	ECM	3.1 to 3.3	0.3-0.33	0.5 (125)
Wilcox 2006 (0.8 IWC)	ECM	2.7 to 2.9	0.35-0.38	0.8 (200)
Springer 2009 (*Home Energy*)	ECM	2.6 to 2.9	0.35-0.39	0.6-1.1 (140-268)
Field Testing				
Wilcox 2006 (CA new construction)	Mixed average	2	0.51	0.8 (200)
Townsend & Ueno 2008 CA Furnace	ECM	2 to 2.4	0.42-0.5	0.8-1 (200-245)
Ueno and Grin 2009 CA Air Handler	ECM	2.7	0.55	1.14 (285)

Correction: 0.55 W/CFM value in last row should be 0.37 W/CFM

STANDARDS

The DOE procedure for testing air conditioner SEER assumes a default air handler fan efficiency, given that exterior condensers are combined with a variety of interior units. This default value is an unrealistically high efficiency, compared to common field measurements.

Sachs and others (2006) proposed an alternate default, which is consistent with field surveys of real HVAC equipment.

SIMULATIONS

Detailed hourly simulations need to assume an air handler fan efficiency. The value used by the simulation Energy Gauge USA for ECMs is shown. For reference, PSC motors are given the value of 2.0 CFM/W or 0.5 W/CFM.

LABORATORY TESTING

Wilcox and others (2006) in California provided laboratory measurements of air handler efficiencies at two external static pressures: 0.5 inches of water column (IWC) and 0.8 IWC, or 125 and 200 Pa. Results are shown in Table 1 for the ECM air handlers; efficiency drops with increasing static pressure.

Springer's study of high-minimum-efficiency reporting values (high-MERV) filters included ECM air handler efficiency figures over a range of pressures. (See "Is There a Downside to High-MERV Filters?" *HE* Nov/Dec '09, p. 32.)

FIELD TESTING

The 2.0 CFM/W or 0.5 W/CFM median figure comes from a 2005 California field survey of 60 furnace systems (Wilcox et al.; motor type not specified), and is a reasonable representation of installed efficiencies of air handler fans. One result of this research will be California standards on air handler minimum-efficiency levels.

Building Science Corporation (BSC) tested four field-installed ECM air handlers in California in 2007. As in many of the previous studies, efficiency was hampered by high static pressures.

BSC also tested an additional ECM air handler in California in 2009, with similar results.

So what do these numbers mean? Overall, measured air handler efficiencies for ECM models varied from 2.0 to 3.3 CFM/W (0.33 to 0.50 W/CFM)—ranging from barely better than the median air handler efficiency to substantially better. This range straddles the assumed fan efficiency value used in simulation programs (2.5 CFM/W or 0.4 W/CFM).

Furthermore, high static pressures are sadly the norm in installed equipment. Systems were typically far from the 0.50 IWC/125 Pa level recommended by manufacturers. This is a particular problem with ECMs; their controls are designed to increase fan speed (and thus energy use) to provide a specific programmed flow, using feedback to determine if the target is being met. Therefore, highly restrictive duct systems directly reduce air handler efficiency, due to equipment strain to reach the air flow target at high speeds.

BUILDING SCIENCE CORPORATION

Measurement procedure, showing digital manometer (Energy Conservatory DG-700) and power meter (The Energy Detective). TrueFlow airflow measurement plate is inside filter slot.

DOING THE MEASUREMENTS

We continued with measurements of an ECM air handler installed in our facility. Variable-speed air handlers are typically field configurable for a range of air flows; this model could be set up to provide air flow for 1.5 to 3 tons of cooling, with additional settings within that range (350, 400, or 450 CFM/ton). A hydronic hot water coil fed by a condensing gas boiler provides heating; cooling is provided by a 2.5-ton outdoor condenser; a 5-inch MERV 11 pleated media filter is installed. The cooling coil is an integrated portion of the air handler cabinet, as opposed to an add-on coil.

