A new residential opportunity: variable speed furnace motors

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Abstract

This study reports on the results of an evaluation of BC Hydro's Variable Speed Furnace Motor Program. There are four main conclusions as follows: first, the Variable Speed Furnace Motor Program has achieved high levels of program participation and high levels of participant satisfaction, but it has been less successful in achieving high levels of awareness and interest in variable speed furnace motors. Second, the effectiveness of financial incentives has been examined through survey information and through econometric models. Analysis of both of these sets of data sources indicates that financial incentives have a significant effect on the customer decision to install a variable speed motor as part of a furnace retrofit. Financial incentives reduce the cost of installing a variable speed motor and consequently increase take-up. Third, evaluated energy savings are 7.2 GWh per year compared to reported energy savings of 5.0 GWh per year. Evaluated peak savings are 1.4 MW compared to reported peak savings of 1.5 MW. Evaluated energy savings are higher than reported energy savings because survey data indicated that annual hours of use are higher than was formerly thought to be the case. The ratio of peak savings to reported energy savings is also lower than reported because of the high hours of use. Fourth, the results of a survey of suppliers including furnace dealers, heating contractors and gas fitters has been used to estimate incremental costs for variable speed furnace motors of $426 for 2008. The price differential between and variable speed motors (efficient) and permanent split capacitor motors (baseline) fell from $513 in 2003 to $426 in 2007.

Introduction

To capture additional energy savings opportunities, residential demand-side management programs need to move beyond their traditional focus on lighting, appliances and shell measures. Interest in improving the efficiency of air handling equipment had been a long standing technical issue that has recently become of broader interest. A range of technologies exist for furnace fan motors including shaded pole, capacitor start, single speed permanent split capacitor and variable speed motors. Older shaded pole motors have efficiencies as low as 10% to 25%, while newer permanent split capacitor models have efficiencies of 55% to 67% in high-speed mode and 34% to 39% in low speed mode. The more efficient variable speed models have 74% to 78% efficiency in high speed mode and greater than 70% in low speed mode. In his ACEEE article, Sachs [1] discusses motor and fan efficiency as well as opportunities for lowing electricity consumption from ductwork. He concludes that an overall reduction of 500 kWh per year per household is possible through the adoption of variable speed motors.

Several studies have examined various aspects of electricity use for furnace fans and blowers. Phillips [2] noted that the switch from shaded pole furnace motors to permanent split capacitor furnace motors, improvements in motor design and improvements in fan design led to nearly a 20% increase in the efficiency of furnace fans. However, this did not translate into reduced energy use because typical power requirements increased from 350 watts to 500 watts. Sachs [1] estimated that 95% of furnaces sold in the United States had permanent split capacitor motors. He noted that over-sizing of furnaces and fans is common, leading to increased energy use. Gusdorf et al. [3] compared energy use in two identical test houses where one was equipped with a permanent split capacitor motor and one with a direct current permanent magnet (variable speed) motor. During heating season use, the variable speed motor reduced electricity consumption by 74%, and during cooling season use the variable speed motor reduced electricity use by 48%. Pigg [4] undertook field testing of 29 furnaces in Wisconsin. He found that static pressure substantially affects the savings from the use of variable speed fans. Lutz [5] examined the impact of static duct pressure on the expected savings of variable speed motors. The study found that in comparing the electricity consumption of single stage furnace with a permanent split capacitor motor with a two-stage furnace with a variable speed motor, the savings were substantially less than expected.

This evaluation indicates that if a standard furnace fan uses approximately 1,500 kWh per year in heating climates, then it can be reduced to about 500 kWh per year if direct current permanent magnet or variable speed furnace motors are used instead of single-speed, permanent split capacitor motors.

