Establishing the Energy Performance of Mini-Split and Central Air-Source Heat Pumps Through Billing Analysis

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ABSTRACT

Heat pumps offer great potential to utilities in heating-dominated climates, whereby they can yield significant energy and winter peak demand savings. Centrally-ducted air-source heat pumps (ASHPs) and mini-split heat pumps (MSHPs) have become popular products in a residential efficient heating program implemented in the province of Nova Scotia, Canada. An initial billing analysis was conducted by Econoler on a limited sample of households that had installed MSHPs, and results demonstrated that billing analyses were an adequate method to establish measured savings for heat pumps in programs where the existing heating system corresponds to the baseline energy consumption level (in this case, electrical resistance heating is the existing system). The billing analysis also revealed that traditional methods that use equivalent full-load hour (EFLH) approximations generally overestimate savings generated by heat pumps.

This 2018 IEPPEC paper presents the results of a second billing analysis of the abovementioned residential efficient heating program. This analysis uses the same methodology as the first, but applies it to a larger sample of participants who installed a MSHP and participants who installed an ASHP. The objective is to establish savings with greater confidence and obtain statistically significant results for participant subgroups, specifically those who use other non-electrical heating systems in addition to a heat pump.

The results of this analysis confirm observations made for MSHPs in the previous study. In addition, they indicate that the conclusions made for MSHPs also apply to ASHPs, namely the fact that ASHP savings are negatively affected by the presence of secondary non-electrical heating systems and that savings measured by the billing analysis are significantly lower than those obtained by analytical methods such as energy modelling. This analysis, however, identifies some limitations of the billing analysis method, especially for households that use non-electrical heating systems.

Introduction

With improvements to heating technologies designed for cold climates in recent years, ductless mini-split heat pumps (MSHPs) are becoming more popular than ever in energy efficiency programs throughout North America. The number of centrally ducted air-source heat pumps (ASHPs) installed has also increased in recent years. The larger savings generated by MSHPs and ASHPs have pushed program administrators to formulate more accurate approaches to estimating savings of such heat pumps. To that effect, a billing analysis specifically targeting MSHPs was conducted by Econoler and the findings were published in a 2017 IEPEC paper (Hamelin et al. 2017). The literature review in that article highlighted the lack of data specific to cold climates. It also demonstrated that the few metering studies performed for heat pumps to date indicate that traditional approaches, such as heating degree-days (HDD) analyses or energy simulations, overestimate heat pump energy savings. The fact that measured savings are significantly below initial estimates might change regulators' perspective on the benefits of heat pump programs. This is especially important given that heat pump programs are blooming in cold-climate regions of the US and Canada. Hence, new more accurate data would have an impact on significant portions of demand-side management portfolios.

The 2017 IEPEC paper presented the findings of a billing analysis of households that had participated in the Efficiency Nova Scotia (ENS) Green Heat program and installed MSHPs. It demonstrated how billing analyses can potentially improve the accuracy of energy savings for heat pumps that displace electric resistance space heating, especially for participants without secondary systems where margins of error are slightly above acceptable levels. It also revealed that there was a statistically significant difference between the energy savings of heat pumps operating with and without a secondary heating system. Lastly, the billing analysis confirmed that savings are overestimated when assessed through traditional methods.

In this 2018 IEPPEC paper, Econoler sought to improve the precision of energy savings by conducting a billing analysis on a larger sample of participants who installed MSHPs, again using data from the ENS Green Heat program. The same methodology was used to establish savings for ASHPs, and the results for both types of heat pumps were then compared.

Description of the Nova Scotia Program

The Green Heat program provides financial incentives to homeowners in Nova Scotia and encourages them to reduce electricity used for heating by either installing high-efficiency electrical systems, such as MSHPs and ASHPs, or replacing existing electrical heating systems with units that use another program-qualified energy source. Green Heat participants only install heating system energy efficiency measures – the program does not incentivize other measures such as controls or envelope improvements.