To measure air flow and electrical power draw, we used common equipment available to most home performance contractors. Air flow was measured with an Energy Conservatory TrueFlow plate flowmeter located in the filter slot. Our previous fieldwork compared TrueFlow results with an Energy Conservatory Duct Blaster fan as a powered calibrated orifice at the air handler; results were relatively consistent.

These air flow measurements are complicated by the fact that ECM air handlers "seek" their target air flow, so they will react to a change in the system flow resistance by increasing or decreasing fan speed accordingly. As a result, the actual flow typically must be calculated with a correction determined by the supply plenum pressures in the two conditions. However, in this case, the TrueFlow plate was close enough in air flow resistance to the installed filter that this correction was an average of 2% of total air flow. Of course, the power measurement must be taken at the correct corresponding state.

Electrical power use was measured with a meter from The Energy Detective (TED), temporarily installed at the electrical disconnect box for the air handler. This unit was used instead of a plug-in meter such as a Kill-A-Watt because these were 220V hard-wired units. The TED has a manufacturer-stated accuracy of ±2%; however, it has a resolution of only 10 watts.

SHOW ME THE DATA

My first few measurements of power use were down around 30–80 watts, and my immediate reaction was "Oops … I must have something hooked up backward!" To me, air handler draws are supposed to be up in the 500W–1,000W range. I double-checked with an amp clamp and found similar results, much to my puzzlement. It then dawned on me that I had the air handler on a relatively low setting (350–550 CFM). I cross-checked with the manufacturer's specifications, and this lined up with their numbers for this speed range. For reference, the fan efficiencies at this low end are roughly 5 to 8 CFM/W (0.15 to 0.20 W/CFM).

I then ramped the air handler through a range of air flows while measuring power draw, but leaving the duct system in its as-found condition. The resulting air flow versus watt draw relationship is shown in Figure 1.

Those of you who pay attention to geeky things might notice that this is a demonstration of the fan laws (well … almost—see below). It demonstrates, specifically, that the horsepower varies with the cube of the RPM (and therefore the cube of the CFM). Therefore, for instance, doubling the air flow (CFM) results in 8 times the power draw.

But why "well … almost?" The simple fan laws don't include any effects of motor efficiency, while in reality, this plot combines both the fan laws and motor efficiency. However, one ECM manufacturer states that its motor efficiency remains almost constant (65%–72%) over the entire speed range (Nailor, 2003). So overall, the dominant effect shown in Figure 1 is the cube fan law. In contrast, a PSC motor has a full-load efficiency of up to 62%, but when speeds are turned down, efficiencies can fall to 12%–45%.

These results then can be plotted in terms of air handler efficiency (CFM/W) versus external static pressure. See Figure 2.

Note that at high static pressures like 0.8 IWC/200 Pa, this unit has efficiencies in the 2.5 CFM/W (0.40 W/CFM) range—similar to the field-measured efficiencies shown previously. But at lower static pressures, the fan efficiency goes up substantially—at 0.5 IWC (125 Pa), close to 4 CFM/W (0.25 W/CFM), and even better at lower static pressures. Those lower static pressures would be likely in heating mode (in a system designed for cooling flows); in first-stage operation of a two-stage unit; or in lower-speed continuous fan-on mode.

This manufacturer provides detailed air flow and power draw tables; the fan efficiency was calculated, and the results were plotted in a similar manner for this 1.5- to 3.0-ton variable-speed air handler. Results are shown at the various tonnage ratings, at 400 CFM/ton. See Figure 3.

