Electricity Savings from Variable-Speed Furnaces in Cold Climates

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ABSTRACT

Electricity use by new furnaces has come under scrutiny in the last several years, particularly in states such as Wisconsin where the furnace market has come to be dominated by furnaces with high gas combustion efficiency. This paper examines electricity use among new condensing furnaces in Wisconsin, and focuses on the electricity savings from variable-speed furnaces that use electronically commutated motors (ECMs). Field testing and monitoring of 31 new furnaces, combined with interviews with several hundred purchasers of new furnaces suggest that variable-speed furnaces do indeed offer significant electricity savings over typical condensing furnace models, but the savings in the field are affected by important technical and behavioral factors. Static pressure in the field is considerably higher than that used in the federal test procedure for rating furnaces, with the consequence that ECM furnaces use more electricity than their ratings would suggest. Moreover, the proportion of households that operate their furnace fan continuously is an important determinant of the average savings from the technology. Here the data suggest considerable take-back of savings due to a propensity for heating contractors to advise their customers to switch to continuous fan operation when purchasing an ECM furnace.

Introduction

Forced air furnaces are present in nearly 50 million US homes (EIA 2004), and represent the primary space heating equipment in fully 75 percent of Wisconsin single-family homes (Pigg and Nevius, 2000). Wisconsin also leads the nation in the market share for high efficiency condensing furnaces (GAMA 2002), a situation that is arguably the result of substantial incentives offered by gas utilities in the 1980s and early 1990s (Prahl and Pigg 1997). Indeed tracking data collected from heating equipment distributors in the state indicate that more than 80 percent of current Wisconsin furnace sales are high efficiency condensing models (ECW 2003).

This situation has led policymakers and energy efficiency program planners in Wisconsin to turn their attention to the electricity consumption of new furnaces. Furnace rating data (including electricity consumption) are based on federal test procedures (ASHRAE 1993), and are published by the Gas Appliance Manufacturers Association (GAMA). These show a full order of magnitude range in furnace electricity consumption, even among models with high gas combustion efficiency.

The furnace models with the lowest electrical use ratings all employ electronically commutated motors (ECMs) for the air handler (and sometimes also for the smaller motor that operates the combustion-air fan). ECMs (also known as brushless DC motors) have two principal advantages over the typical permanent-magnet split capacitor (PSC) blower motors found in the majority of furnaces. First, ECMs are claimed to be 20 to 30 percent more efficient than standard blower motors (Byrne, 2000; Sachs et al., 2002). Second, the typical ECM blower can produce a much wider range of airflow than a PSC blower, which typically has only three or four set speeds over a fairly narrow range. Because power consumption by an air handler rises with the cube of airflow, the ability to reduce airflow when appropriate can dramatically reduce the electrical power draw by the air handler.

Furnace manufacturers have taken advantage of this wide dynamic airflow range by bundling ECM-based air handlers with multi-stage firing capability intended to deliver heat at a lower airflow rate over the majority of the heating season. These furnaces also typically operate at a much lower airflow rate in continuous fan-only operation mode that some households use for ventilation, air circulation or air filtration.

To encourage the market for electrically efficient furnaces in Wisconsin, the statewide Focus on Energy program began offering $150 rewards for the purchase of an ECM furnace in 2002. As of 2003, tracking data indicated that about one in five furnaces sold in the state uses the ECM technology, due no doubt at least in part to these incentives.

At the same time, program implementers and evaluators in the state recognized that little independent data existed on the savings from ECM furnaces. To address this need, two studies were commissioned in 2002 and 2003 to investigate the savings from the technology in Wisconsin homes. Both studies were funded by the State of Wisconsin, Wisconsin Department of Administration, Division of Energy, and were funded through the Focus on Energy program. The first (funded by the program administrator, Wisconsin Energy Conservation Corporation) was a field study of the operational characteristics of new ECM and non-ECM furnaces. The second (funded under the auspices of the program evaluation team) was an interview-based effort to better understand how people operate their furnace air handlers—and how that behavior might be affected by the purchase of an ECM furnace.

As the principal investigators for these two studies, our purpose in this paper is to bring together the technical and behavioral elements related to furnace electricity consumption to provide a more complete picture of the savings that derive from installing ECM furnaces in Wisconsin homes. More detailed information on the individual studies is available from the final reports for each of the studies (DOA, 2003 and 2004).

Methods

Field Study

The field study was based on testing and monitoring of 31 new (<3 years old) furnaces in Wisconsin homes. Study participants were recruited from several sources: participants in a prior study of energy use in new homes; participants in the Wisconsin ENERGY STAR Homes (WESH) Program; and, participants in a prior program that provided incentives for home efficiency upgrades, including the purchase of a new furnace. The objectives of the recruiting were to obtain a balance of ECM and non-ECM furnaces, and a wide variety of makes and models. Despite an additional effort to balance the study between new homes and older homes, all but five of the recruited sites ended up being new homes. All of the furnaces in the study were sealed combustion, condensing units with 90 percent or better combustion efficiency, and all were up-flow "northern" models, ranging from 50,000 to 120,000 Btu/hour input. All but one site also had central air conditioning. Fourteen of the furnaces in the study were variable-speed furnaces with ECM air handlers, 16 were single-stage, non-ECM models, and one was a two-stage, non-ECM furnace.

