Accounting for Real-Life Conditions in Mini-Split Heat Pump Savings: Findings from a Billing Analysis

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ABSTRACT

Cold-climate ductless mini-split heat pumps (MSHPs) were introduced to the Efficiency Nova Scotia residential efficient heating Green Heat program in the fall of 2015 and were an instant success, rapidly becoming the most popular efficient heating system of the program. Despite the rising popularity of this product in residential applications, few impact studies have been conducted to precisely estimate the savings they generate.

Econoler used a billing analysis to measure energy savings generated by MSHPs in households primarily or entirely electrically heated in an effort to cost-effectively improve the accuracy of previous estimates based on equivalent full load hours (EFLHs). Two approaches are adopted and expounded herein: (1) performing a billing analysis on a smaller sample and combining it with a survey; and (2) using solely a billing analysis that covers a larger pool of participants.

This paper demonstrates that billing analyses are an adequate method to provide measured savings for MSHPs in programs that use the existing heating system (in this case, electrical resistance heating) as the baseline for energy savings. This method also allows establishing distinct energy savings values for homes that use a secondary non-electrical heating system and those that do not. A comparison of billing analysis results to savings from the technical literature confirms the hypothesis that traditional methods, applied by most jurisdictions and using EFLH approximations, generally overestimate program savings.

Introduction

Cold-climate ductless mini-split heat pumps (MSHPs) have great potential for utilities in the Northeastern United States and Canada where they yield significant energy and winter peak demand savings. Contrary to standard air-source heat pumps that generally have to operate in electrical resistance mode below -10 °C, MSHPs generate heat at temperatures as low as -20 °C while maintaining fair efficiency levels. MSHPs are therefore better suited to cold climates where they cover all or most of the heating load throughout the cold season. Efficiency Nova Scotia (ENS) included this product in its residential efficient heating demand-side management program in the fall of 2015 and it was an instant success, rapidly becoming the program's most popular efficient heating system. Because of the high number of units sold through the program, the evaluator (Econoler) and ENS sought to rapidly and accurately estimate the savings associated with this measure by relying on a literature review. However, it was found that a wide range of values were used in other jurisdictions and that savings were quite sensitive to climate and operating conditions. Therefore, Econoler decided to use data collected from participants who installed MSHPs in late 2015 and early 2016 to establish savings that were representative of both the MSHPs installed and the conditions under which they operated. This paper presents the findings and lessons learned from the billing analyses conducted for this program evaluation.

Program and Participants

The Green Heat program, under which MSHPs are offered, targets existing Nova Scotia homes that are primarily heated using electricity. Green Heat provides financial incentives to homeowners and encourages them to reduce heating electricity use by either installing high-efficiency electrical systems or replacing electrical systems by systems that use another energy source. As of 2016, 85 percent of the measures installed under this program are MSHPs. 862 MSHPs were installed for the 2016 program year, which is considerable because Nova Scotia is a small jurisdiction with a population of approximately 950,000 inhabitants. Since the Nova Scotia climate leads to very high heating and very low cooling demand, only heating savings are considered for this measure.

The MSHPs eligible under this program must meet the following performance criteria:

- Have an HSPF (Canada - Region 5) of at least 9;
- Be ENERGY STAR® certified (version 5.0 or newer);
- Have a coefficient of performance of at least 1.75 at -15 °C.

There are no requirements in terms of installed heating capacity. Hence, capacity varies greatly among Green Heat participants. The following figure presents the number of systems installed per capacity range for the 955 participants in 2015 and 2016. Overall, the average installed heating capacity per participant is 21,224 Btu/h.

