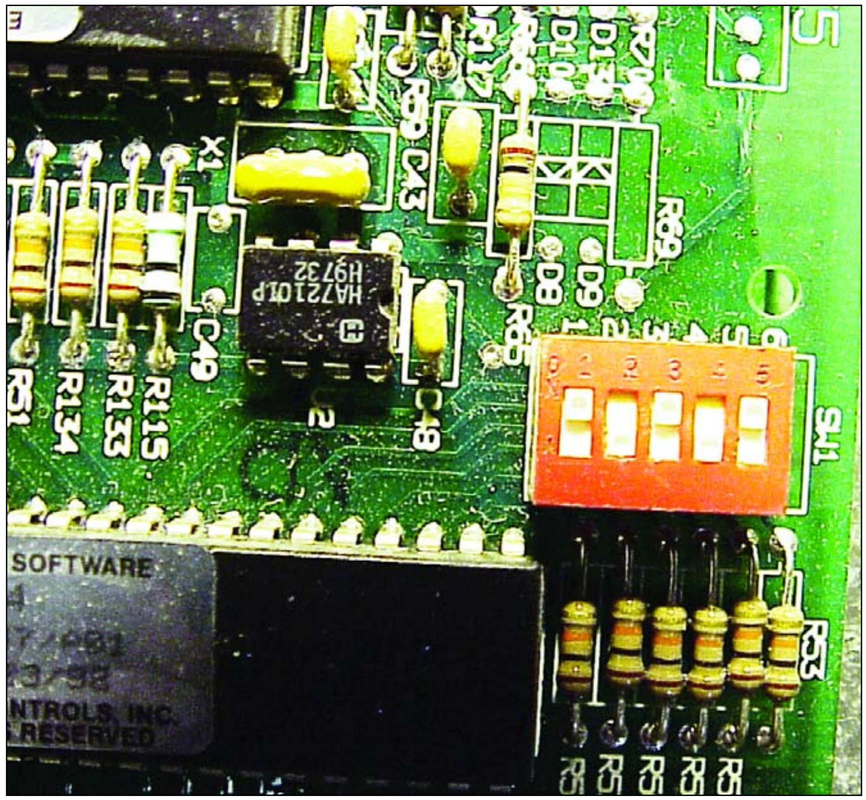
The Electric Side of Gas Furnaces

The motors that drive the fans in air handlers use more power than you might think.

by Scott Pigg



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In much of the United States, space heating is by far the largest energy user in the home, and the venerable forced-air furnace is the most popular means to meet this need. Furnaces are present in nearly 50 million homes around the country. It's no wonder that manufacturers and researchers have spent considerable effort improving the combustion efficiency of furnaces—so much so that some models can wring more than 95% of the energy from their input fuel.

But until recently, the push to develop and promote energy-efficient furnaces has largely ignored the fact that furnaces require a lot of electricity to operate. The furnace fan motor is often the largest motor in the home, and it can easily rack up more than 1,000 hours of operation per year in the course of distributing heat in the winter and cooling in the summer. Furnace electricity use is an especially significant expense in homes where the furnace fan is run continuously for air filtration and other reasons.

The Gas Appliance Manufacturers Association (GAMA) publishes an exhaustive directory of furnace combustion efficiency, as well as a measure of annual furnace electricity use. (Unlike combustion efficiency, which is subject to independent certification, electricity ratings are self-reported by manufacturers.) A quick thumb through the GAMA directory reveals a huge variation in electric consumption among furnaces, ranging from less than 100 kWh per year to well over 1,000 kWh per year. Clearly, furnaces are not all created equal when it comes to electricity use.