The field study involved a combination of short-term tests on each furnace and monitoring of operation over time. At the time the monitoring equipment was installed, each furnace was instrumented for electrical power, static pressure, supply/return air temperature, and airflow measurements. High resolution (1 to 3 second interval) data on these parameters were then collected as the furnace was put through its various operating modes (heating, cooling, fan-only, and standby). This testing was repeated later when the monitoring equipment was removed.

To monitor the operation of the furnaces over time, status loggers were installed to record the operation of the gas valve and air handler. Low- and high-fire operation was tracked separately for two-stage models. A snapshot of the amperage draw of the furnace was also recorded at 90-second intervals, and the air temperature at the thermostat was recorded at 15-minute intervals. Monitoring was conducted over the last half of the 2001/2002 heating season and the entire 2002 cooling season.

The resulting data were reduced to daily totals for run-time and the number of cycles in various modes. These were regressed against daily degree days for nearby weather stations to obtain individual models of furnace operation (daily operating time and number of cycles) for each site. The models also allowed for a variable base temperature for heating and cooling degree days, as well as separate regressions for low- and high-fire heating operation. When combined with long-term outdoor temperature distribution data, the models could then be used to estimate seasonal and annual operating cycles and run-time in each mode. These estimates were then combined with the testing data on furnace power draw while operating—as well as start-up and shut-down sequence electricity consumption—to estimate weather-normalized electricity and gas consumption.

Consumer and HVAC Contractor Interviews

In late 2003 and early 2004, interviews with Wisconsin householders and HVAC contractors were conducted in order to better understand furnace air handler operation practices in the state, and how the purchase of an ECM furnace might affect those practices. In this study, semi-structured interviews were conducted by experienced professional staff with a total of 436 Wisconsin homeowners in five different groups:

1. *HPWES Participants with ECMs*. Glacier Consulting conducted 150 interviews with owners of existing homes who purchased an ECM furnace through the Focus on Energy Home Performance with ENERGY STAR® program (HPWES). The results from this group were used to estimate savings for ECM furnaces installed in existing homes.
2. *Nonparticipant Furnace Replacers*. Glacier Consulting conducted 36 interviews with owners of existing homes who recently purchased a new furnace outside of HPWES. The sample for this group was identified through the Energy Center's Appliance Sales Tracking Study.[1] As the control group for HPWES participants with ECMs, the results from this group were used to estimate savings for ECM furnaces installed in existing homes.
3. *WESH Homeowners with ECMs*. Glacier Consulting conducted 60 interviews with owners of Wisconsin ENERGY STAR Homes (WESH) homes in which an ECM furnace

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[1] This study was conducted in July–September of 2003 and identified homeowners who had purchased a new forced air furnace in the past year.

was installed. The results from this group were used to determine savings estimates for ECM furnaces installed in WESH homes.

4. *WESH Homeowners without ECMs*. Glacier Consulting conducted 90 interviews with owners of WESH homes in which a furnace without an ECM was installed. As the control group for WESH participants with ECMs, results from this group were used to estimate savings for ECM furnaces installed in WESH homes.
5. *Nonparticipant Non-Replacers*. Glacier Consulting conducted 100 interviews with owners of existing homes who had not recently purchased a furnace. This was a listed sample of owner-occupied housing in Wisconsin. Results from this group were used to indicate the type of furnace fan operation practices being used in the general population of existing homes.

The focus of the interviews was to assess how homeowners operate their furnace fans throughout the year and understand the reasons why operation practices have changed among those homeowners who modified their practices either subsequent to the installation of the new furnace for existing homeowners—or after moving into their new home for WESH homeowners. The interviews also addressed contractor/builder advice on furnace fan operation practices, as well as furnace filter maintenance, housing characteristics and household demographics.

In addition, to explore HVAC contractor perspectives (and influence) on continuous-fan operation with respect to ECM furnaces, interviews were conducted with 30 of the most active HVAC contractors in the state in terms of rebated ECM furnaces. The heating contractors were asked a series of questions to address the types of advice they give to homeowners on furnace fan operation.