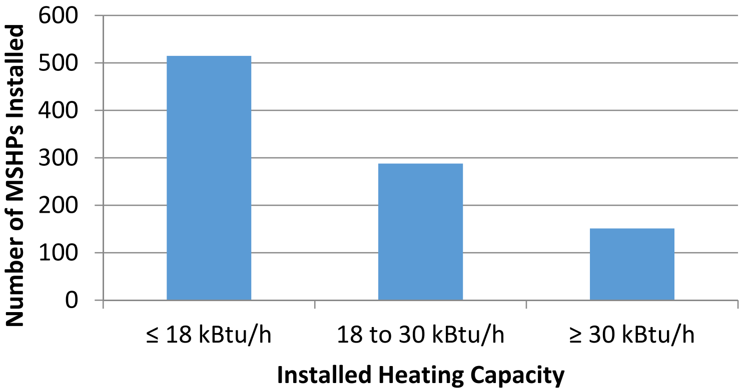

Figure 1. MSHP installed heating capacity

To be eligible under the program, MSHPs must be installed in homes that are at least six months old. Homes must be detached, mobile, town houses, or duplexes. Existing heating systems must mostly or completely heat the home using electricity. Homes with central system heat pumps are only eligible if the existing heat pump has ceased functioning and must be completely replaced. This is because the savings for this program are measured by the difference in energy consumption between the old electric resistance heating system and the new MSHP. 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 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 Green Heat participants who installed an MSHP also had a non-electrical backup system (mostly wood or pellet stoves), as shown in Figure 2.

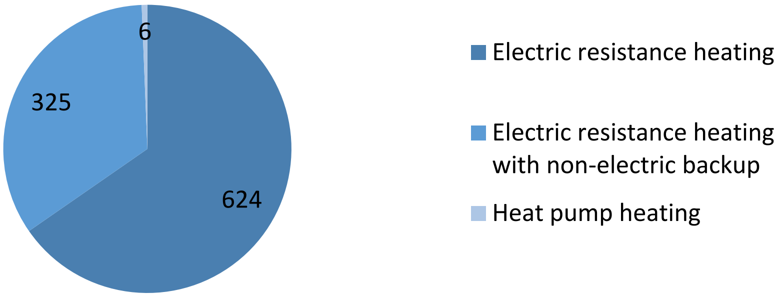

Figure 2. Existing heating systems prior to MSHP installation[2]

Existing Literature on MSHP Savings

Econoler conducted a literature review of the methodologies used to calculate MSHP savings in other jurisdictions. It became apparent that the vast majority of jurisdictions based their calculations on a standard equation that takes into account the performance of heat pumps and the equivalent full load hours (EFLH) for heating and cooling. This is the case for Vermont, Maine, Massachusetts, Illinois, Minnesota, New York, and Pennsylvania.

$$ES_{kWh} = \begin{matrix} HC * \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right] * EFLH_h + \\ CC * \left[\frac{1}{SEER_{base}} - \frac{1}{SEER_{ee}}\right] * EFLH_c \end{matrix}$$

Where:

- HC: Rated heating capacity of the heat pump;
- $HSPF_{base}$: Heating seasonal performance factor for base case system;
- $HSPF_{ee}$: Heating seasonal performance factor for MSHP;
- $EFLH_h$: Equivalent full load hours for heating;
- CC: Rated cooling capacity of heat pump;
- $SEER_{base}$: Seasonal energy efficiency ratio for base case system;
- SEERee: Seasonal energy efficiency ratio for MSHP;
- $EFLH_c$: Equivalent full load hours for cooling.

The EFLH values derived for heat pumps vary from one jurisdiction to another. As described in more detail below, while some jurisdictions use values derived from weather data and balance temperatures, others use more specific values obtained from energy modeling or metering analyses. The Econoler literature review focused on values used for heating since the program for which the analysis was conducted aimed at reducing space heating consumption specifically.

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[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.

[2] One participant was identified as having a wood-fired primary heating system and was excluded from this figure, for a total of 954 participants.

Some jurisdictions use, or had been using until recently, the Air-Conditioning, Heating & Refrigeration Institute EFLH for heat pumps for their respective climate zones, as defined in Standard ANSI/AHRI 210/240 (ANSI/AHRI 2008). This was the case for Maine, Vermont, and Nova Scotia. While these values are drawn from a recognized standard, recent analyses conducted for ENS program evaluations have led to the conclusion that the values were overestimated. In fact, using the EFLH value of 2,750 hours for Region 5 (which includes Nova Scotia) and the average rated heating capacity of MSHPs installed under Green Heat (21,224 Btu/h) results in a heating load of approximately 17,100 kWh, which is significantly greater than the variable electrical load determined by the Econoler billing analysis (12,927 kWh). A comparison of these diverging results is expounded in the Analysis section further below.