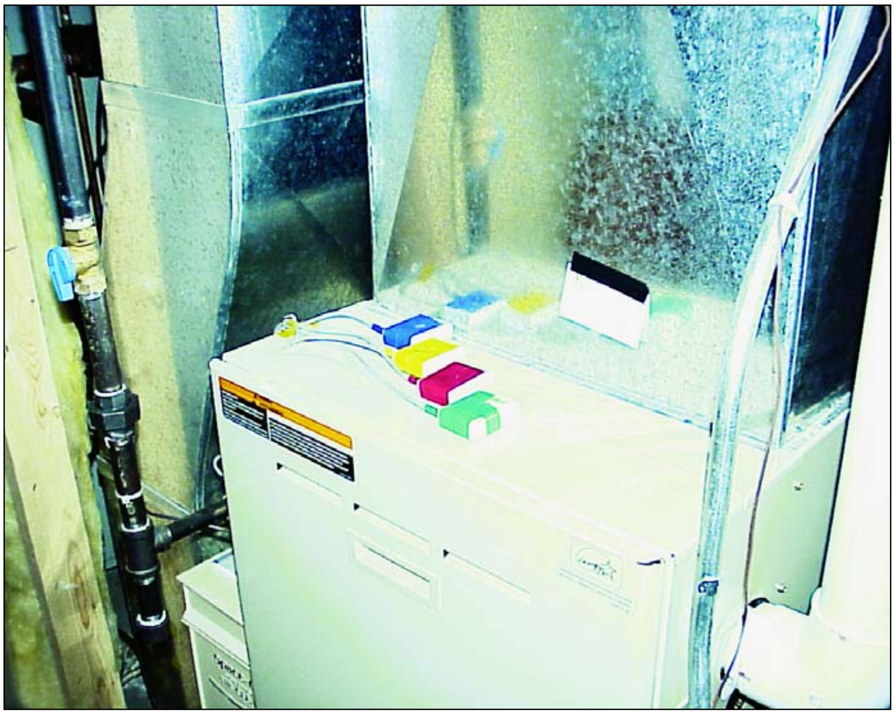
The furnaces with the lowest electricity use ratings use electronically commutated motors (ECMs) instead of the industry standard permanent split-capacitor (PSC) induction motor. ECMs, which are sometimes referred to as brushless DC motors, are known for being somewhat more efficient than a standard blower motor, but mainly for being able to operate over a wider range of speeds with good efficiency (see "Motors Matter," *HE* July/Aug '00, p. 31). These blower motors are often associated with top-of-the-line furnaces that have multistage firing capabilities. Though multistage ECM furnaces have been around for some time, they have only recently started to catch the attention of consumers and energy efficiency advocates.

Wisconsin's Focus on (Motor) Energy

In Wisconsin, ECM furnaces have received interest for the simple reason that the Wisconsin furnace market has been largely transformed in terms of combustion efficiency. Distributor sales data show that eight out of every ten furnaces sold in the state each year are high-efficiency condensing models. With little potential efficiency gains left to achieve on the gas side, Wisconsin's statewide public benefits program, Focus on Energy, began offering cash rewards for electrically efficient ECM furnaces in 2002. Similar rebates are also offered in Oregon and California.

Recognizing that few independent data existed on ECM furnaces and furnace electricity use in general, Wisconsin Energy Conservation Corporation, which administers the residential Focus on Energy programs, asked the Energy Center of Wisconsin, where I work, to undertake a field study of electricity use in new furnaces. The emphasis in the study was on comparing the characteristics of ECM and non-ECM furnaces.

With funding from Focus on Energy, field assistance from Greg Dalhoff of Dalhoff and Associates and George Penn of Global Energy Options, I, with the aid of Brett Bergee and Steve Buss from our office, initiated a field study of 31 new furnaces in Wisconsin in February of 2002. Our goal was to compare the operating characteristics of ECM and non-ECM furnaces, as well as to gather basic data on new furnaces, such as annual hours of operation and annual number of cycles.



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Data loggers attached to each furnace tracked its operation over time. Participants were mailed new data loggers once a month. Brett Bergee of the Energy Center of Wisconsin downloaded more than 750 data loggers over the course of the study.

Most of the 31 furnaces fell into one of two groups: (1) furnaces with PSC blower motors and a single firing stage and (2) furnaces with ECM blower motors and two firing stages. Though other configurations exist, these two groups represent the alternatives faced by most consumers. All of the furnaces in the study were high-efficiency condensing models with sealed combustion and induced draft. The annualized fuel utilization efficiency (AFUE) of the furnaces ranged from 92% to 95%. All but 5 of the furnaces were in new homes, and all were less than three years old at the beginning of the study.

In addition, most of the ECM furnaces in the study used a line of motors manufactured by General Electric, which have a patented mechanism to dynamically adjust the motor speed to maintain constant air flow over a wide range of static pressure. (For this reason, ECM furnaces are sometimes referred to as variable-speed furnaces.)