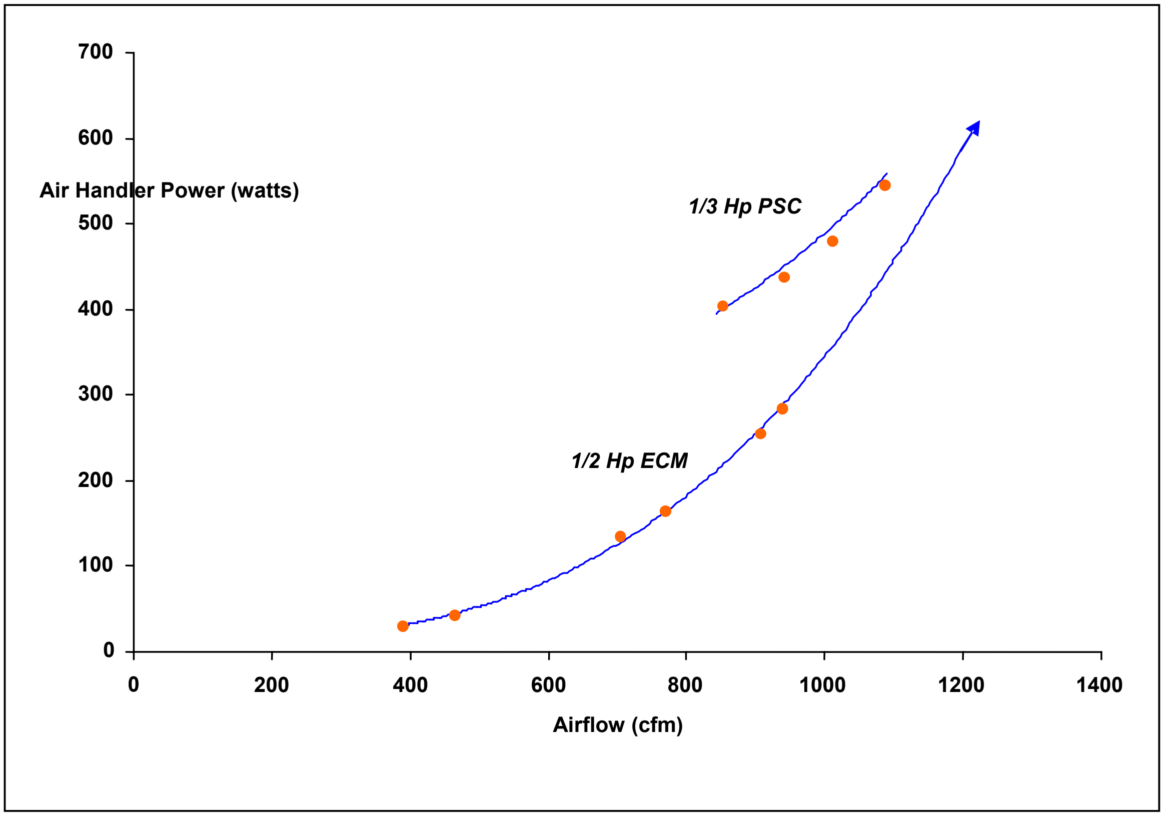
Results

Field Study

Figure 1 illustrates the key differences between the variable-speed ECM furnaces in the study and the single-speed non-ECM models with respect to air handler operation, which the study confirmed to be the dominant determinant of electricity use. Though individual furnaces varied due to differences in site conditions, the two furnaces shown in the figure exemplify the overall pattern that emerged. At any given airflow, the ECM air handler consumes less power due to the inherent efficiency advantage of the ECM compared to a standard PSC motor, despite being a larger motor (all of the ECMs in 60,000 Btu/hr furnaces in the study were 1/2 Hp, and all of the PSCs in furnaces of this size were 1/3 Hp.) Equally (if not more) important, however, is the ability of the variable-speed furnace to operate at lower airflow in low-fire heating and fan-only modes. The cubic relationship between fan power and airflow results in dramatically lower power draw in these modes.

We next examine how these differences play out in the various operating modes for Wisconsin furnaces.

Figure 1. Air Handler Power versus Airflow for Typical 60,000 BTU/hr (63MJ/hr) Furnaces in Similar Static Pressure Environments



Heating Mode

The study data suggest that the typical single-stage, non-ECM furnace in Madison, Wisconsin has about twice the heating capacity needed to maintain a 90F^{o} (50C^{o}) temperature difference between the indoors and outdoors, and will have about 1,000 burner operating hours over the course of an average heating season. These figures are consistent with sizing assumptions built into the federal test procedures and reflected in the rating data.

The multi-stage ECM furnaces in the study operated more hours on average, because most of these furnaces spend the majority of their heating-mode operation time at the reduced firing rate. Nine of the eleven two-stage ECM furnaces in the study operated 70 percent or more of time at low-fire, and the two fully modulating ECM furnaces operated at their lowest output rate more than half the time. Indeed, given the typical degree to which furnaces appear to be oversized for meeting daily heating loads, it appears that high-fire operation is principally needed for recovering from a thermostat setback. Thus, the frequency and depth of thermostat setback determines the proportion of the time a multi-stage furnace will operate at high output. (We would note however, that two furnaces in the study operated more than 90 percent of the time at high-fire: this was apparently the result of interaction between exceptionally long heating cycles at these sites and the staging control algorithm employed by the furnaces, which relied on firing time to determine the need for high-fire.)

Given the large difference in air handler power draw between low- and high-fire for the multi-stage ECM furnaces and the large percentage of the time they tended to operate in this mode, it is not surprising that the median multi-stage ECM furnace used only 0.5 kWh per therm of gas (4.7 kWh/GJ), compared to 1.0 kWh/therm (9.5 kWh/GJ) for the median non-ECM furnace. For a typical Wisconsin home requiring about 800 therms (84GJ) of gas for space heating, this translates into electricity savings of 400 kWh per year in heating mode.

Though substantial, the observed heating-mode savings from the multi-stage ECMs is less than the rating data would suggest. While the non-ECM furnaces in the study averaged about their rated kWh per therm, the median ECM model used 82 percent more than the rated electricity per therm of gas, and 12 of the 14 ECM furnaces used more than their rated electricity per therm.

The most likely explanation for this phenomenon is that static pressure among the sites was generally far higher than that used in the federal test procedure. Although the test procedure stipulates an external static pressure of 0.20 or 0.23 inches (50 or 57 Pa) of water column depending on the output capacity of the furnace, site measurements (taken downstream of the air conditioner evaporator coil on the supply side) showed far higher static pressure environments: these ranged from 0.24 to 1.0 IWC (60 to 249 Pa) with an average of 0.5 IWC (124 Pa) at the airflow corresponding to the highest firing rate.

This results in higher than rated electricity consumption for the ECM furnaces, because nearly all of these furnaces employ a proprietary technology that senses airflow and compensates for higher static pressure by boosting motor speed (and power draw) to maintain the desired airflow. In contrast, the response of a typical PSC blower to higher static pressure is simply to move less air and draw slightly less power.