The first trend to notice is that decreasing the tonnage essentially pushes the efficiency curves upward, that is, efficiency improves. All of these data come from a single unit, so running it at a lower tonnage (speed) means less air flow through the same resistance. This trend is consistent with running the system at lower CFM or RPM (remember the fan laws that I discussed above). This can have a big impact on energy efficiency. At 0.5 IWC

Power Draw versus Air Flow for Tested Air Handler

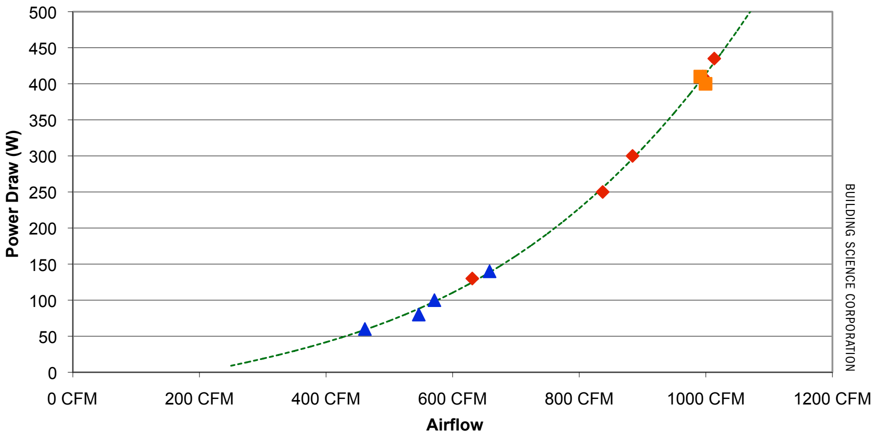

Figure 1. The figure demonstrates that the horsepower varies with the cube of the RPM (and therefore the cube of the CFM).

Fan Efficiency versus Static Pressure for Tested Air Handler

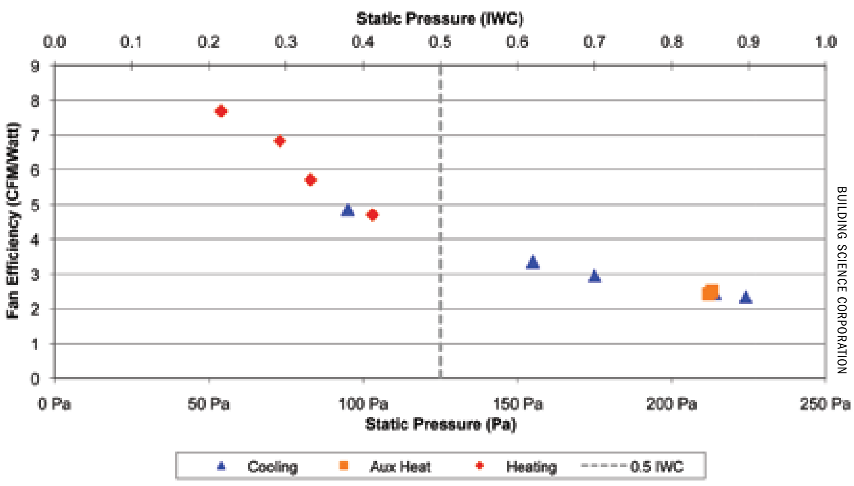

Figure 2. Note that at high static pressures, this unit has efficiencies in the 2.5 CFM/W (0.40 W/CFM) range–similar to the field-measured efficiencies shown previously. But at lower static pressures, the fan efficiency goes up substantially.