To conduct the study, we tested each furnace in various operating modes (heating, cooling, continuous fan-only) while recording high-resolution data on electricity use, static pressure, temperature, and air flow. We measured electricity use with Dent ELITEpro data loggers that recorded the power consumed by the furnace as a whole every three seconds, as well as recording the power used by the air handler and combustion blower separately. We logged static pressure and temperature once a second with pressure transducers and temperature sensors connected to Hobo data loggers. Finally, we measured air flow with the Energy Conservatory's TrueFlow air handler flowmeter.

We monitored the operation of the furnaces over the last half of the 2001–02 heating season, as well as the 2002 cooling season. In the fall of 2002,

Furnaces and Leaking Electricity

Like many other modern appliances, furnaces use electricity even when they're not operating. We measured an average of 8 watts of standby power consumption for the non-ECM furnaces in our study. The ECM furnaces in the study averaged 12 watts of standby power, presumably because they have more complicated control circuitry. Over the 7,000-plus hours that the typical furnace spends in standby mode waiting for a call for heating or cooling, that adds 60–90 kWh annually of standby electricity. Better control board design could probably reduce this substantially.

The ultimate solution is better design. A stopgap solution for the consumer—but not a very effective one—is to switch off the power to the furnace during periods when no space conditioning is needed. However, there are only a few months of the year when most people have no heating or cooling needs.

we returned to each site to remove the monitoring equipment and repeat the testing. We used the monitoring data to develop models of the operation of each furnace as a function of outdoor temperature, and then projected their operation to typical annual Wisconsin heating and cooling seasons.

How the Motors Measured Up

Despite the fact that the furnaces were in different houses with varying duct and filter characteristics, the test data clearly confirmed that ECM air handlers generally draw substantially less power than the PSC blower motors, and can efficiently produce air flow over a much wider range (see Figure 1). We found that the ECM furnaces use less electricity—sometimes considerably less—in each of their three operating modes: heating, cooling, and fan-only. They also use a fair amount of electricity over the many thousands of hours they spend each year in standby mode (see "Furnaces and Leaking Electricity").

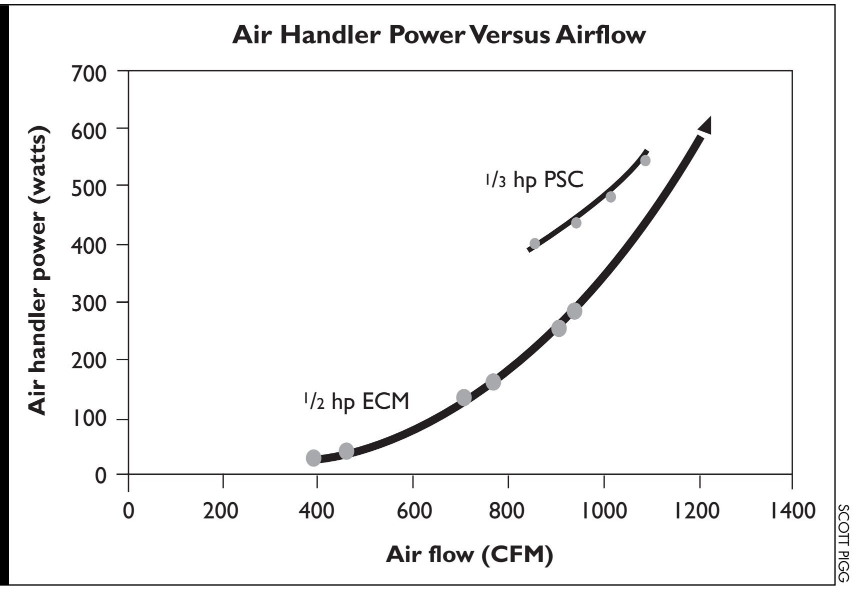


Figure 1. The air flow range of the furnace with the ECM extends beyond that shown in the figure, but the furnace powered by the PSC motor is limited to the four speeds shown. The two 60,000 Btu/hr furnaces operated in similar static pressure environments.

Heating

Heating is the most complicated mode of operation for furnaces, since it involves ignition and shut-down sequences and puts into play the most furnace components (see Figure 2). Though some homes in our study had other heating sources, the data suggest that the typical Wisconsin furnace runs for about 1,000 hours during the heating season, and goes through perhaps 6,000 heating cycles. The average hours of operation we found in the field is fairly consistent with assumptions used to estimate annual gas and electricity consumption for specific furnace models in the GAMA directory (see "What's a Heating Load-Hour?").