As illustrated in Figure 1 below, the evolution of MSHP and ASHP installations under Green Heat and program participation levels have significantly increased in the past two years, totalizing 1,591 MSHP and 143 ASHP installations in 2017. MSHP is the most popular measure offered through the program, accounting for 87 percent of all measures installed.

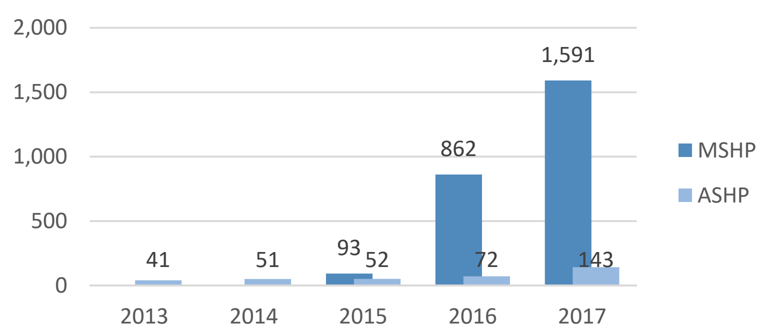

Figure 1. Evolution of MSHP and ASHP installations between 2013 and 2017 under Green Heat

MSHP and ASHP systems installed in 2017 were not included in this billing analysis because a full-year post-installation billing data set could not be obtained at the time of analysis. What follows, therefore, focusses on the program context under which the systems included in the billing analyses were installed.

The ASHPs and MSHPs eligible under Green Heat must meet certain performance criteria. Eligible MSHPs are high performance models that perform well in cold temperature (requiring a coefficient of performance of at least 1.75 at -15 °C). ASHPs do not have specific requirements for cold temperature performance, but must be ENERGY STAR® certified.

The minimum energy performance for eligible heat pumps offered through the program is defined by the Heating Seasonal Performance Factor (HSPF) for climate region V. This metric represents the energy performance in Btu/h of heat delivered per power input in watts at standardized operating conditions, as defined by an Air-Conditioning, Heating and Refrigeration Institute standard (ANSI/AHRI 2012). The HSPF is widely used in North America to characterize heat pumps. For the purposes of this paper, HSPF units have been converted to W/W, with the Btu/W.h value provided in brackets. The average Region V HSPFs of the MSHPs and ASHPs included in the billing analyses significantly surpass program requirements with values of 3.05 W/W (10.74 Btu/W.h) and 2.31 W/W (7.89 Btu/W.h) respectively. No installed heating capacity requirements exist under the program, although the average installed heating capacity per participant is 5,975 W for MSHPs and 10,168 W for ASHPs.

In addition to performance criteria, MSHPs and ASHPs must be installed in homes that are mostly or completely electrically heated. Homes with existing central system heat pumps are only eligible if the existing heat pump has ceased functioning and must be completely replaced, in which case it is assumed that the participant would purchase electrical baseboards to replace the broken heat pump. Since heat pumps have not attained a high penetration level in this market and resistance heating remains the norm for electrically heated homes, the ENS program rationale is to incent participants to replace their electrical resistance system with a heat pump. This means that the savings for this program are a result of the difference in energy consumption between an existing electrical resistance heating system and the new heat pump. This renders billing analysis a more applicable solution for such programs because the difference between the pre and post-installation periods constitutes gross savings.[1] Such is not the case in all jurisdictions where the baseline is sometimes a standard-efficiency heat pump.

It is also worth noting that approximately one third of all participants included in the billing analysis who installed an MSHP also had a non-electrical backup system. The percentage of participants with a non-electrical backup system (one tenth) is lower for participants who installed an ASHP.

Methodology

The Econoler billing analysis consisted of comparing pre and post-installation electrical energy consumption. Electrical consumption data was determined using billing data provided by Nova Scotia Power, with the consent of participants, and included all participants who installed an MSHP or an ASHP between January 2013 (October 2015 in the case of MSHPs) and June 2016. For the pre-installation periods, data from seven billing periods (corresponding to approximately 14 months) were used. For the post-installation periods, data from a minimum of four billing periods (approximately eight months) was necessary to cover the entire winter that followed installation without excluding too many participants, although in most cases seven billing periods were used.