BC HYDRO VARIABLE SPEED FURNACE MOTOR PROGRAM

British Columbia is Canada's westernmost province, is located on the Pacific coast, and has a land and freshwater area of 95 million hectares. It is Canada's third largest province and is larger than any state except Alaska. BC Hydro is one of North America's leading providers of clean, renewable energy serving approximately 95% of the province's population and 1.7 million residential, institutional, business and industrial customers. BC Hydro's facilities generate 54,000 gigawatt hours of electricity annually and electricity is delivered through a network of 18,336 kilometres of transmission lines and 55,705 kilometres of distribution lines. Power Smart conservation programs deliver cost effective energy, producing cumulative annual incremental energy savings of 2,518 gigawatt hours.

The BC Hydro Power Smart Variable Speed Furnace Motor Program provides a financial incentive to encourage residential customers, who are replacing their natural gas furnace, to install a variable speed furnace motor as part of the retrofit. The program is a component of a broader furnace retrofit program conducted jointly by BC Hydro, Terasen Gas and Natural Resources Canada. BC Hydro has participated with Terasen Gas in two major furnace upgrade programs since2000, with Terasen Gas responsible for the furnace upgrade component, and BC Hydro responsible for the furnace motor upgrade component. The first BC Hydro program was offered between June 2003 and December 2003, and it provided a $150 incentive for the installation of a variable speed furnace motor as part of the furnace retrofit. The second BC Hydro program was co-funded by Natural Resources Canada. Between September 2005 and March 2007 this initiative provided a $100 incentive for the installation of a variable speed motor.

When the first variable speed motor program was launched, several factors provided the rationale for the program, which aimed at increasing the sales of variable speed motors in replacement furnaces. These factors included:

1. Increased availability and reliability of direct current permanent magnet motors which can operate at up to four speeds and which are substantially more efficient than the commonly used, single speed, permanent split capacitor motors.
2. Rapid growth in sales of two-stage furnaces that operate up to 90% of the time in low firing mode, which may be associated with an increase in the number of fan operating hours during the heating season, by perhaps 40% to 50%.
3. Increased use of the furnace blower motor to partially meet home ventilation requirements, which can result in an increase in fan operating hours by an additional 8 hours per day.
4. Low customer and trade ally awareness and knowledge of the nature, efficiency, and reliability of variable speed furnace motors compared to the commonly used single speed motors.

Approach

This paper reports on the process, market, and impact evaluation of a variable speed furnace motor program. The main evaluation methodology for this study is a post-only, quasi-experimental design. The post-only, quasi-experimental design uses post-program measurement of a participant group who installed variable speed motor with an efficient furnace and a non-participant comparison group who installed a permanent split capacitor motor with the new efficient furnace. The key idea is that if the participant and non-participant groups are reasonably similar, then differences in outcomes for the two groups can be plausibly viewed as due to the installation of a variable speed motor and therefore attributable to the program. Conversely, if the participant and non-participant groups are dissimilar, then differences in outcomes might be due to differences between the groups rather than the installation of the variable speed motor. Analysis is based on comparisons between the participant and non-participant groups for various indicators, and the statistical significance of the differences is quantified using z-tests.

For this study there are five main sets of evaluation issues, as noted below.

- **Program Review.** Determine the level of customer awareness of the program and the level of customer satisfaction with various program attributes and review the logic of the program model.
- **Supply Side Assessment.** Assess trade ally views of the replacement furnace motor market, including sales, prices, and incremental costs by type of motor.
- **Demand Side Assessment.** Assess the determinants of customer choice of furnace system, assess customer satisfaction with furnace system attributes and estimate the free rider rate[1].