Efficiency Vermont (2015) now calculates MSHP heating savings by conducting a weather bin analysis. A similar methodology is used by other jurisdictions for air-source heat pumps (ASHPs) and MSHPs. For instance, Illinois (Illinois Stakeholder Advisory Group 2016) relies on Environmental Protection Agency (EPA) EFLH values contained in the EPA ENERGY STAR calculator spreadsheet for air-source heat pumps (DOE/EPA 2013) to estimate ASHP energy savings. These data are derived from two weather parameters, namely degree days and design temperature, and do not adequately address heat pump oversizing and other issues known to affect actual operating hours (Korn and Walczyk 2016). Hence, the EPA data was scaled down by Illinois using billing data to account for oversizing and the resulting EFLH overestimations. Illinois results were then adapted to the climates of other jurisdictions, as is the case for Minnesota EFLH heating values for MSHPs (Minnesota Department of Commerce 2016) and Wisconsin EFLH heating values for ASHPs (Public Service Commission of Wisconsin 2017).

Other jurisdictions estimate EFLHs for residential heating based on energy modeling of building archetypes. For instance, the Pennsylvania Public Utility Commission (2016) provides EFLHs for MSHPs in residential dwellings based on energy modeling of building archetypes, as well as on the assumption that, on average, heat pumps are oversized by 40 percent. New York State Joint Utilities (2016) uses a similar methodology to estimate cooling EFLHs of MSHPs, as well as cooling and heating EFLHs of ASHPs, by performing an energy simulation with DOE-2.2 using the Database for Energy Efficiency Resources building archetypes that are recognized throughout the United States as a standard methodology.

Relying on standardized EFLH values that are based on typical buildings and constant usage levels does not factor in variables that affect the actual usage of heat pumps, such as control strategies and interactions with other HVAC systems. To account for this, some program administrators and evaluators conduct detailed metering studies. This is the case in Illinois where EFLHs for MSHPs are derived from a metering study of 40 all-electric multi-family homes that underwent weatherization improvements and in which MSHPs were installed (Illinois Stakeholder Advisory Group 2016, p. 67). A metering study of both cold-climate and non-cold-climate ductless MSHPs was conducted in 152 homes located in Massachusetts and Rhode Island over two consecutive winters (The Cadmus Group 2016). The findings of this study revealed average EFLH values (442 in 2015 and 451 in 2016) that were considerably lower than values previously used in both the Massachusetts and Rhode Island technical reference manuals (1,200 hours).[3] However, the average EFLH values of the top 25th percentile of MSHPs (1,275 in 2015 and 1,117 in 2016) were found to be close to the technical reference manual values. This demonstrates that under some conditions, MSHPs can yield high savings. Other utilities, such as Emera Maine, conducted metering studies on MSHPs to estimate energy consumption rather than EFLHs (EMI Consulting 2014). Submetering was performed on 64 households throughout Maine to isolate MSHP electrical consumption. Regression models were then used to determine energy savings. The study revealed a large variation in the electricity consumption of MSHPs, ranging from 342 kWh to 7,372 kWh per year due to varying user operating patterns.

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[3] The Massachusetts TRM for the 2016-2018 program years has been updated with the EFLHs obtained through the Cadmus metering study.

One study used a billing analysis methodology similar to that presented in this paper to estimate savings for MSHPs (Ecotope 2013). That study was conducted for the Northwestern United States (Washington, Oregon, Montana, and Idaho) and included 3,899 participants who had installed an MSHP to displace heat from a zonal electrical system. Billing analysis results demonstrated an average annual savings value of 2,081 kWh, with values ranging between 496 and 2,416 kWh, depending on geographical areas. The analysis identified supplemental fuel usage as a major determinant of energy savings. Three of the eight geographical areas included in the study presented negative average energy savings for houses that use supplemental fuel heating systems. That study was preceded by a metering study performed on 95 participating households, whose results were compared to those of the Ecotype billing analysis; it was found that the savings from the billing analysis were "within 15% of the savings observed in the metering study when similar screens for supplemental fuels were applied".