The objective of the billing analysis was to compare the electrical energy consumption of the sampled participants before and after heat pump installation. To do so, a regression model based on HDDs for each participant's region was used. This statistical method calculates the linear regression specific to each participant based on data from nearby weather stations instead of analyzing the data as a whole. The regression model is expressed in the following equation:

$$CONS = \alpha + \beta \cdot HDD + \varepsilon$$

Where:

- CONS is the average daily consumption;
- α is the daily base consumption constant;

[1] The fact that a certain proportion of participants might have purchased a standard heat pump in the absence of the program is addressed by measuring free-ridership.

- β is the consumption coefficient per HDD;
- HDD is the average daily heating degree days on an 18 °C basis from the closest city for each participant (values range between 4,041 HDD and 4,618 HDD);
- ε is the random error component.

The daily base consumption constant (α) represents the everyday electrical consumption not related to outdoor temperature (i.e. the HDDs) and includes most of the energy consumption by lighting, appliance, domestic hot water (DHW), and electronic device. The unitary consumption coefficient (β) corresponds to the electrical consumption that varies according to outdoor temperature and mostly consists of the portion of electrical consumption used for space heating. This methodology therefore assumes that most of the variation in electricity consumption is due to heating and that the energy consumption due to other end uses remains constant throughout the year. In reality, there might be a portion of DHW and lighting energy consumption that varies according to HDDs (shorter days in winter result in higher lighting usage, and DHW usage is known to increase in the winter). Since the energy savings calculation is based on the difference between the pre and post-installation periods, it is assumed that the correlation between HDDs and energy consumption for end uses other than space heating remain similar for both periods and that this does not result in a significant error in the savings calculation. This assumption is true if the number of HDDs is similar for the pre and post-installation periods, so that the seasonal energy consumption is divided by approximately the same HDD value for both periods. This was the case for most years since HDDs were steady from one year to another except for the 2014-2015 winter which was particularly cold in Nova Scotia. Comparing HDDs between the months of October to May inclusively for the 2014-2015 and 2015-2016 winters reveals that HDDs were almost 10 percent higher in the first winter. For participants that have their pre-installation period in the 2014-2015 winter, the pre-installation coefficient β is lower, resulting in potentially slightly underestimated energy savings.

The pre and post-installation billing data of each participant were analyzed using the linear regression model presented above and savings were established by subtracting the annualized electricity consumption that varies as a function of HDDs for the pre and post-installation periods, as illustrated by the equation below.

$$SAVINGS = (\beta_{PRE} - \beta_{POST}) \cdot HDD_{ANNUAL} + \varepsilon$$

Where:

- SAVINGS is the calculated annualized energy savings in kWh for a given participant;
- β_{PRE} is the beta coefficient obtained for a given participant in the pre-installation period;
- β_{POST} is the beta coefficient obtained for a given participant in the pre-installation period;
- HDD_{ANNUAL} is normalized annual heating degree-days (Government of Canada 2017).

The normalized HDD values were used to establish the average savings that are not specific to a particular year.

Only one category of participant was excluded from the analysis, participants who had a heat pump as their existing main heating system. Though program eligibility requires that existing heat pumps not be functional (or only operate in electrical resistance mode), it was not possible to accurately identify the moment when the heat pump stopped working. Therefore, these data points were excluded.

The statistical significance of the above described regression model was used to establish which results should be retained. This selection process was strictly based on statistical observations using the following criteria:

- A statistically significant coefficient β for both the pre and post periods;
- A positive daily base consumption constant α;
- A coefficient of determination (R2) above 0.65;

- A savings-per-installed-capacity value within two standard deviations of the average.

The statistical significance of coefficient β was established at a confidence level of 95 percent using a t-test. The criterion of having a coefficient of determination of more than 0.65 was added to ensure that a large proportion of the electricity consumption variation could be explained by HDDs.