1. Free ridership represents activities undertaken by participants who would have conducted the same activities if there had been no initiative (project, program, policy instrument). Energy savings from free riders are not attributable to the initia-

Table 1. Evaluation Issues, Data Sources and Methods

Evaluation Issue	Main Data Sources	Method
Program review	Program interviews Participant survey Non-participant survey	z-tests
Supply side assessment	Trade ally Survey Literature review	Cross tabulations
Demand side assessment	Participant survey Non-participant survey	z-tests
Market model	Trade ally surveys Official data	Multiple regression analysis
Energy and peak savings	Participant survey Non-participant	Engineering algorithms

Table 2. Trade Ally Survey Respondents

Description	Number	Percent
Furnace dealer and heating contractor	9	18%
Independent heating contractor	13	26%
Gas fitter	2	4%
All of the above	23	46%
Other	3	6%
Total	50	100%

Table 3. Participant and Non-participant Characteristics (Percent)

Dimension	Participant (n = 100)	Non-Participant (n = 100)	Difference	z-value
Share 55 or older	54%	63%	-9%	-1.29
Share married/common law	81%	71%	10%	1.66
Share completed university/college	39%	33%	6%	0.88

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

- **Market Model.** Estimate a demand and supply model for variable speed furnace motors.
- **Energy and Peak Savings.** Evaluate net energy and peak savings due to the program through March 2008. Where net or incremental energy savings due to the Variable Speed Motor program.

The evaluation issues, data sources, and methods for the study are summarized in Table 1.

DATA SOURCES

A number of data sources were used for this study. A trade ally survey of 50 establishments was used to collect information on supply side characteristics from. A participant survey of 100 randomly chosen participating customers and a non-participant survey of 100 randomly chosen non-participating customers were used to collect information on demand side characteristics. The trade ally and customer survey data was collected in 2007 [6, 7]. Surveys conducted previously were also used to build the database for the market modelling [8].

Table 2 summarizes the business types sampled for the trade ally survey. The 50 businesses surveyed included furnace dealers and heating contractors, independent heating contractors, gas fitters, and others. Surveyed trade allies were asked how they described their business activity with the results shown in Table 2.

Table 3 compares the participant and the non-participant groups on several key characteristics, which may be drivers of the decision to purchase a variable speed furnace motor. Here we are interested in determining whether or not there are significant differences between the participant and non-participant groups that might explain differences in outcomes. The difference between the participant and non-participant group characteristics is examined using standard z-tests for the difference between population proportions. Since none of the z-values are statistically significant at the 10% level, we conclude that there is not sufficient evidence that the participant and non-participant groups are significantly different in terms of the characteristics examined. In other words, the selected comparison group (the non-participant group) is viewed as valid for the purposes of this analysis.

tive, that is, these energy savings are not 'additional' to what would otherwise have occurred. Energy savings due to free ridership are subtracted from overall (gross) energy savings in order to obtain the net energy savings attributable to the program or the program's incremental energy savings.

Table 4. Awareness of Variable Speed Motors Prior to Installing Furnace (Percent)

Dimension	Participant (n = 100)	Non-Participant (n = 100)	Difference	z-value
Aware of the VSM	21%	17%	4%	0.72
Considering purchase of VSM	12%	6%	6%	1.48

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

Table 5. Participant and Trade Ally Satisfaction (Percent Very or Extremely Satisfied)

Dimension	Participant (n = 100)	Trade Ally (n = 40)	Difference	z-value
Information on the rebate	75%	66%	9%	1.40
Furnace types available for rebate	66%	74%	-8%	1.23
Procedures to obtain rebate	74%	72%	2%	0.32
Amount of rebate	62%	56%	6%	0.86

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

Results

PROGRAM REVIEW

The objective of the program review is to determine the level of customer awareness of the program and customer satisfaction with various program components and review the logic of the program model. The main data sources included interviews with program staff and surveys of customers and trade allies.

Table 4 summarizes customer awareness of variable speed furnace motors prior to the installation of the new furnace. Awareness of variable speed motors was relatively low at 21% for program participants and 17% for program non-participants, and the difference between the two groups was not statistically significant. Table 4 also summarizes customer consideration of purchase of a variable speed motor prior to the installation of the new furnace. Consideration of purchase of a variable speed motor was also low at 12% for the participant group and 6% for the non-participant group, and again the difference was not statistically significant. The differences between participant and non-participant respondents were not significant. These results suggest that enhanced activities to increase awareness of variable speed motors (VSM) on the part of potential furnace buyers could be warranted, since increased awareness could increase program participation.