Billing Analysis 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, for all eligible 2015 and 2016 MSHP participants. For the pre-installation period, seven billing periods (corresponding to approximately 14 months) were factored in to include the full winter period preceding installation. For the post-installation period, a minimum of four billing periods was established (approximately eight months), which covered the winter period following installation without excluding too many participants. The sample of participants available for the analysis was limited since MSHPs were only introduced to the program in late 2015. The initial sample included 93 participants and was reduced to 71 respondents based on the above criteria.

The objective of the billing analysis was to compare the electrical energy consumption of the sampled participants before and after MSHP installation. To do so, a regression model based on the Princeton Scorekeeping Method (Fels, 1986) was used. This standard statistical method calculates the linear regression specific to each participant based on weather data from nearby weather stations instead of analyzing the data as a whole. The regression model is expressed in the following equation:

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

Where:

- CONS is the average daily consumption;
- α is the daily base consumption constant;
- β is the consumption coefficient per HDD;
- HDD is the average daily heating degree days on an 18 °C (64 °F) basis from the closest city for each participant;[4]
- 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, appliances, domestic hot water (DHW), and electronic devices. On the other hand, 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 electricity consumption variation 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

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[4] Participants were assigned to one of five geographical areas to determine the source of their HDD data, with the following cities representing each region: Halifax; Greenwood; Yarmouth; Sydney; and Debert.

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. Unfortunately, the 2014-2015 winter was particularly cold in Nova Scotia; comparing HDDs between the months of October to May inclusively for those two winters reveals that HDDs were almost 10% higher in the first winter. This means that the coefficient β for the first winter is lower, resulting in slightly underestimated energy savings. This billing analysis will be repeated for the 2016-2017 winter, which should allow for better estimates of the impact of weather variations on energy savings estimates.

The pre and post-installation billing data of each participant were analyzed using the linear regression model presented above; to obtain annualized electricity consumption that varies as a function of HDD, the coefficients β were multiplied by the normalized annual HDD (Government of Canada 2017). The normalized HDD values were used to establish the average savings that are not specific to a particular year. Table 1 presents the normalized HDD data for the five cities used in this analysis.

Table 1. Normalized HDD per city

City	Normalized HDD (18 °C)
Halifax	4,367
Greenwood	4,218
Yarmouth	4,041
Sydney	4,618
Debert	4,438

Only one category of participant was excluded from the analysis, participants who had a heat pump as their existing 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 from the analysis.

The statistical significance of the regression model described above was used as a discriminating criterion to define which results should be retained. The analysis was strictly based on statistical observations using the following criteria:

- A statistically significant β coefficient for both the pre and post periods;
- A positive daily base consumption constant α;
- A coefficient of determination (R^2) 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.

Billing Analysis Results

Econoler first estimated average savings for MSHPs by conducting a billing analysis of participants who had installed a unit in 2015 and had sufficient available billing data (71 participants). At the time of analysis, 2016 MSHP participants could not be included since sufficient billing information was not available. This analysis was combined with two phone surveys, the first of which was conducted to ensure the validity of the data and gain understanding of how 2015 participants used their heating systems. The second survey included 2016 participants and aimed to both determine the typical usage of MSHPs installed under that program year and adjust the results of the billing analysis to ensure that the data represented actual usage.

The first survey led to the identification of changes made to the home either before or after the installation of the MSHP, which can affect heating energy consumption. More specifically, survey questions were designed to identify changes made to building envelopes and space heating systems. This survey was conducted with 50 of the 71 MSHP participants, which led to the conclusion that very few participants had implemented changes that affected the space heating consumption of their homes. The pre and post-installation space heating consumption of the few participants who declared such changes was compared to those that did not and no statistically significant difference was observed; therefore these participants were not excluded from the analysis. The fact that the billing analysis was restricted to the year before installation also ensured that a limited number of changes would impact the analysis.