These statistical criteria were applied to participants for whom sufficient billing data was available, which was the case for 288 participants who installed MSHPs and 73 participants who installed ASHPs. Table 1 presents how statistical criteria served to determine which participants were retained for the energy consumption analysis.

Table 1: Average Energy Savings per Installed Capacity per Participant Category

	Number of participants	
	MSHP	ASHP
Initial number of participants	288	73
Participants who did not meet statistical criteria		
Significant level of correlation for pre- and post-installation coefficient B	75 (25%)	22 (30%)
Positive daily base consumption constant A	5 (2%)	2 (3%)
R2 above 0.65 for pre and post-installation	28 (10%)	9 (12%)
Having a savings-per-installed-capacity value within two standard deviations of the average	10 (3%)	3 (4%)
Remaining participants for energy consumption analysis	170 (58%)	37 (51%)

For both MSHPs and ASHPs, the criterion which excluded the most participants was the statistical significance of coefficient β. Overall, between 42 and 49 percent of participants were excluded from the analysis on the basis of an insufficient correlation between their energy consumption and heating degree-days or high deviations from average results. Since the energy savings were defined as the difference between the pre and post-installation coefficients β multiplied by HDDs, the statistical criteria to ensure that these coefficients are significant and related to HDDs are important. Looking at the variation in coefficient β, instead of looking at the overall change in energy consumption, isolates changes to heating systems. However, this presents a drawback; it excludes participants that do not have a good correlation between energy consumption and HDDs.

It is also worth noting that Econoler considered including the effect of cooling on electrical consumption by adding cooling-degree day (CDD) values in the linear regression model. This was attempted for ASHPs only since they would more likely provide large amounts of cooling to the home as central systems. The results revealed that only seven participants out of 73 had a significant level of correlation for both the pre and post-installation coefficient associated with CDDs. It was therefore concluded that CDDs were generally not good predictors of energy consumption and that no adjustment to energy savings should be made based on this variable. This is explained by the fact that summers in Nova Scotia are fairly mild, with less than 144 CDD, on a basis of 18 °C, for Halifax (the largest city of the province, which is centrally located and representative of Nova Scotia climate). Consequently, Econoler considered that any correlation between CDD and electricity would have minimal impacts on energy savings.

Another methodological element that could have been included in this analysis is a control group, as recommended by the Uniform Methods Project (UMP) protocol for whole building retrofits (NREL 2017). This would have improved the precision of the analysis by isolating changes in energy consumption that are specifically due to program influence. However, because the program was recently launched and few participants who had heat pumps installed were able to provide data for a full heating season at the time of analysis, Econoler used almost all past participants in the billing analysis.

Consequently, no past participants were available for a control group. Another option would have been to use more recent participants, in this case participants who had heat pumps installed after the end of the post-installation period (approximately June 2017); at the time of analysis, this group was too small and would not have allowed for a proper comparison. Econoler did not establish a general population control group because of the added complexity of this method.

Results for MSHPs

The previous MSHP billing analysis demonstrated that the difference in savings per installed capacity between households with secondary non-electrical sources (typically wood stoves – defined as mainly electrically heated households) and those without (defined as fully electrically heated households) was statistically significant. Therefore, the new billing analysis results for those two categories of participating households are presented separately in Table 2.

Table 2: Average energy savings per installed capacity - MSHPs

	Fully electrically heated households	Mainly electrically heated households
Number of observations	118	52
Mean (kWh/W)	0.611	0.205
Standard deviation (kWh/W)	0.508	0.515
Absolute margin of error* (kWh/W)	± 0.075	± 0.116
Relative margin of error*	±12.3%	±56.7%

*Margins of error are calculated with a confidence level of 90 percent.