Table 5 summarizes participant and trade ally satisfaction with various program attributes. Satisfaction levels with these attributes were not examined for non-participants because they did not have direct program experience. About 75% of the participant group and 66% of the trade ally group were very satisfied or extremely satisfied with information on the rebate. About 66% of the participant group and 74% of the trade ally group were very satisfied or extremely satisfied with the range of furnaces available for a rebate. About 74% of the participant group and 72% of the trade ally group were very satisfied or extremely satisfied with the procedures to obtain a rebate. About 62% of the participant group and 56% of the trade ally group were very satisfied or extremely satisfied with the amount of the rebate. These satisfaction levels are all good to excellent, and they suggest that the program is meeting the needs of both participants and trade allies.

Table 6 summarizes the logic model for the variable speed furnace motor program. Because the BC Hydro program is part of a more comprehensive program, we have also shown the related furnace replacement element on the logic diagram. At each level of the program logic, the basic concept is that successful achievement of that level leads to the successful achievement at the next level, if the assumptions of the model are correct.

SUPPLY SIDE ASSESSMENT

The objective of the supply side assessment is to understand the nature and evolution of the markets for variable speed furnace motors, including sales and prices for furnaces and for furnace motors. There is some discussion of the retrofit furnace market to establish the context for the variable speed furnace motor analysis. The main data sources were trade ally surveys conducted in 2004 [8] and 2007 [6, 7].

Table 7 summarizes the estimated distribution of retrofit furnace sales by efficiency level for 2003 and for 2007. The estimates are based on reported shares of permanent split capacitor and variable speed motor furnaces from the 2004 and 2007 trade ally surveys applied to estimated total sales. The share of high efficiency furnaces increased from about one-half in 2003 to nearly two-thirds in 2007.

Table 8 provides the estimated distribution of retrofit variable speed motor sales by efficiency level for 2003 and 2007. The estimates are based on reported shares of permanent split capacitor and variable speed motors from the 2004 and 2007 trade ally surveys applied to estimated total sales. The share of variable speed motors remained unchanged at about 56% in 2003 and 2007. The 2003 estimates are based on a survey of distributors and may omit a small number of furnaces sourced from outside of the province of British Columbia.

Table 9 provides estimated prices (CAD) for mid efficiency and high efficiency furnaces for 2003 and 2007. Both mid efficiency and high efficiency furnace prices increased between 2003 and 2007. Since the price increase was higher for mid effi-

Table 6. Variable Speed Furnace Motor Program Logic Model

	Marketing	Motor Replacement	Furnace Replacement	Assumptions
Inputs	Customers and trade allies are aware of the advantages of variable speed motors	Financial incentives for furnace motor replacement	Financial incentives for furnace replacement	Offer is attractive to customers
Outputs	Expected number of residential customers participate in program	Variable speed furnace motor fans installed	High efficiency condensing furnaces installed	Level of take back is not significant
Purpose	Reduce energy use Increase customer satisfaction			Level of energy savings is significant
Goal	Reduce long-term energy acquisition costs Increase long-term system reliability			

Table 7. Retrofit Furnace Sales, 2003 and 2007

	Mid Efficiency	High Efficiency	Total
2003	5,485	5,704	11,189
2007	4,405	8,181	12,586

Table 8. Retrofit Furnace Motor Sales, 2003 and 2007

	Mid Efficiency	High Efficiency	Total
2003	4,923	6,266	11,189
2007	5,538	7,048	12,586

Table 9. Retrofit Furnace Prices, 2003 and 2007

	Mid Efficiency	High Efficiency	Difference
2003	$2,300	$3,350	$1,050
2007	$2,738	$3,493	$755

Table 10. Retrofit Furnace Motor Prices, 2003 and 2007

	Permanent Split Capacitor	Variable Speed	Difference
2003	$256	$769	$513
2007	$205	$631	$426

ciency furnaces than for high efficiency furnaces, the estimated price differential fell from $1,050 in 2003 to $755 in 2007.