Using the aforementioned statistical criteria, 29 of the initial 50 participants were retained for further analysis. On average, these 29 participants saved 3,560 kWh annually, which translated into an average of 0.183 kWh per Btu/h of installed heating capacity. The first survey served to obtain more information on the characteristics and usage of the heating systems, notably whether a secondary non-electrical heating system was used prior to heat pump installation, which portion of the home was heated by a heat pump (one room, a few rooms, entire home), and finally if the heat pump was used throughout the heating season or if it was turned off during the coldest winter periods. Unfortunately, the small sample size prevented establishing distinct savings values that were statistically significant for each answer. Although the large variety of heat pump usage levels seems to indicate there would be value in quantifying the impact of these parameters, Econoler concluded that it would not be feasible considering the small population size available at that time.

Due to the limited number of valid results obtained from the first sample of 50 survey respondents, Econoler conducted a second billing analysis a few months later and included all MSHP participants for whom sufficient billing data could be obtained from the 2015 and 2016 program years. This allowed drawing from a larger pool of 126 participants, and extending the post-installation period for which billing data was available for participants included in the previous billing analysis. Deciding which participants to include in the savings calculations was strictly based on statistical observations using the same criteria as the previous billing analysis, the results of which are listed in Table 2 below.

Table 2. Exclusion criteria for second billing analysis

Criteria	Nb of Participants Excluded
Statistically significant coefficient β for both the pre and post periods	36
Positive daily base consumption constant α	1
Adjusted R2 above 0.65	10
Outlier savings value (beyond 2 times standard deviation)	5

The criterion that excludes the most participants from the analysis is the significant correlation for both the pre and post-installation coefficient β. These 36 participants were excluded as follows:

- 13 did not have a significant coefficient β for the pre-installation period;
- 7 did not have a significant coefficient β for neither the pre nor post-installation periods;
- 16 did not have a significant coefficient β for the post-installation period.

The assumption that the presence of non-electrical backup systems might cause the temperature-related consumption coefficient to be statistically insignificant was tested. Of the 19 participants with an insignificant coefficient for the pre-installation period, nine had secondary non-electrical heating systems, while of the 20 participants with an insignificant coefficient for the post-installation period, 10 had such secondary systems. For the 81 participants who did obtain a significant coefficient for both pre and post-installation periods, the proportion of participants with non-electrical secondary system was 37 percent. This difference is not large enough to conclude with certainty that the presence of a secondary non-electrical heating system is related to a statistically insignificant correlation between electricity consumption and heating degree days.

This analysis therefore resulted in valid savings being calculated for a total of 74 participants. Table 3 summarizes the average savings obtained, as well as the standard deviation and error calculations.

Table 3. Average energy savings and energy savings per installed capacity

	Energy Savings	Energy Savings per Installed Capacity
Number of Observations	74	74
Mean	3,671 kWh	0.180 kWh/Btu/h
Standard Deviation	3,150 kWh	0.147 kWh/Btu/h
90% Confidence Interval	±601 kWh	±0.028 kWh/Btu/h
Relative Uncertainty	±16.4%	±15.6%

Econoler also calculated distinct energy savings based on whether or not participants had a non-electrical secondary heating system prior to installing a heat pump. This parameter was, in fact, identified as having a major impact on energy savings in the previously referenced Ecotope study. Table 4 presents the details of this comparison.

Table 4. Average energy savings and energy savings per installed capacity

	Energy Savings		Energy Savings per Installed Capacity	
	With Secondary Non-Electrical System	Without Secondary Non-Electrical System	With Secondary Non-Electrical System	Without Secondary Non-Electrical System
Number of Observations	27	47	27	47
Mean	2,800 kWh	4,170 kWh	0.124 kWh/Btu/h	0.212 kWh/Btu/h
Standard Deviation	3,630 kWh	2,760 kWh	0.148 kWh/Btu/h	0.139 kWh/Btu/h
90% Confidence Interval	±1,190 kWh	±660 kWh	±0.048 kWh/Btu/h	±0.033 kWh/Btu/h
Relative Uncertainty	±42%	±16%	±39%	±16%

Statistical significance could not be established for the difference in absolute energy savings values, but once savings were normalized per installed heating capacity, the difference became statistically significant. Results are consistent with what was observed in the Ecotope study, i.e. that savings are higher for homes that do not have a secondary non-electrical heating system.