These results confirm the conclusion that the difference in energy savings is statistically significant. Indeed, the confidence interval for energy savings ranges between 0.536 and 0.686 kWh/W for fully electrically heated households and 0.089 and 0.321 kWh/W for mainly electrically heated households. Hence, these intervals do not overlap. Furthermore, energy savings represent 26 percent and 11 percent of variable electricity consumption for fully and mainly electrically heated households respectively; this confirms the relevance of using electricity consumption for the entire household to measure energy savings.

While the relative margin of error for fully electrically households is close to the target value of 10 percent, the relative margin of error for mainly electrically heated households are much higher. While the absolute margin of error is somewhat higher for mainly electrically heated households, the much lower calculated savings mostly explain the high relative margin of error for this category of households. It was expected that the variability of savings in mainly electrically heated households would be higher than in fully electrically heated households since the usage level of the secondary non-electrical heating systems is another variable that adds to the complexity of predicting electricity consumption. Given the standard deviation values presented above, the required number of observations to reach a margin of error of 10 percent for energy savings per installed capacity for fully electrically heated household would be 185. For mainly electrically heated households, upwards of 1,700 observations would be required, so, although the sample size for those participating households is smaller, it is not what explains most of the higher margin of error.

Econoler also calculated the heating equivalent full load hours (EFLH) value resulting from the energy savings billing analysis to obtain a value that can be more easily compared to the results of energy savings analyses conducted in other jurisdictions. To do so, the EFLH variable was isolated from the general heat pump energy savings algorithm below.

$$Energy\ Savings_{kWh} = \left(HC\ *\left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right]*EFLH_h\right)$$

Where:

- HC is the heat pump nominal heating capacity [W or kBtu/h];
- $HSPF_{base}$ is the heating seasonal performance factor (Region V) for the baseline equipment [W/W or Btu/W.h];
- $HSPF_{ee}$ is the heating seasonal performance factor (Region V) for the new heat pump [W/W or Btu/W.h];
- $EFLH_h$ are the annual heating equivalent full load hours [h].

The isolated EFLHh value is therefore calculated as follows.

$$EFLH_h = \frac{ES_{kWh}}{HC * \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right]}$$

Distinct EFLH values were obtained for fully and mainly electrically heated households. Energy savings values were calculated based on the average savings per capacity presented in Table 2 above. The average rated heating capacity (HC) for fully electrically heated households was 5,737 W and 5,869 W for mainly electrically heated households, resulting in energy savings of 3,504 kWh and 1,201 kWh respectively. The capacity-weighted average $HSPF_{ee}$ for installed MSHPs was 3.14 W/W (10.72 Btu/W.h) for fully electrically heated households and 3.19 W/W (10.89 Btu/W.h) for mainly electrically heated households. The $HSPF_{base}$ was 1.00 W/W (3.412 Btu/W.h - equivalent to 100% efficient electrical resistance heating). Therefore, EFLH values of 896 hours and 298 hours were established for fully electrically heated households and mainly electrically heated households respectively.

The Evaluator compared the EFLH values with values obtained from either billing analyses or metering studies in other jurisdictions. Only a few jurisdictions have conducted metering studies to estimate MSHP energy savings. Massachusetts derived EFLH for MSHPs from a metering study of 152 homes over two consecutive winters (The Cadmus Group, Inc. 2016). This metering study of both non-cold climate and cold climate units found that EFLH were lower than expected when compared to other means of estimating EFLH mainly because some units were not used regularly during each heating season, and some units operated coincidentally with other systems or did not operate at all. The findings of this study revealed that EFLH for cold climate heat pumps (526 hours in winter 2015 and 420 hours in winter 2016) are of the same magnitude as the average value obtained through the billing analysis presented herein, which is 713 hours when considering all participants – both with and without secondary non-electrical heating systems.