Table 10 provides estimated prices for permanent split capacitor motors and variable speed motors for 2003 and 2007. Variable speed motors cost about three times as much as permanent split capacitor motors. The price differential between permanent split capacitor motors and variable speed motors fell from $513 in 2003 to $426 in 2007.

DEMAND SIDE ASSESSMENT

The objective of the demand side analysis is to assess the determinants of customer choice of furnace motor, assess customer satisfaction with furnace system attributes, and estimate the free rider rate. The main data sources were surveys of program participants and program non-participants conducted in 2007.

Table 11 summarizes the factors affecting the choice of retrofit furnace system by showing the share of customers (percent) who state that the factor was either very important or extremely important in the choice of the retrofit furnace system. The questions were based on a 5-point scale. For participant group respondents the most important factors influencing furnace system choice were *comfort in your home* and *energy efficiency*. For non-participant group customers the most important factors influencing furnace system choice were *comfort in your home* and *indoor air quality*.

Table 12 summarizes customer satisfaction with various furnace attributes. It shows the shares (percent) of surveyed customers indicating that they were extremely satisfied or very satisfied with the particular attribute (5-point scale). In three of the areas – choice of furnaces available, reliability of your furnace, and ease of installation – 75% or more of participants

Table 11. Importance of Factors Influencing Furnace System Choice (Percent Extremely / Very Important)

Factor	Participant (n = 100)	Non-Participant (n = 100)	Difference	z-value
Comfort in your home	82%	82%	0%	0.00
Indoor air quality	67%	81%	-14%	2.26*
Energy efficiency	85%	75%	10%	1.77
Initial cost	63%	67%	-4%	0.60
Operating cost	64%	71%	-7%	1.06

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

Table 12. Satisfaction with Furnace Attributes (Percent Very / Extremely Satisfied)

Dimension	Participant (n = 100)	Non-Participant (n = 100)	Difference	z-value
Choice of furnace	86%	80%	6%	1.13
Price of your furnace	66%	66%	0%	0.00
Reliability of your furnace	90%	90%	0%	0.00
Ease of installation	76%	75%	1%	0.16
After sales service	56%	66%	-10%	1.45
Natural gas bill after installation	52%	60%	-8%	1.14
Electricity bill after installation	51%	61%	-10%	1.42

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

Table 13. Free Rider Analysis

	Very Important (5)	(4)	(3)	(2)	Not at all important (1)	Don't Know	Total	Free rider rate
Distribution of responses (n = 100)	26%	27%	17%	10%	13%	7%	100%	-
Weight	1	0.75	0.50	0.25	0	0	-	-
Product	0.26	0.20	0.09	0.03	0.00	0.00	0.57	0.43

and non-participants were very satisfied or extremely satisfied. In the four other areas – price of your furnace, after sales service, natural gas bill after installation, and electricity bill after installation - at least 50% of participants and non-participants were satisfied or extremely satisfied. There were no significant differences between participant and non-participant group customers.

Participants were asked to rate the importance of the financial incentive on their decision of purchase a variable speed motor, where "1" meant not at all important and "5" meant very important. The responses were weighted as shown in Table 13 to produce a weighted 'incentive influenced' score of 0.57 indicating that some 57% of participants were influenced by the program incentive in their purchase decision. This implies a free rider rate of (1 – 0.57) = 0.43 indicating some 43% may have been considering purchase of a variable speed motor without the incentive.