For the majority of furnaces in the study, most of the electricity used during the heating season goes toward operating the air handler (Figure 3). An ECM air handler substantially reduces electricity consumption; the average ECM furnace in our study used about 0.5 kWh of electricity per therm of gas consumed, which is about half what we measured for the non-ECM furnaces. That translates into about 400 kWh less electricity over the course of an average heating season in Wisconsin.

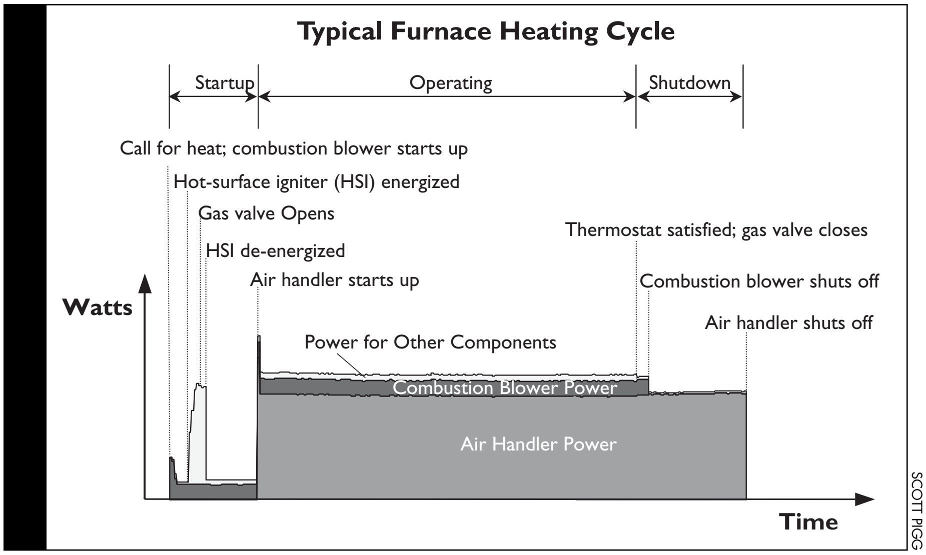
Though they are quite substantial, the heating mode savings we obtained are less than one would expect from the GAMA

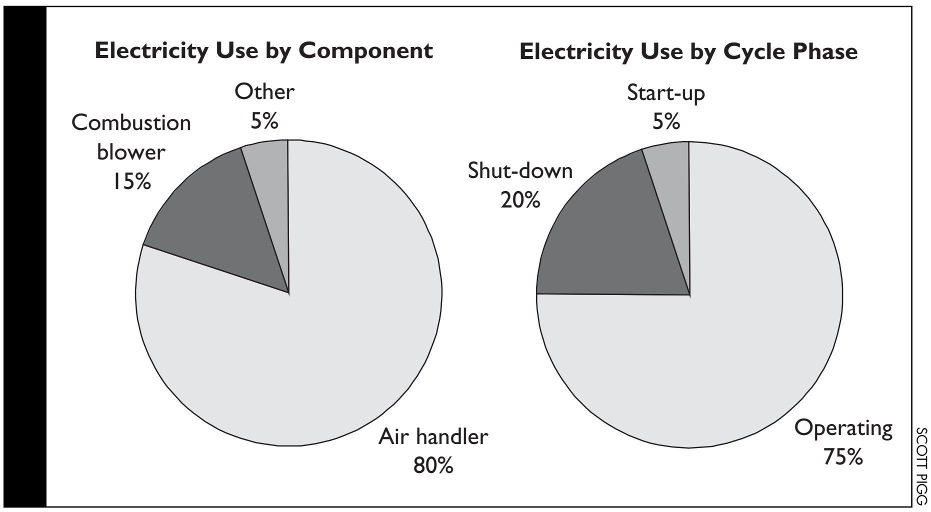
What's a Heating Load-Hour?

Annual gas and electricity consumption ratings for furnaces in the GAMA directory are based on a national average of 2,080 heating load-hours. The GAMA directory provides a map to adjust the ratings to heating load-hours in different areas of the country. Does this mean that the average furnace runs for 2,080 hours per year? No. Furnaces are rated according to ASHRAE Standard 103-1993; a close reading of this standard shows that a heating load-hour is not always what it seems to be.