The significant impact of secondary non-electrical heating systems on average savings (decrease of 60% in this billing analysis when compared to households without secondary non-electrical systems) was also observed in a billing analysis conducted by Ecotope for the Northwestern United States (Washington, Oregon, Montana, and Idaho), which included 3,899 participants who had installed an MSHP to displace heat from a zonal electrical system (Ecotope 2013). That study revealed a decrease in energy savings of 73 percent for participants with a secondary heating system; savings of 2,718 kWh were measured for fully electrically heated households and 747 kWh for households with a secondary heating system. The similar conclusions obtained by both aforementioned studies suggest that the billing analysis results presented herein are representative of the real savings associated with the MSHPs installed through Green Heat.

Results for ASHPs

The same linear regression model and the same methodology as the MSHP billing analysis were used for ASHPs. Since this measure has been included in ENS Green Heat program for longer, all participants from 2013 to 2016 who installed an ASHP were included in the analysis. The initial sample included 197 participants of whom 142 had sufficient data for both the pre-installation and post-installation periods. A total of 69 participants were removed from the analysis since their old primary heating system was also a heat pump or, for three cases, because information on the capacity of the heat pump could not be found. As mentioned in the methodology section of this paper, statistical criteria were applied to determine which among the 73 remaining participants would be retained for the billing analysis, and 37 participants were identified.

These 37 participants were categorized based on type of heating system:

1. Fully electrically heated with no secondary system;
2. Mainly electrically heated with a non-electrical secondary system;
3. Fully electrically heated with a secondary heat pump.

The third category was added to account for the non-negligible number of participants who installed a central ASHP but who already had another heat pump (often an MSHP) in their home.

Table 3 presents the savings for each category, for categories 1 and 3 combined, and for all participants.

Table 3: Average Energy Savings per Installed Capacity - ASHP

	1 - Fully electrically heated	2 - Mainly electrically heated	3 - Fully electrically heated with secondary HP	1 and 3 – Fully electrically heated, with or without secondary HP	All participants
Number of observations	21	4	12	34	37
Energy savings per installed capacity					
Mean (kWh/W)	0.478	-0.338	0.089	0.345	0.321
Absolute Margins of Error (kWh/W)	±0.266	±01.095	±0.246	±0.150	±0.147

Given the small sample sizes, it is difficult to establish distinct unitary savings for any of these categories. However, it seems that participants who do not have a secondary heating system have greater unitary savings than the other categories. It would be useful to broaden the sample size in future years to verify whether unitary savings differences become statistically significant. Considering the low savings for participants with secondary heat pumps (category 3) and the large proportion of participants in this category, further investigation would be advisable. On-site visits might allow to better determine how heat pumps interact with one another and explain the low savings obtained through this billing analysis. It is possible that secondary heat pumps in fact provide a large portion of home heating and that the displaced heating load by the new heat pump does not originate from electrical resistance heating; these assumptions could be validated by careful on-site examination of secondary heating systems.

Econoler further studied the results for ASHPs installed in homes with no secondary heating systems (category 1) and compared them to other studies. Since these participants had an average installed heating capacity of 10,125 W, results suggest average annual energy savings of 4,838 kWh. Despite its large margin of error, the EFLH were calculated based on this value to provide a point of comparison. By isolating the EFLH variable from the energy savings algorithm and using the energy savings of 4,838 kWh and the average HSPF of 2.31 W/W (7.89 Btu/W.h) in the algorithm below, EFLH are estimated at 842 hours.

$$EFLH_h = \frac{ES_{kWh}}{HC * \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right]}$$

It is difficult to find comparable ELFH values in the literature because other jurisdictions often use EFLH values obtained through energy modelling or an analysis of heating degree days. However, the Independent Electricity System Operator (The Cadmus Group Inc. and IESO 2017) conducted a billing analysis of ASHPs that replaced electrical heating systems and obtained very similar conclusions. For the 43 central ASHPs included in the IESO billing analysis, average energy savings were estimated at 4,139 kWh. ASHPs were installed across Ontario, essentially between Windsor and Ottawa, with a few installations in Sudbury and North Bay. As a point of reference, annual HDDs for Toronto are estimated at 4,066 degree days and 4,263 for Halifax. Both climates are therefore comparable. IESO also surveyed billing analysis participants and asked them about their supplemental heat usage: 17 percent of ASHP participants said that they use supplemental heat “very often” or “all the time”; the fact that those participants were included in the 4,139 kWh might explain why savings were marginally lower in Ontario than for the fully electrically heated participants in the present study.