MARKET MODEL

The objective of the market model is to estimate a demand and supply model for variable speed furnace motors. The data sources included customer and trade ally surveys that were used to build a dataset for the statistical modeling. The equations are estimated using both ordinary least squares and maximum likelihood methods. The ordinary least squares models assume that the residuals are not correlated over time while the maximum likelihood models assume that the errors follow a first-order auto-regressive scheme.

We estimate a simple market model in which price for product i (where i = 1 is a variable speed furnace motor and i = 2 is a high efficiency furnace) is determined by the presence of the program and by year. In other words, at any point in time we assume a perfectly elastic supply curve, which falls each year as supply prices fall, perhaps due to economies of scale. Price is also reduced by the value of the incentive for those years when an incentive was offered. The quantity of variable speed motors is determined by the price of the product and the presence of the program. This gives us a demand curve which is downward sloping with respect to the log of price.

Table 14 provides estimates of the demand and supply curves for variable speed furnace motors and for high efficiency furnaces. For the demand equation, which is Equation (1), the independent variable is the number of purchases, and the dependent variables are a dummy variable for the program years

Table 14. Demand and Supply Curves for VSM and High Efficiency Furnaces Ordinary Least Squares

	Variable speed motors		High efficiency furnaces	
	Quantity (1)	Price (2)	Quantity (3)	Price (4)
Constant	13462*** (2253)	998*** (4.4)	13683*** (2540)	784*** (33)
Program	1128*** (374)	-94*** (5.3)	1491 (983)	-253*** (16)
Time	-	-29*** (0.89)	-	-24*** (5.2)
Price	-10.2*** (2.6)	-	-11.5*** (3.9)	-
Adjusted R^2	0.82	0.99	0.66	0.93
F-statistic	14.3 (0.02)	484.6 (0.00)	6.7 (0.05)	41.3 (0.00)
Durbin-Watson	2.31 (-0.16)	1.54 (0.23)	2.71 (-0.36)	2.67 (-0.34)

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

Table 15. Demand and Supply Curves for VSM and High Efficiency Furnaces Maximum Likelihood

	Variable speed motors		High efficiency furnaces	
	Quantity (5)	Price (6)	Quantity (7)	Price (8)
Constant	11605*** (2255)	999*** (6.3)	14487*** (1118)	7928** (21)
Program	1620*** (686)	-93*** (5.0)	1492*** (582)	-240*** (34)
Time	-	-30*** (1.4)	-	-27*** (5.0)
Price	-8.2*** (2.8)	-	-12.8*** (1.6)	-
Log likelihood	-52.1	-21.1	-49.6	-32.6
Durbin-Watson	2.14 (-0.07)	1.81 (0.09)	2.32 (-0.16)	1.85 (0.10)

Note. One, two or three asterisks indicate significance at the 10%, 5% or 1% level.

and the real price in constant dollars (CAD). For the supply equation, which is Equation (2), the dependent variable is the price and the independent variable is time in years.

The results of the ordinary least squares regression are presented in Table 14. Equation (1) has a good fit with an adjusted R-squared of 0.82, and all the coefficients are significant at the 5% level or better. The equation says that the presence of the program increases sales of variable speed motors by 1,128 per year while a reduction in variable speed motor price of $1 increases sales by 10 units. Equation (2) has a good fit with an adjusted R-squared of 0.99, and all the coefficients are significant at the 5% level or better. The equation says that the presence of the program reduces the price of variable speed motors by $94 and that price is falling by $29 per year ignoring the impact of the program. Equation (3) has a good fit with an adjusted R-squared of 0.66, although the coefficient on the program variable just misses being significant at the 10% level. The equation says that the presence of the program increases sales of high efficiency furnaces by 1,491 per year while a reduction in high efficiency furnace price of $1 increases sales by 11 units. Equation (4) has a good fit with an adjusted R-squared of 0.93, and all the coefficients are significant at the 5% level or better. The equation says that the presence of the program reduces the price of high efficiency furnaces by $253 and that price is falling by $24 per year. Equations (1) through (4) show significant evidence of auto-correlation.