The static pressures measured in this study are comparable to what others have measured in the field (Phillips, 1998 and Proctor and Parker, 2000), and suggest that the current federal test procedure does not accurately reflect field conditions, a discrepancy to which electricity consumption ratings for ECM furnaces are particularly sensitive.

As a final note on heating-mode operation, the higher electrical efficiency of ECM furnaces has been shown by others to increase gas consumption, particularly if the furnace fan is operated continuously (Gusdorf et al. 2003). This is a consequence of having less motor waste heat in the air stream, which must be made up by slightly longer firing times. As we discuss later in this paper, the electricity savings from continuous-fan operation with an ECM are substantial and almost certainly more than offset extra gas costs. In the more typical fan-auto operation, the effect is less clear: though in theory reduced blower heat would need to be made up on the gas consumption side, the annual fuel utilization efficiency (AFUE) ratings for the ECM furnaces in our study averaged about two percentage points higher than the non-ECM models in the study. If valid under field conditions (the field study did not attempt to measure this effect directly), this would largely offset the need for more gas consumption to compensate for reduced blower heat when the air handler only operates during calls for heating.

Cooling Mode

Figure 2 shows the measured air handler power versus airflow in cooling mode for the sites in the study. The data suggest that at 1000 cfm (which would be typical for a 2.5-ton air conditioner common in Wisconsin) an ECM air handler will draw about 175 Watts less than a PSC air handler. Over the 400 hours of cooling season operation that the monitoring data suggest is typical for Wisconsin, this would result in about 70 kWh of direct cooling-season electricity savings. Reduced power draw by the air handler also means less waste motor heat in the air stream that must be removed by the air conditioner; we estimate these additional indirect savings at about 25 kWh per year.

Fan-Only Mode

We observed the largest difference in operating power in fan-only operation, such as when the thermostat fan switch is set to "on" instead of "auto," or the air handler is interlocked with the operation of central ventilation equipment such as a heat recovery ventilator. In this mode, the furnaces with ECM air handlers generally dropped to their lowest airflow rate (typically 400-500 cfm), and drew a median of 100 Watts of power (Figure 3). In contrast, the PSC-based air handlers ran at the heating speed, producing 800-1,000 cfm of airflow, and drawing a median of 500 Watts of electricity.

Figure 2. Air Handler Power versus Airflow at Cooling Speed

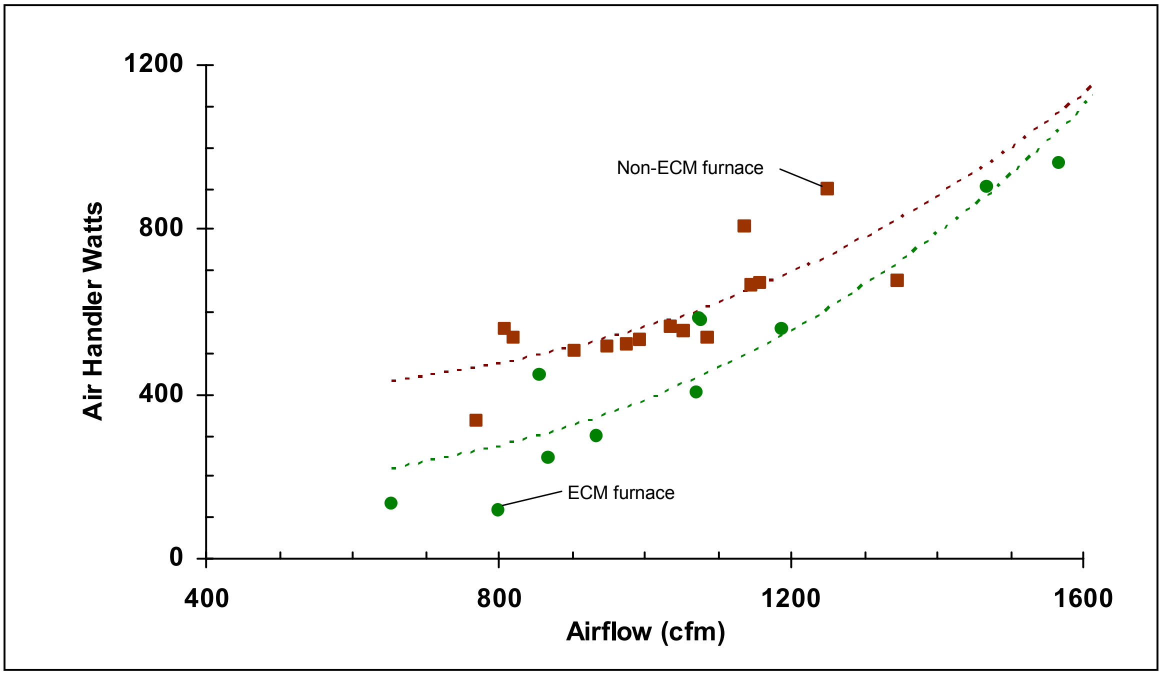
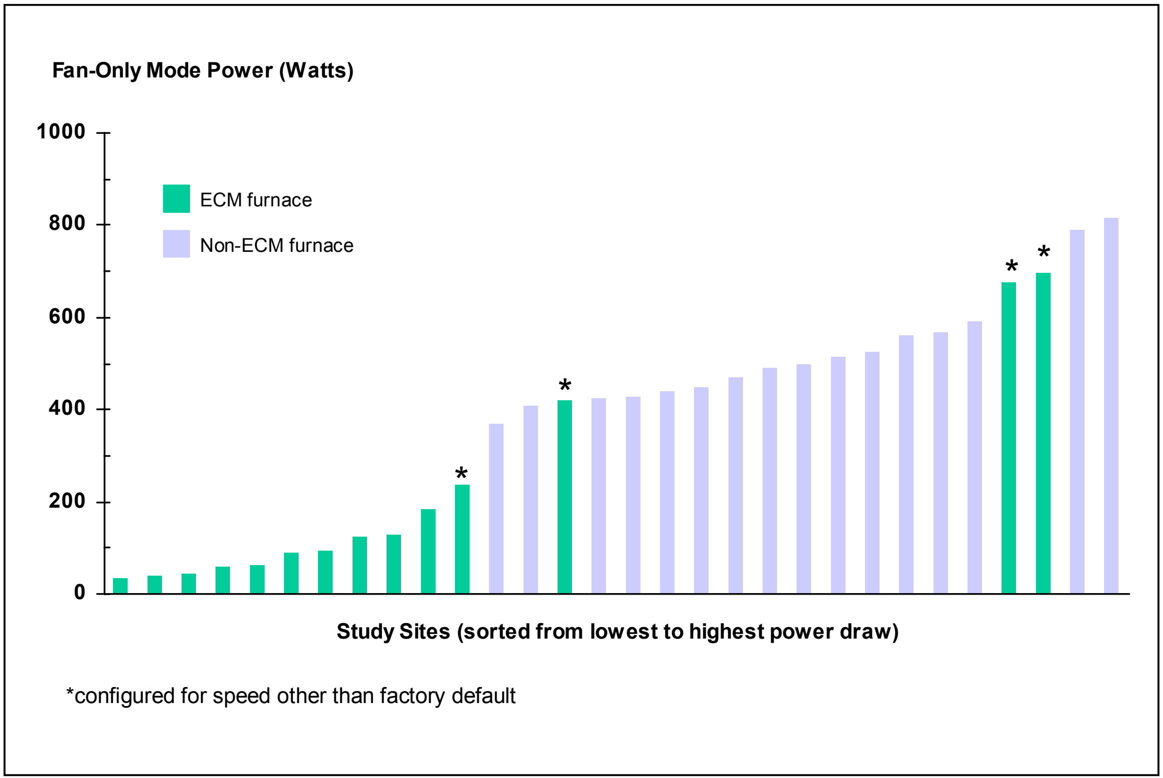