Fan Efficiency versus Static Pressure: Manufacturer's Data

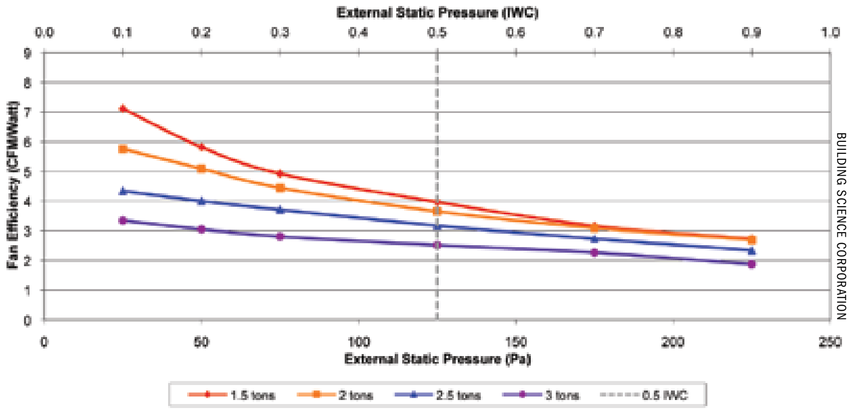

Figure 3. Notice that decreasing the tonnage essentially pushes the efficiency curves upward, that is, efficiency improves. All of these data come from a single unit, so running it at a lower tonnage (speed) means less air flow through the same resistance.

(125 Pa), at 3 tons of air flow (1,200 CFM), the unit runs at 2.5 CFM/W (0.4 W/CFM). But if you drop the same unit to 1.5 tons (600 CFM), efficiency jumps to 4 CFM/W (0.25 W/CFM).

At 0.5 IWC (125 Pa), efficiencies are in the 2.5 to 4 CFM/W (0.25 to 0.40 W/CFM) range—noticeably higher than the field measurements. However, at 0.8 IWC/200 Pa, the curves collapse down to a narrow range of 2 to 3 CFM/W (0.33 to 0.5 W/CFM). On the other hand, at static pressures lower than 0.5 IWC (125 Pa), the fan efficiencies go even higher.

The author completes the measurements.

One final note. Over the course of these measurements, we found that when the air handler was not operating (that is, when it was in standby mode), there was a continuous reading of 10 watts on the meter. Given the resolution of the TED, this could be in the 6W–14W range. This is consistent with similar appliances that I have measured, and with the findings in Scott Pigg's Wisconsin study (see "The Electric Side of Gas Furnaces," *HE* Nov/Dec '03, p. 24), at an average of 12 watts for ECM air handlers. It would be a positive development if manufacturers were motivated to reduce the standby loads on their equipment, as the manufacturers of consumer electronics have done.

AND SO ...

The main conclusion that we would draw from this study is that although the use of an ECM has the potential to reduce fan electrical power draw, much of the benefit is lost in systems with excess static pressures. A full analysis of this problem was done by Lawrence Berkeley National Laboratory (Lutz et al., 2006). In other words (as in many cases in the building industry) the benefits of high technology can be defeated by poor design and faulty installation or implementation. Problems can include excessively constricted duct designs and installations, restrictive return plenum fittings, or excessively restrictive filters (see "Is There a Downside to High-MERV Filters?" *HE* Nov/Dec '09, p. 32).

However, with better designs, air handler efficiencies can be improved—significantly beyond the typical values assumed in previous work (that is, 2.5 CFM/W or 0.4 W/CFM). This is especially true when a given air handler is used at the lower end of its speed range. For instance, a 1.5- to 3-ton unit being used at 2 tons air flow at 0.5 IWC static pressure has an efficiency in the range of 3.7 CFM/W (0.27 W/CFM). Of course, reducing air flow for a given size of outdoor unit can have negative consequences, such as reducing overall efficiency (SEER and EER). But this factor can provide additional ammunition when arguing for tighter sizing of cooling equipment, and/or two-stage equipment with a variable-speed air handler. In other words, if you can keep the air flows down (all other things being equal), you are giving your ECM a better chance to achieve high CFM/W efficiencies.

The measurement of air handler efficiency is relatively simple; it can be done mostly with gear that a home performance contractor is likely to have. An air handler powered from an electrical receptacle can be quickly measured with a plug-in power meter such as a Kill-A-Watt. However, power measurements are more time-consuming if the air handler is hard wired. But overall, increasing the data set of installed ECM air handler efficiencies could be very informative, as would measuring and recording the operating external static pressures for these units.

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>> For more information:

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