The maximum likelihood regressions are presented in Table 15. Equation (5) has an improved Durbin-Watson statistic compared to Equation (1), indicating that auto-correlation has been reduced, and all the coefficients are significant at the 5% level or better. The equation says that the presence of the program increases sales of variable speed motors by 1,620 per year while a reduction in variable speed motor price of $1 increases sales by 8 units. Equation (6) has an improved Durbin-Watson statistic compared to Equation (2), indicating that auto-correlation has been reduced, and all the coefficients are significant at the 5% level or better. The equation says that the presence of the program reduces the price of variable speed motors by $93 and that price is falling by $30 per year ignoring the impact of the program. Equation (7) has an improved Durbin-Watson statistic compared to Equation (3), indicating that auto-correlation has been reduced, although the coefficient on the program variable just misses being significant at the 10% level. The equation says that the presence of the program increases sales of high

Table 16. Average Annual Unit Savings

Furnace Motor Use Category		Permanent Split Capacitor			Variable Speed Motor		
		Share Annual Hours Of Use	kWh/yr	Weighed kWh/yr	Share Annual Hours Of Use	kWh/yr	Weighted kWh/yr
Heating only	Intermittent	0.418	654	273	0.418	310	130
Heating only	Seasonal	0.143	1399	200	0.143	411	59
Heating/cooling	Intermittent	0.110	1003	110	0.110	553	61
Heating/cooling	Seasonal	0.198	2518	499	0.198	797	158
Continuous	Six months	0.077	2106	162	0.077	543	42
Continuous	All year	0.055	4226	232	0.055	937	52
Average Annual Consumption				1477			501
Average Annual Unit Savings				976			

Table 17. Variable Speed Furnace Motor Program Energy and Peak Savings, F2003-F2008

	Reported	Evaluated
Energy Savings	5.0	7.2
Peak Savings	1.5	1.4

efficiency furnaces by 1,492 per year while a reduction in the high efficiency furnace price of $1 increases sales by 13 units. Equation (8) has an improved Durbin-Watson statistic compared to Equation (4), indicating that auto-correlation has been reduced, and all the coefficients are significant at the 5% level or better. The equation says that the presence of the program reduces the price of high efficiency furnaces by $240 and that price is falling by $27 per year. With the maximum likelihood estimation procedure auto-correlation is no longer significant so that the maximum likelihood equations and results are preferred.

ENERGY AND DEMAND IMPACTS

The purpose of the impact analysis is to estimate the net energy savings for 2007 based on the average annual savings for installed variable speed motors and the net number of variable speed motor installations attributable to the program. The ratio of 2007 net and program reported energy savings is then used to estimate energy savings for the program as a whole. That is:

- Net $Savings_{2007}$ = Average Annual Unit $Saving_{2007}s$ * Net Number of Units $Installed_{2007}$
- Realization $Rate_{2007}$ = Net $Savings_{2007}$ / Program Reported $Savings_{2007}$
- Program Net $Savings_{2003\text{-}07}$ = Realization $Rate_{2007}$ * Program Reported $Savings_{2003\text{-}07}$

The analysis was undertaken in seven steps, as noted below. First, annual hours of use were estimated for both permanent split capacitor motors and variable speed motors in order to determine average annual unit savings.

Average Annual Unit Savings

1. For four furnace motor usage categories the average share of the furnace motor annual hours of use was estimated using survey data for those customers who had installed variable speed motors.
2. Engineering data on kW load for permanent split capacitor motors and variable speed motors were used to estimate the average annual consumption if the motor was used continuously in a particular mode.
3. Annual consumption for permanent split capacitor motors and variable speed motors was estimated as the weighted average of consumption for the various modes, and unit savings was calculated as the average consumption for permanent split capacitor motors minus the average consumption for variable speed motors.

Average annual consumption for a permanent split capacitor motor is 1,477 kWh per year and for variable speed motor is 501 kWh per year for unit savings of 976 kWh per year, as noted in Table 16.