Figure 3. Fan-Only Mode Power Draw



This 400-Watt power draw difference adds up to nearly 3,000 kWh of electricity savings over the 7,400 hours of fan-only operation that the models suggest would be typical of a Wisconsin homeowner operating with a continuous-fan setting year-round. For seasonal continuous-fan operation, the savings would be less dramatic, but still substantial: 1,400 kWh savings over 3,500 hours of continuous-fan operation during the heating season, and 800 kWh over 2,000 hours of operation in the cooling season.

It is noteworthy that four of the 14 ECM air handlers in the study had been unnecessarily field configured for much higher airflow in fan-only operation. This suggests that some installers may not fully understand the benefits of being able to reduce airflow in this mode, and may thus obviate electricity (and comfort) savings in some homes.

Standby Mode

Though not a major power draw, standby mode actually represents the state that most furnaces spend the vast majority of their time in. The study data suggest that a typical Wisconsin furnace that is called upon to operate only when there is a demand for heating or cooling will spend about 7,500 hours per year in standby mode.

Standby mode power draw ranged from 4 to 13 Watts, with the multi-stage, ECM-based furnaces drawing about 4 Watts more on average than their more conventional counterparts—likely due to the more complicated control circuitry involved. Over the course of a typical year, this suggests that a multi-stage ECM furnace will use about 30 kWh more electricity in standby mode than a comparable single-stage, PSC-based model.

Table 1 summarizes the electricity savings that the field study suggests would be typical of installing a multi-stage ECM-based furnace in a Wisconsin home instead of a single-stage, PSC-based model. As the table shows, the savings can vary over nearly an order of magnitude, depending primarily on the extent to which continuous-fan operation is used for air circulation or filtration exclusive of calls for heating and cooling. The average electricity savings experienced in a population of households that installs these furnaces thus depends strongly on the proportion of households that practice continuous-fan operation at various times of the year. To assess this issue, we turn now to the results of the consumer and contractor interviews that examined this question directly.

Table 1. Summary of Annual Electricity Use and ECM Savings For a Typical Wisconsin Home

	No continuous-fan use			Year-round continuous-fan use		
Mode of Operation	**Non-ECM**	**ECM**	**Difference**	**Non-ECM**	**ECM**	**Difference**
Heating (kWh)[a]	800	400	400	800	400	400
Cooling (kWh)[b]	225	155	70	225	155	70
Continuous-Fan (kWh)	0	0	0	3,700	740	2,960
Standby (kWh)	60	90	-30	0	0	0
Total (kWh)	1,085	645	440	4,725	1,295	3,430
Indirect AC (kWh)[c]			25			25
Overall including indirect (kWh)			465			3,455

[a] For annual gas use of 800 therms.

[b] For a 2.5-ton air conditioner with airflow of 1000 cfm and 400 hours of operation per year.

[c] Represents additional air conditioning electricity difference from reduced need to remove air handler waste heat.