Two adjustments are needed to get from heating load-hours to the number of hours the burner operates in a heating season. First, the ASHRAE standard applies an empirical adjustment of 0.77 to "adjust the calculated…heating load hours to the actual heating load experienced by the heating system." Second, the 2,080 figure is based on furnaces that are sized to just meet the design heating load of the home. In fact, most furnaces are considerably oversized for their heating load, a fact that is incorporated in the GAMA ratings. Though the assumed amount of oversizing varies with the size of the furnace, it averages about 100%, meaning that a furnace has about twice the heating capacity needed to meet design conditions.

Applying these adjustments shows that 2,080 heating load hours really implies just (2,080 x 0.77/2) 801 burner hours for the national average furnace, or about 960 hours for a furnace in Madison, Wisconsin. The latter figure is very close to the median result of the Wisconsin field study.





(top) **Figure 2.** This figure illustrates electricity use over a typical gas furnace heating cycle. *(bottom)* **Figure 3.** As shown in this breakdown of heating-mode electricity use for a typical (non-ECM) furnace by component and cycle phase, the air handler accounts for most of the electricity use.

directory ratings. Our data suggest that the ratings tend to underestimate electricity use by ECM furnaces, and therefore overestimate the electricity savings from ECMs. The majority of the ECM furnaces in our study used more electricity (per therm of gas) than the rating data would suggest, with the median furnace using about 80% more than its rating value. The non-ECM furnaces, on the other hand, averaged about their rated kWh per therm, with some using more and some using less.

What explains this difference? Though there are many individual factors that affect the operation of furnaces in actual homes compared to standard test conditions ("your mileage may vary"), static pressure—and differences in how the two types of furnaces respond to static pressure—is probably a key one. Static pressure in real homes appears to be far higher than that used in the rating test procedure. Unlike standard furnace fans, most ECM furnace fans compensate for higher static pressure by cranking up to a higher speed to maintain proper air flow. The result is that ECM furnaces in actual homes will use more electricity than they do in the test procedure.

At the outset of the study, we were very curious to find out how much the two-stage ECM furnaces used their reduced firing rate. Manufacturer claims for low-fire operation range from 70% to more than 90% of the time. The assertion that two-stage ECMs offer quieter and more comfortable heating is based on these claims, and the claims were largely supported by the field data. Most of the two-stage ECMs in the study operated almost constantly on low fire. These furnaces run for more hours, but since low-fire operation averages about 65% of full output heating capacity while drawing only 30% of the electrical power used in high-fire operation, they save electricity overall. (The same cannot be said of two-stage furnaces that do not use ECMs.)

In fact, our empirical estimates of furnace sizing in the study indicate that the average furnace is about twice as big as needed to meet the home's peak heating load. For two-stage furnaces, this means that low-fire operation alone can meet the heating load of the home even in severely cold weather. As a rule, high-fire operation for the two-stage furnaces in our study occurred only when the furnace was recovering from a thermostat setback period. The amount of high-fire operation is thus strongly affected by how much—and how often—homeowners set back the thermostat.

For this reason, multistage ECM furnaces offer a technological fix for the furnace-sizing problem; they operate mainly as smaller furnaces, but they offer that extra capacity to kick the temperature back up after a setback. Another plus is that these furnaces may help keep a heating contractor who is worried about installing a too-small furnace from getting the jitters.

It is worth noting that the reduced electricity draw by ECM furnaces means less waste motor heat in the home during the winter, which could be expected to increase gas consumption slightly. Researchers at the National Research Council in Canada who studied furnaces that operate in continuous-fan mode during the winter have documented this effect. For furnaces that operate in fan-auto mode (meaning that the air handler operates only when the furnace is providing heat), the net effect is less clear. Though our calculations suggest perhaps 15 therms of additional gas use per year to make up for the lost motor heat, the AFUE of the ECM furnaces in the study averages about two percentage points higher, which would largely offset this amount.

Finally, multistage ECM furnaces are sometimes marketed as providing more precise temperature control in the living space. Although the 15-minute-interval temperature data we collected at the thermostat allow only a limited examination of that claim, these data suggest that the temperature swing between heating cycles was minimal (within about 0.5ºF of the setpoint) for most of the sites, regardless of whether they had an ECM model or not. Temperature swing is as much—or more—a function of the thermostat—and its location—as it is of the furnace itself.