Net Number of Units Installed

4. The gross number of variable speed units receiving incentives (taken from program records) was multiplied by one minus the free rider rate (estimated from participant survey data) to estimate the net number of units attributable to the program.

   Net Number of Units Installed = 5,667 * (1 - 0.43) = 5667 * 0.57 = 3,230

Net Energy Savings

5. The net number of variable speed units was multiplied by the average annual unit savings to estimate net evaluated energy savings.

   Net $Savings_{2007}$ = 3,230 * 976 kwh/yr = 3.2 GWh/yr

Realization Rate and Net Energy Savings

6. Net evaluated energy savings for 2007 were compared to program reported energy savings for 2007 to produce the program's realization rate or net to gross rate.

   $\text{Realization Rate}_{2007}$ = 3.2 / 2.2 GWh/yr = 0.144

7. The realization rate or net to gross rate calculated from 2007 data was applied to program reported savings for the period 2003-2007 to estimate net energy and peak savings for the whole program period.

   $\text{Program Net Savings}_{2003\text{-}07}$ = 0.144 * 5.0 GWh/yr = 7.2 GWh/yr

Table 17 indicates the energy savings and peak savings for the whole program period. Evaluated net energy savings are 7.2 GWh per year compared to reported energy savings of 5.0 GWh per year. Evaluated net peak savings are 1.4 MW compared to reported peak savings of 1.5 MW. Evaluated energy savings are higher than reported energy savings because survey data indicated that annual hours of use are higher than was formerly felt to be the case. The ratio of peak savings to reported energy savings is also lower than reported because of the high hours of use.

Conclusions

Variable speed furnace motors can substantially reduce electricity consumption and peak demand in residential dwellings and increase comfort as part of a home ventilation strategy. For electric utilities, installation of variable speed motors, in cooperation with gas utilities supporting efficient furnace replacement, can provide cost effective, electric consumption and peak demand savings.

PROGRAM DESIGN AND IMPLEMENTATION

The Variable Speed Furnace Motor Program has achieved high levels of program participation, and high levels of participant satisfaction, but it has been less successful in achieving high levels of awareness and interest in variable speed furnace motors**.** We recommend that marketing research focus on understanding the needs and values of those householders, furnace dealers, heating contractors and gas fitters in the furnace retrofit market, with a view to identifying promotional approaches that will encourage consumers to consider efficient motors, and to encourage trade allies such as furnace dealers, heating contractors and gas fitters to stock, install and service variable speed motors.

EFFECTIVENESS OF INCENTIVES

The effectiveness of financial incentives has been examined through survey information and through econometric models. Analysis of both of these sets of data sources indicates that financial incentives have a significant effect on the customer decision to install a variable speed motor as part of a furnace retrofit. Financial incentives reduce the cost of installing a variable speed motor and consequently increase take-up**.** We recommend continuation of the financial incentives for the installation of variable speed motors at least until the next impact evaluation of the program is undertaken. The current incentive level of $100 per variable speed furnace motor appears to be appropriate.

ENERGY AND PEAK SAVINGS

Evaluated net energy savings are 7.2 GWh per year compared to reported energy savings of 5.0 GWh per year. Evaluated net peak savings are 1.4 MW compared to reported peak savings of 1.5 MW. Evaluated net energy savings are higher than reported energy savings because survey data indicated that annual hours of use are higher than was formerly thought to be the case. The ratio of peak savings to reported energy savings is also lower than reported because of the high hours of use.

INCREMENTAL COSTS

The trade ally survey has been used to estimate incremental costs for variable speed furnace motors of $426 for 2008. The price differential between permanent split capacitor motors and variable speed motors fell from $513 in 2003 to $426 in 2007. We recommend that an incremental cost of $426 per variable speed motor be used for the cost benefit analysis of the Variable Speed Furnace Motor Program.

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