Consumer and Contractor Interviews on Fan Operation Practices

Table 2 summarizes the furnace fan operation practices used throughout the year by households in each of the five interview groups of homeowners. In this table, "auto" refers to households that consistently keep the thermostat fan switch set to "auto" so that the air handler operates only when there is a call for heating or cooling; "continuous" refers to households that consistently keep the fan switch set to "on" so that the air handler operates continuously regardless of the need for heating or cooling; and, "sporadic" refers to households that practice continuous-fan operation on an ad hoc basis, but not consistently.

As the table shows, the incidence of continuous furnace fan operation varies significantly across the groups. Participating homeowners with ECM furnaces and those living in new WESH homes are much more likely to practice continuous-fan operation than are nonparticipating households in existing homes that have replaced a furnace recently and those that have not replaced a furnace recently.

Table 2. Furnace Fan Operation Practices

Season	Fan Operation Practice	HPWES Participants	WESH Participants		Nonparticipants	
		Existing Homes w/ECM Furnace (n=150)	New Homes w/ECM Furnace (n=60)	New Homes w/o ECM Furnace (n=90)	Replaced Furnace in Last Year (n=36)	Not Replaced Furnace in Last Year (n=100)
Heating Season	Auto	61%	50%	69%	92%	91%
	Continuous	33%	33%	21%	6%	3%
	Sporadic	6%	17%	10%	3%	6%
Cooling Season	Auto	54%	53%	61%	78%	85%
	Continuous	35%	32%	29%	14%	2%
	Sporadic	11%	15%	10%	8%	13%
Shoulder Periods	Auto	72%	68%	76%	89%	87%
	Continuous	19%	18%	13%	6%	2%
	Sporadic	9%	13%	11%	6%	11%

It is also revealing to examine how fan operation practices changed following the purchase of a new furnace (as well as—in the case of WESH participants—moving into a new home). As Table 3 shows, participating homeowners who purchased an ECM furnace, either as a replacement for a furnace in an existing home or with a new home, are more likely to have changed their fan operation practices than those who purchased a non-ECM furnace. Moreover, the direction of this change is toward a higher incidence of continuous-fan operation. In the remainder of this section, we discuss these findings in more detail (separately for existing and new homes) and then show the ramifications of these findings on savings.

Existing homes. Nearly one in four (23%) households that received a cash reward for the purchase of a replacement ECM furnace switched from auto to continuous fan operation during the heating season after the purchase of their ECM furnace, compared to three percent of nonparticipating households in existing homes that have replaced a furnace recently. Thus, among the one-third of households in this group of ECM furnace purchasers who practiced continuous-fan operation at the time of the interview, the majority (70 percent) had not done so prior to the purchase of the ECM furnace.

On the other hand, households that received a cash reward for the purchase of a replacement ECM furnace have a higher incidence of continuous fan operation both before and after the furnace installation compared to nonparticipating households in existing homes that have replaced a furnace recently and those that have not replaced a furnace recently (9% vs. 0% and 3%, respectively). This indicates that the HPWES program is achieving some success at attracting customers who are predisposed to continuous fan operation, an outcome with the greatest savings potential.

Table 3. Changes in Furnace Fan Operation Practices

Season	Previous Practice	Current Practice	HPWES Participants	WESH Participants		Nonparticipants	
			Existing Homes w/ECM Furnace[a] (n=150)	New Homes w/ECM Furnace[b] (n=60)	New Homes w/o ECM Furnace[b] (n=90)	Replaced Furnace in Last Year[a] (n=36)	Not Replaced Furnace in Last Year[c] (n=100)
Heating Season	Auto		60%	48%	68%	92%	91%
	Continuous		9%	13%	11%	3%	3%
	Sporadic		3%	3%	4%	3%	6%
	Auto	Continuous	23%	18%	10%	3%	—
	Auto	Sporadic	3%	13%	6%	0%	—
	Other[d]		3%	3%	1%	0%	—
Cooling Season	Auto		53%	52%	59%	78%	85%
	Continuous		14%	17%	19%	8%	2%
	Sporadic		10%	5%	10%	8%	13%
	Auto	Continuous	19%	12%	10%	6%	—
	Auto	Sporadic	1%	10%	0%	0%	—
	Other[d]		3%	5%	2%	0%	—
Shoulder Periods	Auto		72%	67%	76%	89%	87%
	Continuous		5%	8%	8%	3%	2%
	Sporadic		5%	5%	10%	6%	11%
	Auto	Continuous	12%	10%	6%	3%	—
	Auto	Sporadic	4%	8%	1%	0%	—
	Other[d]		2%	2%	0%	0%	—

[a] Previous furnace operation method represents how previous furnace was operated before installation of new furnace.

[b] Previous furnace operation method represents how furnace was operated in previous home.

[c] Although there were no furnace replacements within this group, results on this group's current operation is included again in this table to facilitate comparison to other groups.

[d] Includes less frequently occurring changes, specifically changing from: (1) sporadic to continuous, (2) continuous to sporadic, (3) continuous to auto, and (4) sporadic to auto.

Similarly, it is possible that homeowners who switch to continuous-fan operation are predisposed to this switching behavior and deliberately seek out ECM furnaces in order to save on operating costs. The data, however, suggest that in the majority of these cases, another factor is at work; namely, the advice of the heating contractor who installs the unit. When asked why they had switched from fan-auto to fan-continuous operation, participants most prevalently cited that this change in behavior was based on advice from their HVAC contractor.