Comparison Between ASHPs and MSHPs

Table 4 summarizes the findings obtained for ASHPs and MSHPs installed in fully electrically heated households.

Table 4: Comparison of results for MSHPs and ASHP in fully electrically heated households

	Average energy savings per installed capacity (kWh/W)	Average installed capacity (W)	Resulting average energy savings (kWh)	Resulting ELFH (h)
MSHPs	0.611	5,737	3,504	896
ASHPs	0.478	10,125	4,824	842

These results demonstrate that while EFLH are similar for both types of heat pumps, they are much lower than the values typically used in the technical reference manuals of other jurisdictions with cooling-dominated climates. For instance, Minnesota, which has similar HDDs as Nova Scotia, uses an EFLH value of 2,280 hours for heat pumps (MSPHs or ASHPs) installed in homes.

When analyzing the EFLH results for MSHPs only, MSHPs were assumed to sometimes be used for only a portion of the house and that, when they are used with other heating systems, this can pose operating control issues and explain why EFLH were much lower than anticipated. While this might be true, the preliminary ASHP results indicate that using a heat pump as a central system does not result in much higher EFLH values.

However, another element seems to explain the low EFLH value for ASHPs: the size of these systems allows them to generate much more heat than the requirements of typical houses in Nova Scotia. A billing analysis conducted on past Green Heat participants using only electrical space heating demonstrated that the typical space heating load for those participants was of about 14,600 kWh (Econoler 2013). By comparison, a 10,125 W ASHP operating for 2,750 EFLHs, as defined by the AHRI Standard for Region V, would generate 27,843 kWh of heat, hence almost twice as much as what is needed for a typical Green Heat participant. This does not necessarily mean that ASHPs are not sized adequately – they might be of larger capacity to provide sufficient heat in peak design conditions – but rather that previously estimated EFLH values did not accurately consider how heat pumps are sized.

Conclusion

This billing analysis built on a previous analysis conducted with a smaller sample of households that had installed MSHPs to replace an electrical heating system under the same program. By performing this analysis on a larger sample of participants, the precision of results for MSHPs installed in fully electrically heated households was improved, and the level of precision approximated the target margin of error of 10 percent. The small savings and highly variable results for participants who use secondary non-electrical heating systems render it difficult to achieve an acceptable level of precision using billing analysis only. This analysis also provided preliminary results for ASHPs. Although margins of error are high, the results were in line with those of a separate billing analysis study conducted in another jurisdiction with a similar climate. With larger sample sizes, savings are expected to be estimated with acceptable precision for ASHPs installed in fully electrically heated households. The results indicate that energy savings values based on HDD analysis or energy simulation, which are widely used across jurisdictions in North America, are most likely overestimated, as is the case for MSHPs. Using a control group, once sufficient participant data are available, would improve the precision and accuracy of this analysis in two ways. First, it would better isolate the impact of the program on energy consumption variations. Second, it would allow comparing overall energy consumption variations rather than only the variation in consumption correlated to heating degree days.

This paper also demonstrated some of the benefits and limitations of using a billing analysis to measure heat pump energy savings. This method is an inexpensive and efficient way of obtaining energy savings when: (1) the existing heating system corresponds to the baseline energy consumption level; and (2) a sufficiently large sample of participant data is available. This method also captures real energy savings because it takes into account interactions between heating systems in a way that energy modeling or HDD analysis cannot. However, the method does not provide detailed insight on how heat pumps operate; this would require energy metering on individual heat pumps. It also does not permit identifying reasons for outlier data, such as variance in occupancy or modifications made to a home. Finally, this method is limited by participating households that have non-electrical heating systems, whereby the variance in energy savings is too high to obtain values with a reasonable margin of error unless the sample is very large or includes most of the program population.

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