To better understand the impact of secondary non-electrical heating systems, the 13 participants for whom an increase was observed between the pre and post-installation coefficient β were further analyzed, as presented in Table 5. These 13 participants included some of the participants that were originally excluded on the basis of having savings that were outside of the two standard deviation range.

Table 5. Characteristics of participants with negative energy savings

Participant	Annual Electricity Consumption, Pre-Installation (kWh)	Average Pre-Installation Variable Electricity Consumption (kWh)	% of Variable Electricity Consumption	Heating Capacity Installed (Btu/h)	Non-Electrical Secondary Heating System
1	42,106	30,492	72%	13,600	None
2	11,617	2,898	25%	32,000	Wood stove
3	16,305	3,155	19%	18,000	Oil furnace
4	18,273	13,655	75%	18,000	Wood stove
5	15,947	5,191	33%	18,000	Wood stove
6	17,173	4,948	29%	16,000	Wood stove
7	23,578	7,852	33%	16,000	None
8	17,862	4,306	24%	50,000	Wood stove
9	7,362	3,475	47%	16,000	Wood stove
10	12,466	4,572	37%	18,000	Wood stove
11	14,663	6,037	41%	18,000	Wood stove
12	12,113	7,419	61%	18,000	Wood stove
13	18,875	14,448	77%	20,200	Wood stove
AVERAGE	17,565	8,342	47%	20,908	-

Most participants who obtained negative energy savings had a low to medium total electricity consumption and a low variable consumption. They all installed MSHPs with fairly low heating capacity, with one notable exception: the participant who installed the greatest MSHP capacity, 50,000 Btu/h, obtained negative savings. Without this single participant, the average installed heating capacity would have been 18,483 Btu/h, which is below the program average of 21,224 Btu/h. One characteristic almost all of these participants share is that they have a non-electrical secondary heating system; interestingly, while 35 percent of Green Heat participants had a non-electrical secondary heating system, 85 percent (11 participants) of participants who obtained negative savings had a wood stove or an oil furnace. The possibility that a portion of the heating load that was previously met by this non-electrical system is now covered by the MSHP is a plausible reason for the increase in electricity consumption per HDD after MSHP installation. This also indicates that secondary non-electrical heating systems might have negatively affected electricity savings for other participants.

Figure 3 presents the distribution of annual energy savings for all 74 participants as a function of installed heating capacity.