The interviews with contractors support this assertion. When asked how often they recommend continuous fan operation to customers who install ECM furnaces, almost all of the contractors recommend continuous fan operation at least half of the time—and 60 percent reported making this recommendation all of the time. Next, we asked about *why* they recommend continuous fan operation to customers who install ECM furnaces. The common themes that emerged involve comfort (through more even temperatures in the house), air quality (consistent filtering), and low cost (inexpensive to run fan on ECM furnace continuously).

We also asked contractors if customers who operated their previous furnace in auto mode would decrease their electricity and/or natural gas usage if they were to install an ECM furnace and change their furnace fan operation practice from auto to continuous mode. About three-quarters of contractors reported that switching furnace fan operation practices from auto to continuous mode when installing an ECM furnace would decrease electricity usage (and slightly more than half reported that this change in practice would decrease natural gas usage). In fact, the field data indicate that even at the low wattage draw of an ECM, operating in continuous-fan mode year-round represents a slight *increase* in furnace electricity use. Information from their manufacturers was cited frequently as the basis for their opinion, and many of the contractors who thought that continuous-fan operation would decrease natural gas usage believed that the thermostat would not call for heat from the furnace as often because continuous fan operation would provide more even temperatures in the house.

Finally, we asked contractors how often they recommend continuous fan operation to customers who install furnaces without ECMs. About a quarter of contractors never make this recommendation while 40 percent reported making this recommendation infrequently or rarely, and only 13 percent reported making this recommendation at least half the time (with 10 percent making this recommendation all of the time) to customers who install furnaces without ECMs.

New homes. After moving into their WESH home, nearly one in five (18%) households in the ECM group switched from auto to continuous fan operation during the heating season, compared to ten percent of households in the non-ECM group. This result is similar to that for existing homes, except that the difference in the incidence of switching between the ECM and non-ECM groups for WESH households is smaller.

The incidence of continuous fan operation both before and after moving is comparable among the ECM and non-ECM groups for WESH households (13% during the heating season in the ECM group and 11% in the non-ECM group). This indicates that WESH households have the same predisposition to continuous fan operation, regardless of whether or not the WESH home has an ECM furnace. This result is different than that for existing homes, where the ECM group was more likely to be predisposed to continuous fan operation.

Finally, it is possible that WESH homeowners who switch to continuous-fan operation are predisposed to this switching behavior and deliberately seek out WESH homes with ECM furnaces in order to save on operating costs. As with existing homes, the data suggest that in the majority of these cases the advice of the builder or the HVAC contractor appears to play a key role: when asked why they had switched from fan-auto to fan-continuous operation, both groups of WESH homeowners most prevalently cited that this change in behavior was based on the advice of their builder or heating contractor. The primary factors on which this advice is based include: presence of an air to air exchanger; moisture control; air filtration; and more even temperature distribution.

Ramifications on savings. The above findings show that a considerable number of homeowners who purchase ECM furnaces switch from auto- to continuous-fan operation. The root cause for this change has substantial ramifications on ECM furnace savings estimates. At one extreme, if switching is due entirely to installation of the ECM furnace (technology-induced), then the savings from the installation of the ECM furnace are entirely negated and energy use actually increases. This is because the increase in operating hours from switching more than offsets the increase in efficiency of the ECM furnace over the non-ECM furnace.

At the other extreme, if switching is due entirely to the installation of new furnaces in general and is independent of the installation of an ECM furnace (naturally occurring), then savings from the installation of the ECM furnace increase. This is because these homeowners would have switched behavior even if they had installed a non-ECM furnace. Therefore, the degree to which switching fan operation behavior is technology-induced or naturally occurring is crucial for determining ECM furnace savings estimates.

Based on the survey data, we considered using three different baseline scenarios from which to calculate ECM savings for participants who switched fan operation behavior subsequent to the ECM furnace. The first is to use practices of participants before the installation as the baseline. This assumes that all switching is technology-induced. The second is to use the practices of participants after the installation as the baseline. This assumes that all switching is naturally occurring. The third is to use changes in practices among a control group to understand naturally occurring changes in practices. This assumes that the incidence of changes in practices among the control group is representative of changes in practices that are naturally occurring due to the installation of new furnaces in general.

As Table 4 illustrates, savings estimates vary widely depending on the baseline assumptions used.

Table 4. Alternate Baseline Assumptions

Program	**Savings Estimates by Baseline Assumptions**		
	Before Installation (All Switching Technology-Induced)	**Control Group**	**After Installation (All Switching Naturally Occurring)**
HPWES (Existing Homes)	646	773	1,407
WESH (New Homes)	772	1,126	1,363

For existing homes, the use of the control group results in a much higher prevalence of technology-induced versus naturally occurring switching. For example, the 773 kWh estimate is much closer to the 646 kWh estimate, which assumes that all changes were technology-induced, than the 1,407 kWh estimate, which assumes that all changes are naturally occurring. In other words, the use of the control group tells us that homeowners who install ECM furnaces tend to increase their furnace fan operation more than would be expected (via the switching behavior of the control group) had they installed a non-ECM furnace. We assert that the predominance of technology-induced over naturally occurring switching is entirely reasonable given that advice from HVAC contractors/builders plays a pivotal role in homeowner's decision to change from auto to continuous mode subsequent to the installation of the ECM furnace.