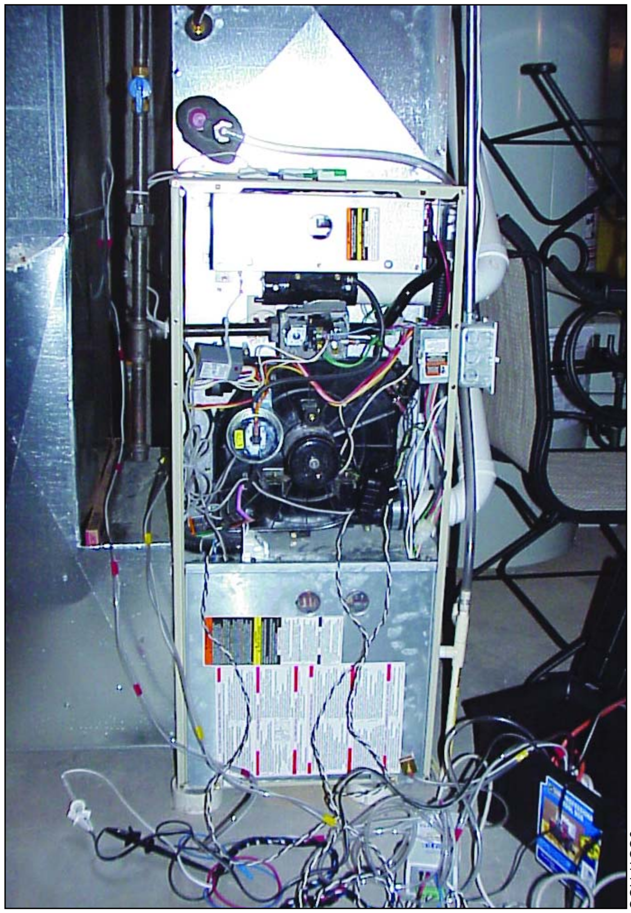
Cooling

In cooling mode, only the furnace air handler operates, but it usually does so at a higher speed than that needed for heating. Our data suggest a 150W–175W reduction in air handler power consumption for ECM furnaces for the 2- to 3.5-ton central air systems that are common in Wisconsin.

During cooling operation, the waste heat from the air handler must be removed by the air conditioning system, so reducing air handler power draw saves both directly, by saving air handler energy, and indirectly, by reducing the load on the air conditioner. Our estimates suggest that the average consumer will save perhaps 80–95 kWh over a Wisconsin cooling season that requires 400 hours of cooling operation. Moreover, the performance of central air conditioning systems can be compromised by inadequate air flow. The ability of most ECMs to deliver a preset air flow—and maintain this over time—helps make the air conditioning system more robust in the face of inadequate attention to providing proper air flow on the part of the installer and inadequate filter maintenance on the part of the homeowner.

Fan-Only Operation

The wide air flow range of the ECM furnaces really comes into play in continuous fan-only operation. Homeowners who use this mode are generally seeking a gentle circulation of air through the home to even out temperature differences, filter air through an electronic air cleaner, or perhaps distribute heat from a wood stove. The ECM furnaces that we studied all had the ability to ramp down to a low air flow of 400–600 CFM (though unfortunately several had been field-configured for higher air flows). The non-ECM furnaces, on the other hand, all ran at the heating speed when operated in fan-only mode, and averaged about 500 watts of power draw, compared to about 100 watts for the ECM models.



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Detailed measurements of electricity use, air flow, and other parameters were made for each furnace in the study.

That extra power draw really adds up over the 7,400 hours of fan-only operation that we estimate to be typical for people who use this mode year-round. These households will save about 3,000 kWh annually—worth $240 at typical Wisconsin electricity prices—by installing an ECM furnace rather than a typical furnace with a PSC air handler.

How many people really practice continuous-fan operation? Five of the 31 participants in our study did so year-round, an additional 3 participants did so consistently during either the heating or cooling season, and 3 participants did so occasionally on an ad hoc basis. We, and others, are currently engaged in additional research to help determine how often (and why) people run their furnace fans continuously.

As the Costs Come Down

Since ECMs are typically bundled with other features as a premium furnace product, the higher cost (currently $500–$600) is not within everyone's budget. An ECM furnace is a no-brainer for households that practice year-round continuous-fan operation; the payback for these consumers is under three years. For others, the quieter and gentler heat of a two-stage ECM furnace is still a worthwhile value. And the cost of these furnaces can be expected to come down as the market for ECM furnaces heats up and contractors become more comfortable with the technology.

The future may bring additional enhancements to furnace air handlers, such as improved fan designs that reduce noise and move air more efficiently. In the meantime, our study substantiates claims that multistage ECM furnaces offer significant electricity savings and quieter operation.

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