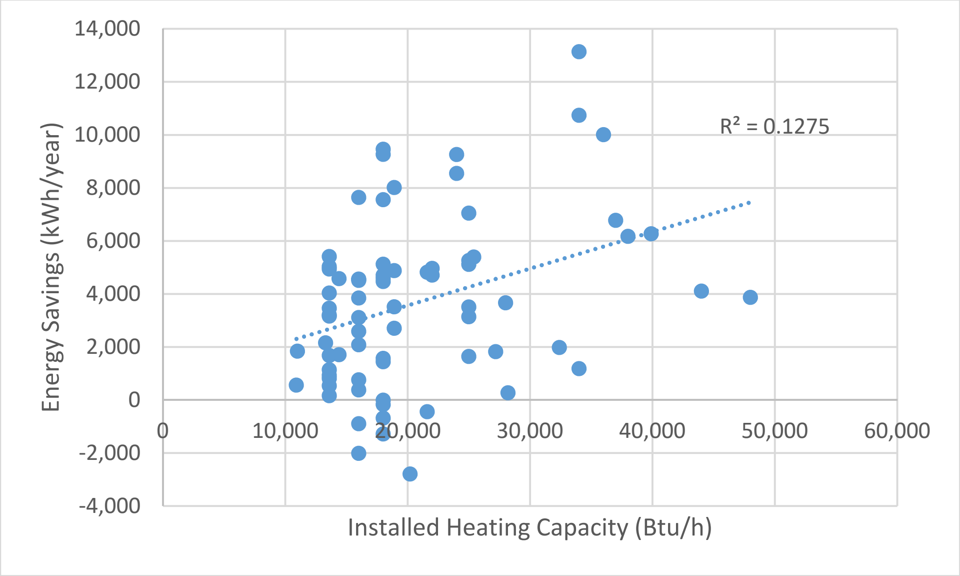

Figure 3. Energy savings as a function of installed heating capacity

This figure demonstrates that the correlation between energy savings and installed heating capacity is poor. Although the highest savings values tend to be generated by higher capacity heat pumps, some high-capacity heat pumps exhibit relatively low savings.

Comparison to EFLH Values

To provide perspective on the scale of the savings obtained through this billing analysis, Table 6 compares average energy savings to both the average variable electricity load and EFLHs.

Table 6. Analysis of average energy savings

Average Energy Savings	Average Pre-Installation Variable Electricity Consumption	% of Variable Electricity Consumption Saved	EFLH Heating
3,671 kWh	12,186 kWh	30%	890 h

The value for average pre-installation variable electricity consumption was calculated as the product of the average coefficient β (pre-installation) by the average HDDs for all 74 participants included in the final savings analysis. To calculate the EFLH value, the EFLH variable was isolated from the energy savings equation previously presented in the Existing Literature on MSHP Savings section above.

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

The average rated heating capacity (HC) for the 74 participants was 20,728 Btu/h. The weighted average $HSPF_{ee}$ for installed MSHPs was 10.63 and the $HSPF_{base}$ was 3.412 (equivalent to 100% efficient electrical resistance heating).

The average HSPF value of 10.66 indicates that MSHPs should have reduced the heating load by almost 67 percent if the entire variable electricity load had been space heating and if MSHPs heated the entire home; instead, on average MSHPs reduced the variable electricity load by only 30 percent. The results of the survey (whereby a significant proportion of participants indicated that their MSHPs did not heat their entire home and/or they used secondary heating systems) and the knowledge that loads other than space heating are sensitive to HDDs indicate that a mix of these two conditions contributed to the lower savings. The EFLH value calculated based on average energy savings is significantly below values suggested in the ANSI/AHRI Standard 210/240 (2,750 h) and used in other jurisdictions with similar cold climates (e.g. Minnesota, 2,208 h).

Conclusions

More analyses should be conducted to refine the savings estimations of MSHPs since these products are becoming increasingly popular in cold climates. The literature review revealed that many jurisdictions rely on either weather data or secondary data to estimate participating home heating loads and corresponding energy savings. Metering studies are certainly the most rigorous method of validating MSHP energy savings because they can account for all variables that affect the performance and energy consumption of MSHPs. However, such studies are too expensive to be conducted on a large scale in most jurisdictions that offer MSHP programs and it can be difficult to extrapolate results to all program participants because metering studies on a small sample of participants might not be representative of the average operating conditions of all MSHPs installed through a given program.

The Econoler billing analysis permitted the estimation of energy savings that are specific to the MSHP systems installed under the ENS Green Heat program and to the conditions under which they operate. While the margins of error were slightly above the usual standard of ±10 percent at a confidence level of 90 percent, the analysis results provided new information indicating that methods based on EFLH calculations overestimate savings. Savings were established specifically for homes that have a secondary non-heating system and for those that do not; the savings for these two categories of homes are significantly different. Homes without such secondary systems obtained approximately 70% higher savings.

The billing analysis approach is mostly useful for MSHP programs whose baseline scenario is the existing heating system, as is the case for ENS Green Heat. For programs whose baseline is a standard efficiency heat pump, pre and post-installation analyses are not adequate. This approach, however, offers the advantage of being considerably less expensive than a metering study given that the analysis can be conducted using billing data collected by the utility rather than data collected by installing onsite meters.

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