While there are several limitations to this study, the two which we view as most significant are related to the control group.[2] First, the control group is based on a relatively small

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[2] We also have identified three other key limitations to this study. First, while the study provides a snapshot of furnace fan operation practices at a point in time, it is reasonable to expect that furnace fan operation practices in the market may change over time and this study did not address broader market trends over time. Second, the study did not formally address the potential effects of furnace fan operation methods on the run times of furnaces and CACs.

sample size of nonparticipant replacers. Unfortunately, the budget allocated for this evaluation research was not sufficient to fund the extra cost to identify additional nonparticipant replacers. Second, self-selection issues are inherent in any research that employs a control group. In this study, for example, we cannot say with certainty that participants are not comprised of those who are predisposed to switching furnace fan behavior. While future research can attempt to address self-selection issues, the efforts will be hindered by the fact that the data required from the respondent is based, in part, on responses to hypothetical scenarios and self-reported actions in the absence of information to which they have already been exposed. In other words, the purchase decision process they experienced as a result of the ECM furnace installation has the potential to bias their responses to hypothetical questions about what they would have done in the absence of going through the purchase process in the first place.

Despite the study's limitations, the findings clearly demonstrate that (1) a considerable number of homeowners who purchase ECM furnaces switch from auto- to continuous-fan operation; (2) advice from HVAC contractors/builders plays a pivotal role in homeowner's decision to increase fan operation; and, (3) HVAC contractors are much more likely to tell homeowners to increase their fan operation if they install an ECM furnace versus a non-ECM furnace. When taken together, these three findings are indicative of technology-induced switching behavior, which is entirely consistent with the representation of the control group. Therefore, we conclude that the control group provides the best possible benchmark currently available for determining the extent to which switching fan operation behavior subsequent to the installation of the ECM furnace is technology-induced versus naturally occurring.

Conclusions

The field study evidence indicates that multi-stage furnaces using ECMs are substantially more electrically efficient than their more conventional counterparts. However, they appear to save less in the field than their rating data would suggest, due to the fact that the static pressure in the field is typically higher than that used in the rating procedure. The sensitivity of ECM furnace electricity use to static pressure suggests that one way to maximize the electricity savings from these furnaces is through careful attention to filter selection and maintenance, as well as (in the case of new construction) duct design to minimize airflow resistance. Though one of the selling points of ECMs is that they maintain the appropriate airflow regardless of static pressure, they achieve this at the expense of some of their efficiency advantage.

To the consumer, arguably the main selling point for multi-stage ECM furnaces is that they operate much of the time at reduced airflows, and are therefore noticeably quieter and less likely to produce uncomfortable drafts. However, here we have the interesting situation in which heating contractors are apparently advising consumers to, in essence, trade away the electricity savings from these furnaces to gain perceived comfort advantages from low-level continuous fan operation. From an energy policy standpoint, this phenomenon serves to reduce the average impact of the technology on electricity consumption, as some consumers take back the electricity savings in the form of increased air handler run time. The energy consumption and comfort trade-offs associated with continuous-fan operation bear additional investigating, both in terms

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Third, although the study identified a number of potential non-energy benefits from increased fan operation, the study did not formally assess the extent to which these benefits accrued to homeowners.

of empirical evidence of the impact on indoor temperature variation and air quality, as well as the perception of consumers about these trade-offs.

References

American Society for Heating Refrigeration and Air Conditioning Engineers (ASHRAE). 1993. "Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers," ANSI/ASHRAE Standard 103-1993. Atlanta, Georgia; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Byrne, Jeanne. 2000. "Motors Matter," in *Home Energy Magazine*, July/August 2000.

Wisconsin Department of Administration (DOA). 2003. *Electricity Use by New Furnaces: A Wisconsin Field Study*. Technical Report 230-1. Madison, Wisconsin: Wisconsin Department of Administration.

Wisconsin Department of Administration (DOA). 2004. *ECM Furnace Fan Impact Assessment*. Focus on Energy Statewide Evaluation Report. Madison, Wisconsin: Wisconsin Department of Administration.

Energy Center of Wisconsin (ECW). 2003. Unpublished data from Furnace and Air Conditioner Tracking System (FACTS) project.

Energy Information Agency (EIA) 2004. Residential Energy Consumption Survey (Preliminary Data); www.eia.doe.gov/emeu/recs/

Gas Appliance Manufacturers Association (GAMA). 2002. Historical shipment data provided by Mark Kendall under Department of Energy Docket EE-RM/STD-01-350.

Gusdorf, J, M Swinton, E Entchev, C Simpson, and B Castellan. 2003. "The Impact of ECM furnace motors on natural gas use and overall energy use during the heating season of CCHT research facility." Institute for Research in Construction, NRCC-38443, www.nrc.ca/irc/ircpubs.

Phillips, Bert. 1998. "Impact of Blower Performance on Residential Forced-Air Heating System Performance." In *ASHRAE Transactions*, V. 104, Pt.1. Atlanta, Georgia; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Pigg, Scott and Monica Nevius. 2000. *Energy and Housing in Wisconsin: A Study of Single-Family Owner-Occupied Homes.* Report 199-1. Madison, Wisconsin: Energy Center of Wisconsin,

Prahl, Ralph, and Scott Pigg. 1997. "Do the Market Effects of Utility Energy Efficiency Programs Last? Evidence from Wisconsin," in *Proceedings of the 1997 Energy Evaluation Conference*, Chicago, 523-531.

Proctor, John, and Danny Parker. 2000. "Hidden Power Drains: Residential Heating and Cooling Fan Power Demand," in *Proceedings of the 2000 American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings.* Washington, D.C.; American Council for an Energy-Efficient Economy.

Sachs, Harvey, Toru Kubo, Sandy Smith and Kalon Scott. 2002. "Residential HVAC Fans and Motors Are Bigger than Refrigerators," In *Proceedings of the 2002 American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy.