Q. Reference: “2022/2023 General Rate Application,” Newfoundland Power, May 27, 2021, Volume 2, Section 3.

Please provide any reports and the data and data analysis prepared on Newfoundland Power’s heat pump study.

A. Attachment A provides the report on the first winter season of the heat pump study. The next report is scheduled to be finalized by early Fall 2021.

Heat Pump Load Study
Winter 2020 Results
July 16, 2020

HEAT PUMP LOAD STUDY WINTER 2020 RESULTS

NEWFOUNDLAND POWER

Final Report

July 16, 2020

ECONOLER

ABBREVIATIONS

COP	Coefficient of performance
DHP	Ductless heat pump
DHW	Domestic hot water
HSPF	Heating seasonal performance factor
SEER	Seasonal energy efficiency ratio

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INTRODUCTION

Econoler was commissioned to design and conduct a study to quantify the impacts of ductless heat pumps (DHPs) on Newfoundland Power's grid. The primary objective of the study is to determine the impacts that DHPs have on the electricity system's load shape and particularly peak demand, as adoption of this technology continues to grow. The secondary objective of the study is to analyze data about DHPs by focusing on their power demand and energy consumption.

This study is being conducted in collaboration with Ecofitt and Simptek. Ecofitt has implemented the study's homeowner-recruitment strategy and installed the metering equipment. Simptek is responsible for wirelessly collecting the metering data and compiling it. The study is being implemented according to the Evaluation Plan submitted to Newfoundland Power in the fall of 2019.[1]

This report provides the preliminary results and findings of the study after the first three months of metering (January through March 2020). It includes a description of the methodology implemented, a review of the quality of data collected, a validation of the control group and the treatment group, a discussion of the key metrics (energy consumption and savings) calculated based on the data collected over the first three months of metering and an analysis of those results.

[1] Econoler, *Heat Pump Load Study Evaluation Plan*, a report prepared for Newfoundland Power, December 19, 2019.

1 OVERALL APPROACH

The Heat Pump Load Study was aimed at assessing the impacts of the growing popularity of residential DHPs on Newfoundland Power's electricity system. The study results will be used to assess DHPs' potential impact on system load shapes by focusing on the system peak. The study results will also inform future energy conservation and demand management program designs and customer education initiatives. This study is also aimed at providing insights on how customers use DHPs, such as their DHP usage patterns and control methods.

To accomplish these objectives, metering equipment was installed in 264 Newfoundland homes to monitor their DHPs' electricity consumption. The monitoring period is expected to last at least one year and both the study and the metering period could be extended to up to 18 months. Approximately half of those participating homes each have a DHP (and they are the treatment group); the other half are each heated with an electrical-resistance heating system (and they are the control group). Ecofitt installed a meter dedicated to the DHP in each of the treatment-group homes so that the electricity consumption of the DHP can be monitored separately from that of the whole house. The metered electricity-consumption data for the whole house and for the DHP was to be used to obtain the following metrics, which was the objective of the study:

- The hourly average energy-savings load shapes[2] correspond to the average difference in whole-house metered electricity consumption between the control group and the treatment group. This result corresponds to the savings achieved by replacing an electric-resistance heating system with a DHP. Once a full year of metering is completed, the annual load shapes will reveal the annual energy savings in kWh.
- The hourly average peak-demand-savings load shapes correspond to the average difference in whole-house metered electricity demand between the control group and the treatment group under the grid's peak conditions.
- The hourly average load shapes of DHPs' electricity consumption. This result corresponds to the electricity consumption added to the grid if a DHP replaces a non-electrical heating system.
- The average DHP electricity demand under peak conditions. This result corresponds to the demand load added to the grid under peak conditions if a DHP replaces a non-electrical heating system.

These results are to be calculated for two subgroups of the study, namely Climate Zone 1 (which corresponds to the central and western parts of Newfoundland with the coldest climate) and Climate Zone 2 (which corresponds to those areas with more moderate winter temperatures, as listed in Table 1 below.

[2] Hourly load shapes express the distribution of energy consumption or savings over the day and over the year. Load shapes might cover multiple days (for example, one load shape could represent all weekdays of a given month), but once all load shapes have been calculated for a year, they will represent all the conditions over that year and cover all 8,760 hours.

Table 1: Climate Zones

Climate Zone	Areas Included
1	Grand Falls
	Gander
	Corner Brook
	Stephenville
2	Bonavista
	Avalon
	St. John's
	Burin

More details about the sampling and homeowner-recruitment methodology and the metering equipment installed have been provided in Sections 2 and 3 of the Evaluation Plan.

2 DATA COLLECTION

This section provides an assessment of whether the data-collection requirements set in the evaluation plan were met and details about the data-cleaning process.

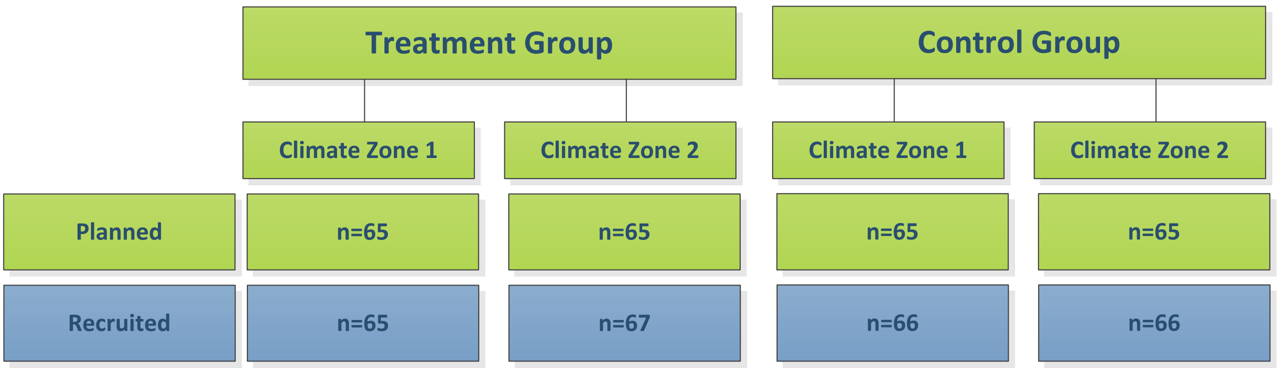
Assessment of Implementation of the Data-collection Requirements

In the evaluation plan, Econoler has set out the requirements for data collection to ensure that the study would meet its objectives. When participant recruitment was completed, Econoler validated whether participant recruitment and data collection met the evaluation plan's requirements.

Participant Recruitment

Figure 1 below outlines the recruitment strategy and the number of participants recruited for the study in each climate zone.

Figure 1: Participant Recruitment



With 264 participants recruited, Ecofitt reached or surpassed the minimum number of homes required for each sampling category. Furthermore, Econoler verified whether the Grand Falls region represented 30% of the homes recruited in Climate Zone 1 treatment and control groups, thereby sufficiently representing the coldest climate zone under peak conditions. During the recruitment process, Econoler also validated whether the income levels of the treatment and control groups were sufficiently comparable for each climate zone so that adjustments could be made before all the participants were recruited.

Participant Information

Ecofitt collected complete data on the participants and their homes, such as address, construction year, size (sq. ft), number of occupants, income, primary heating system type, etc. For the treatment group, Ecofitt also gathered information on DHPs, namely their capacity, HSPF, SEER, and COP. The information about DHPs was complete, except for 5% of the participants' DHPs, whose number of indoor heads and locations were unknown.

Timeline

Installation of the 264 units of metering equipment began on November 4, 2019 and was completed on January 13, 2020, as detailed below.

- 253 installed between November 4 and December 31, 2019.
- 11 installed between January 1 and January 13, 2020.

Data-cleaning

Econoler and Simptek performed several data-cleaning steps to ensure that the study results were accurate. The treatment group participants each had both a whole-house meter and a DHP-circuit meter installed, whereas the control group participants each only had a whole-house meter installed. All those participants were removed from the analysis if their whole-house metering data was considered insufficient with too many data points missing over a given metering period. However, those participants with sufficient whole-house metering data but insufficient DHP-circuit metering data were kept in the analysis for savings calculations purposes but removed from the analysis of DHPs' energy consumption. Appendix I describes in more detail the data-cleaning steps taken to determine whether or not the participating homes' whole-house metering data was sufficient.

As summarized in Figure 2 below, data-cleaning has led to the removal of 23 participants from the analysis.

Figure 2: Sample of Participants after Data-cleaning

	Treatment Group		Control Group	
	Climate Zone 1	Climate Zone 2	Climate Zone 1	Climate Zone 2
Planned	n=65	n=65	n=65	n=65
Recruited	n=65	n=67	n=66	n=66
After Data Cleaning	n=61	n=61	n=60	n=59

3 VALIDATION OF TREATMENT AND CONTROL GROUPS

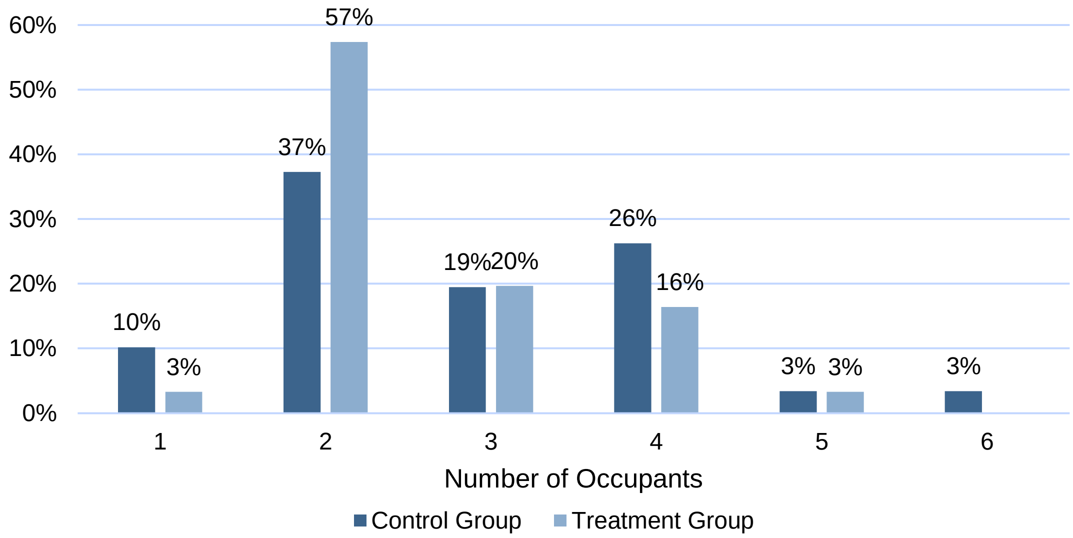
As previously explained, one of the study's objectives was to establish the savings achieved by replacing an electric-resistance heating system by a DHP by comparing the energy consumption patterns of a control group (without DHPs) with the patterns of a treatment group (with DHPs). Therefore, the study has been designed to recruit participants who are similar in terms of electricity consumption. Upon completion of the first three months of metering, Econoler validated whether this goal was achieved by comparing the characteristics of the control group and the treatment group by looking at all the following parameters expected to have a significant correlation with electricity consumption:

- The number of occupants per household
- The year when the house was built
- The house's square footage
- The income level
- The domestic hot water (DHW) fuel source
- Presence and usage of a secondary heating system
- Presence of special electric loads (hot tubs, electric vehicles, etc.)

Most of these parameters did not show statistically significant variations between the treatment group and the control group. Some parameters, however, exhibited variations that prevented the whole-house electricity consumption of the two groups from being used directly to estimate the energy and peak demand savings attributable to the replacement of electrical heating systems by DHPs. The following paragraphs described the adjustments that Econoler made to make that comparison statistically valid.

The number of people per household showed the most significant discrepancy, and this variable exhibited a strong correlation with electricity consumption. The initial distribution of the number of occupants per household is shown in Figure 3 below.

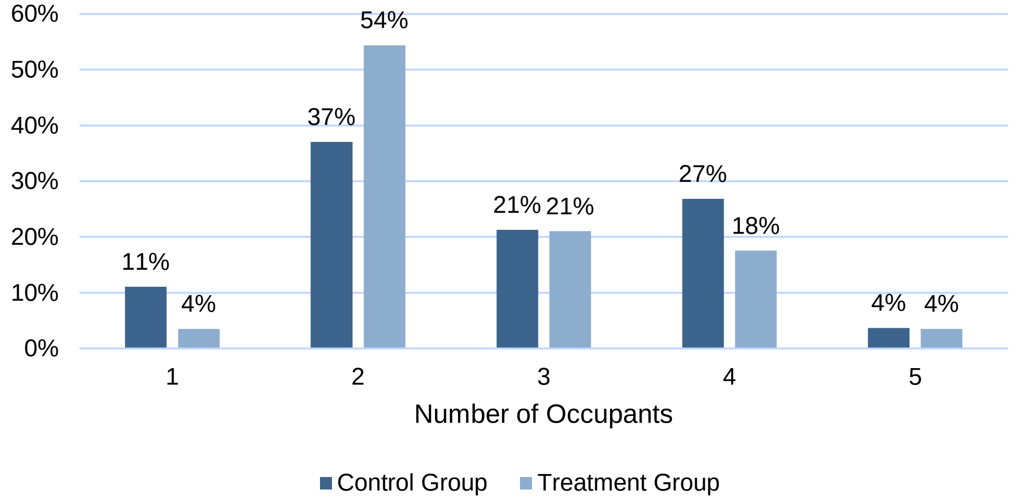
Figure 3: Initial Distribution of the Number of Occupants per Household in the Treatment and the Control Groups



The households with four or more members were more common in the control group, whereas the treatment group included many households with only two occupants. This distribution is useful because it provides information about the types of households that are more likely to install a DHP. To make the two groups more comparable, Econoler first excluded those households with six people from the control group. Econoler made this priority adjustment to the control group because excluding the types of participating households that are not in the group of households who installed DHPs (namely the treatment group) does not affect the validity of savings. However, this adjustment was insufficient to create an average number of occupants per household that was similar between the two groups. So, Econoler also removed six participating households with 2 occupants from the treatment group. Although modifying the composition of the treatment group has made the group less representative of participants that are likely to install a DHP, Econoler has chosen to make this adjustment to avoid underestimating the electricity consumption of the treatment group and later overestimating the savings.

After the above changes were made, the treatment group had an average of 2.63 people per household and the control group, 2.75. These two averages were statistically similar and have resulted in the adjusted distribution of households shown in Figure 4 below.

Figure 4: Adjusted Distribution of the Number of Occupants per Household in the Treatment and the Control Groups



In selecting treatment group households of two people to be excluded, Econoler also aimed to correct the statistically significant difference in house square footage between the two groups. The participants selected for inclusion were among those with a larger house than average. This correction has partially reduced the gap in house square footage between the two groups. The average house size has been estimated at 1,500 ft² for the control group and at 1,620 ft² for the treatment group. Despite these adjustments, the difference between the two groups' average house sizes remains statistically significant in Climate Zone 1, because a few large houses have been included in the treatment group. Therefore, Econoler eliminated three treatment-group participants each with the house size above 3,000 ft². Although these treatment-group participants could generate significant savings (due to the high heating load of their houses), the fact that the control group did not contain such large houses made it impossible to obtain comparable groups if these participants with a large house were kept in the treatment group.

The last adjustment made to the control group concerned the presence and usage of secondary heating systems. In three of the four subgroups, only two or three participants used their woodstoves on a regular basis. In contrast, the control group of Climate Zone 1 included as many as 12 such participants. As expected, electricity consumption was lower for participants who met a portion of their space-heating needs with a non-electrical system, such as the woodstove. Econoler therefore removed from the control group 7 participants who were among those that used their woodstoves most regularly; this change resulted in a more comparable impact of woodstove usage between the treatment group and the control group.

As each of those adjustments were made, Econoler validated whether each adjustment associated with a specific variable did not have an adverse impact on other key variables in the final sample. below outlines the final sample participants, following the adjustments to make the treatment group and the control group more comparable. After performing data cleaning and adjustments to the control and treatment group, 219 participants remained in the data analysis, which represents 84% of recruited participants. This value was in line with study design which assumed a 20% data loss.

Figure 5: Final Sample of Participants after the Adjustments to Make the Treatment Group and the Control Group More Comparable

	Treatment Group		Control Group	
	Climate Zone 1	Climate Zone 2	Climate Zone 1	Climate Zone 2
Planned	n=65	n=65	n=65	n=65
Recruited	n=65	n=67	n=66	n=66
After Data Cleaning	n=61	n=61	n=60	n=59
After Treatment and Control Group Comparison	n=54	n=57	n=51	n=57

4 DHP CHARACTERISTICS

For all the recruited participants with a DHP, detailed information on their DHPs was collected as part of this study. This section presents an overview of the DHPs installed in all the recruited homes (including those excluded from the savings analysis due to insufficient data or following the efforts to make the treatment and control groups comparable).

In total, 75% of the DHPs in the treatment group have been installed in the past two years, indicating that the treatment group's DHPs are very recent. In terms of HSPF criteria, DHPs with an HSPF region IV greater than 10 meet the Northeast Energy Efficiency Partnership standard for cold-climate DHPs. As illustrated in Figure 6 below, 88% of the DHPs had an HSPF region IV above 10. The average HSPF of the DHPs was 9.6 for region V and 11 for region IV, meaning that the average HSPF of the DHPs in the treatment group met the cold-climate standard for high energy efficiency.

Figure 6: Proportion of Metered DHPs Meeting NEEP Standard for Cold-climate DHPs (HSPF Region IV Greater than 10)

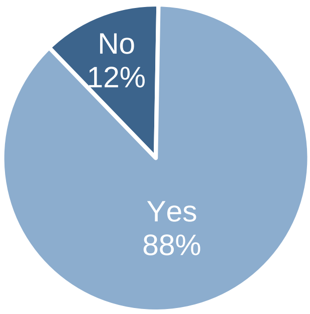


Table 2 below provides the average heating capacity values of the metered DHPs. The average heating capacity in Climate Zone 1 is higher than the average in Climate Zone 2. The cause of those variations is analyzed after the presentation of metering results, in Section 5.4.

Table 2: Average DHP Heating Capacity

	Average Heating Capacity (Btu/h)
Climate Zone 1	25,000
Climate Zone 2	20,000
Total	**23,000**

5 CONSUMPTION AND SAVINGS RESULTS

This section first presents the results of the energy savings, peak demand savings and DHP electricity consumption calculations. Then, we analyze the factors that can explain those results, notably in terms of the differences observed between Climate Zone 1 and Climate Zone 2.

5.1 Energy Savings

The first key result of this study is the hourly average energy savings value, which is the average difference in whole-house metered electricity consumption between the control group and the treatment group. These differences represent the savings achieved by replacing an electric-resistance heating system by a DHP.

The daily hourly average energy savings value (load shapes) was calculated for both the weekdays and the weekend days of the three months covered by data-metering to date for Climate Zone 1 and Climate Zone 2 separately. To obtain results that were representative of a typical meteorological year, Econoler applied a correction factor to each data point to account for the difference between each day's temperature and the corresponding day's temperature in a typical meteorological year. Details of the calculation steps to obtain the load shapes are described in Appendix II.

The load shapes appear to be quite similar when the weekdays are compared with the weekend days, or when one month is compared with another in a given climate zone. However, Climate Zone 1's load shapes appear to be different from those of Climate Zone 2, as illustrated below by the example load shapes in and Figure 8 for weekdays in February 2020. The curves are less flattened and the difference between the treatment group and the control group is larger in Climate Zone 2.

Figure 7: Whole-house Electricity Consumption Load Shapes for February Weekdays, Climate Zone 1

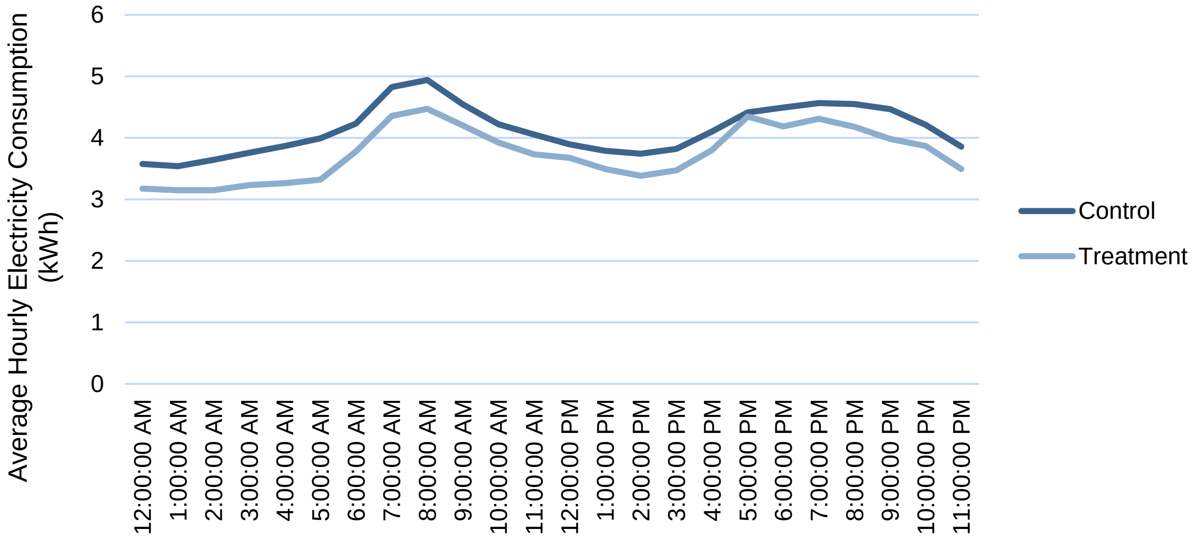
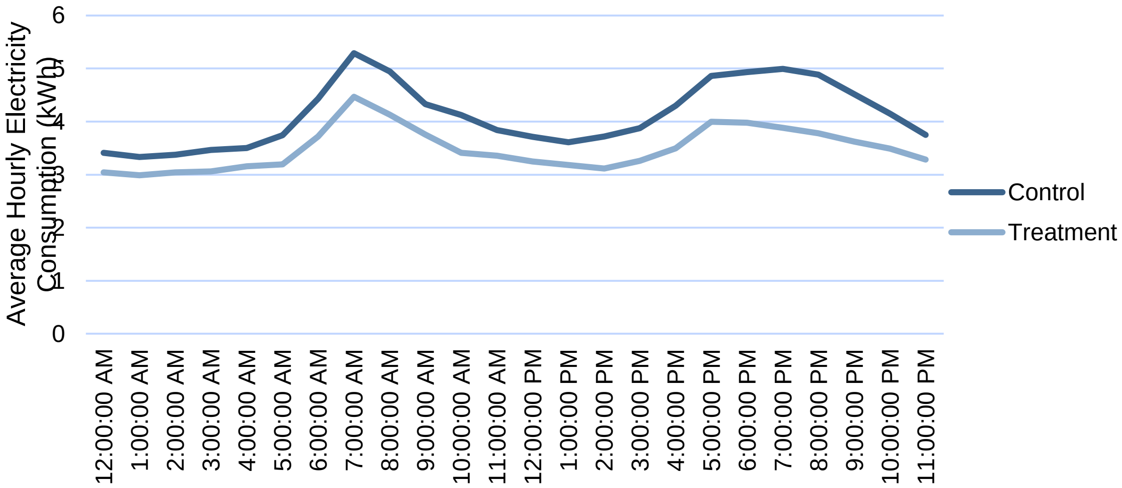


Figure 8: Whole-house Electricity Consumption Load Shapes for February Weekdays, Climate Zone 2



For each climate zone, month and day type, Econoler calculated the average savings in daily electricity consumption. The relative savings in a percentage of the total electricity consumption were also calculated. It should be mentioned that those percentages are lower than the savings expressed in a percentage of the space-heating consumption (which is often how DHP savings are expressed). The results are shown in Table 3 and Table 4 below for Climate Zone 1 and Climate Zone 2 respectively.

Table 3: Calculation of Daily Savings in Electricity Consumption for Climate Zone 1

	Daily Electricity Consumption in kWh							
	Weekday				Weekend Day			
	Control	Treatment	Savings	Savings (%)	Control	Treatment	Savings	Savings (%)
January	103.4	92.9	10.6	10%	97.9	88.3	9.6	10%
February	99.1	89.9	9.1	9%	105.9	95.4	10.4	10%
March	85.7	79.5	6.2	7%	88.5	80.6	7.9	9%

Table 4: Calculation of Daily Savings in Electricity Consumption for Climate Zone 2

	Daily Electricity Consumption in kWh							
	Weekday				Weekend Day			
	Control	Treatment	Savings	Savings (%)	Control	Treatment	Savings	Savings (%)
January	96.8	84.8	12.0	12%	104.3	93.2	11.2	11%
February	99.1	83.7	15.4	16%	103.3	88.2	15.1	15%
March	91.4	76.4	15.0	16%	92.7	77.3	15.4	17%

The percentages of savings shown in the above tables should be interpreted with caution. Most importantly, it should be mentioned that they represent the savings for only the three months of metering already done and those savings cannot be used to estimate the annual energy savings that can be expected from DHPs.

These savings also have a sampling margin of error, which is inherent in any study that is based on a sample of participants rather than the measurement of each individual in a population. Below is an example of the calculation of the margin of error at a confidence level of 90% for the savings value on February weekdays.

Table 5: Margin of Errors on Energy Savings – February Weekday Example

	Climate Zone 1			Climate Zone 2		
	Control (n=49)	Treatment (n=54)	Savings	Control (n=57)	Treatment (n=57)	Savings
Average Hourly Electricity Consumption (kWh)	4.114	3.752	**0.362**	4.125	3.499	**0.626**
Standard Deviation (kWh)	1.295	1.124		0.986	1.171	
Absolute Margin of Error (kWh)	±0.307	±0.256	**±0.403**	±0.218	±0.259	**±0.336**
Confidence interval at 90% (kWh)	3.807 to 4.421	3.496 to 4.008	**-0.041 to 0.765**	3.907 to 4.343	3.240 to 3.758	**0.290 to 0.962**
Relative Margin of Error	±7.1%	±6.8%		±5.3%	±7.4%	

Although the margins of error on the electricity consumption of the subgroups in the control group and the treatment group are quite small (between 5% and 8% depending on the month), the absolute margins of error on the savings of Climate Zone 1 are actually higher than the savings themselves. The margin of error of 0.403 kWh established at a confidence level of 90% means that we can be 90% confident that the true value of savings is between -0.041 kWh and 0.765 kWh and that there is a 5% chance that the savings are below that interval and there is a 5% chance that savings are above that interval. To determine whether the savings are statistically significant, we need to be quite confident that the savings are actually not nil. So, Econoler calculated the probability of savings being below zero, which is 7%. Typically, a statistical significance level of 5% or lower is the convention among experimental scientists, although it is not uncommon for a metering study of this type, to encounter a probability of nil savings between 5% or 10%.[3] In conclusion, for Climate Zone 1, savings are statistically significant, but towards the upper limit of what is acceptable.

For Climate Zone 2, the savings obtained are clearly statistically significant. Although the margins of error on the electricity consumption of the treatment group and the control group are similar to those of Climate Zone 1, the savings calculated for Climate Zone 2 are much higher than those of Climate Zone 1. As a result, the probability for the savings to be actually nil is below 0.1% and the average savings can be assumed with high confidence to be representative of the whole population.

[3] For instance, measured savings as part of the one of the most detailed metering studies to be conducted on DHP, which were used to evaluate the residential programs of Electric and Gas Program Administrators of Massachusetts and Rhode Island, also present margins of error that are of the same magnitude as the savings themselves. See The Cadmus Group, Inc., *Ductless Mini-Split Heat Pump Impact Evaluation*, Report prepared for The Electric and Gas Program Administrators of Massachusetts and Rhode Island, 2016, Table 12, p. 67

5.2 Peak Demand Savings

The second group of key results of this study are the electricity savings achieved specifically in grid peak conditions. This section first discusses the definition of the peak demand period used in subsequent calculations, and then presents the results of those calculations.

5.2.1 Identifying the Peak Demand Periods

To determine which days and hours should be considered as meeting the peak conditions, Econoler used the grid-level hourly demand data provided by Newfoundland Power for the period of January through March 2020.

Econoler has applied a value of 95% of the 2019-2020 seasonal maximum grid demand, which corresponds to 1,288 MW, as the definition for the peak conditions. Based on this definition, the peak conditions occurred over a total of 26 hours scattered over 8 days (namely January 10, 15 and 22[4], February 14, 15, 20 and 21 and March 10, 2020). All these 8 days were weekdays, except February 15. Of the 26 peak hours, 17 hours occurred between 7 am and 10 am, and 7 hours occurred between 5 pm and 9 pm.

Econoler also compared these peak conditions to those that occurred in the 2019 winter to determine whether the savings observed during the period of January through March 2020 could be considered as representative of the savings in harsher peak conditions, because the 2019 winter was significantly colder. Indeed, the grid demand surpassed the threshold of 1,288 MW for 90 hours in 2019. The maximum grid demand for the 2019 winter (1,480 MW) was also higher than that of the 2020 winter (1,373 MW). However, in the 2019 winter, the temperatures at which the peaks occurred were not lower, as shown in Table 6. This may indicate that the higher grid demand was not necessarily linked to colder temperatures in the 2019 winter.

Table 6: Comparison of Average Temperatures during the 2019 and 2020 Winter Peak Periods

	Climate Zone 1 – Gander			Climate Zone 2 - St John's		
	2019	2020	Difference	2019	2020	Difference
Average temperature when demand was above 1,288 MW	-14.5°C	-15.7°C	1.2°C	-11.1°C	-12.8°C	1.7°C

Although the highest grid demand in 2019 was reached during some of the coldest hours of the year when temperatures reached approximately -16°C and -19°C, the 2020 peak-condition hours also included a few hours during which the temperatures were almost as cold.

Because the heating load is directly proportional to the ambient temperature and a DHP's performance decreases with the ambient temperature, the savings from DHPs are closely linked to

[4] On January 22, 2020, there was a major snowstorm in Newfoundland.

the ambient temperature. Therefore, Econoler thinks that the 26 peak hours identified based on the peak condition definition above is appropriate and that the savings established for those hours are likely to be representative of the savings to be expected on the peak days in the future.

5.2.2 Load Shapes for Peak Demand Savings

Using the whole-house electricity consumption data of the control group and the treatment group, Econoler calculated the average whole-house electricity consumption over the eight peak days for the two groups respectively and established a load shape representing the hourly savings over the peak days. For these calculations, electricity consumption was not adjusted to obtain the results that are representative of a typical meteorological year, because the ambient temperatures on the 8 peak days were the temperatures at which the grid peak conditions occurred. Figure 9 and Figure 10 below show the differences between the treatment group and the control group in electricity consumption on the peak days. These differences follow a pattern similar to what was observed for the daily energy savings over the whole heating season.

Figure 9: Whole-house Electricity Consumption Load Shapes on the Peak Days in Climate Zone 1

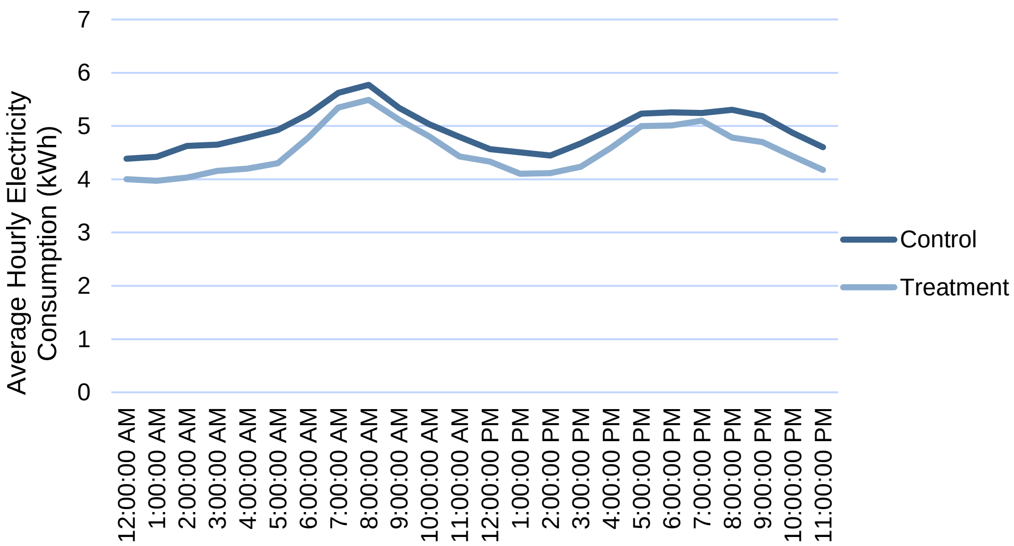
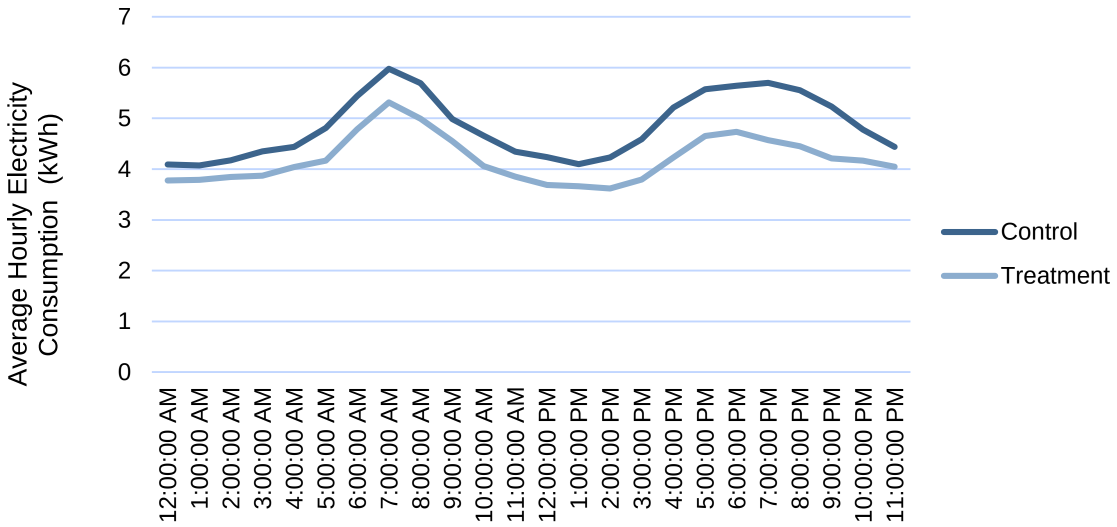


Figure 10: Whole-house Electricity Consumption Load Shapes on the Peak Days in Climate Zone 2



Econoler also calculated the peak demand savings for each climate zone by comparing the specific hourly electricity consumption of the control group with that of the treatment group specifically for the 26 hours in peak conditions previously defined. The results are presented in Table 7 below.

Table 7: Average Demand Savings during the Peak Hours

	Climate Zone 1			Climate Zone 2		
	Control	Treatment	Savings	Control	Treatment	Savings
Hourly kW	5.63	5.50	**0.13**	5.90	5.12	**0.78**
Standard Deviation	1.76	1.88		1.51	1.93	
Absolute Error	±0.42	±0.43	**±0.59**	±0.33	±0.43	**±0.54**
Relative Error	7.4%	7.8%		5.7%	8.4%	

Although the absolute margins of error on the average hourly electricity consumption of each subgroup in the control group and the treatment group were quite small, the margin of error on the peak demand savings is large compared to the magnitude of those savings, especially for Climate Zone 1. Climate Zone 1 has positive savings of 0.13 kW, meaning that the homes in the treatment group consumed on average less electricity during those 26 peak hours. However, the margin of error of that value is large and the probability for the savings to be actually negative has been estimated at 36%. In short, the measured savings value cannot be considered to be statistically significant because that probability is far beyond the maximum threshold of 10%. Climate Zone 2's savings value is considered to be statistically significant because the probability for the savings to be below zero is only 1%.

5.3 Energy Consumption of DHPs

This section provides an overview of DHPs' energy consumption during January, February and March of 2020. This level of energy consumption is expected to be added to the grid load if DHPs replace non-electrical heating sources.

A similar approach to analyzing the energy savings load shapes was used. The daily hourly average energy savings (load shapes) were calculated for both the weekdays and the weekend days during the three months of data-metering to date for Climate Zone 1 and Climate Zone 2 separately. To obtain the results that are representative of a typical meteorological year, Econoler applied a correction factor to each data point to account for the difference between each day's ambient temperature and the temperature in a typical meteorological year. Details of the calculation steps for obtaining the load shapes are described in Appendix II.

Average Daily Consumption of DHPs

Table 8 below lists the average daily energy consumption of DHPs on the weekdays and the weekend days in January, February and March 2020. The difference between the averages of daily weekday and weekend-day energy consumption was small for all three months and the two climate zones, which is consistent with finding that the large majority of participants did not have a programmed lower setpoint for their DHP over the periods of time when they were away from their homes. The DHPs' energy consumption was lower in Climate Zone 2 than in Climate Zone 1, which is consistent with Climate Zone 2 being in a warmer climate.

Table 8: Average Daily Consumption of DHPs in kWh

Month	Climate Zone 1		Climate Zone 2	
	Weekdays	Weekends	Weekdays	Weekends
January	27.3	24.5	21.5	23.1
February	24.6	26.3	22.3	22.7
March	20.6	20.9	19.2	18.3

Figure 11 and Figure 12 below provide a visual representation of the average hourly consumption of DHPs in February 2020. The figures for January and March 2020 show very similar patterns and thus are not shown here. There was little variation between the weekday and weekend energy consumption patterns.

Figure 11: DHPs' Average Hourly Energy Consumption on Weekdays in February 2020

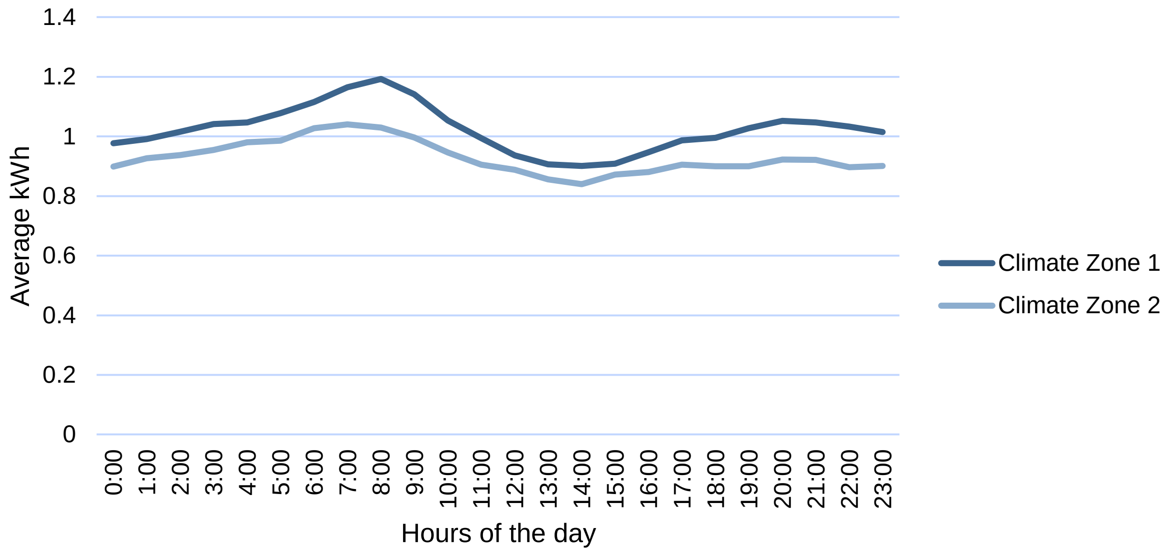
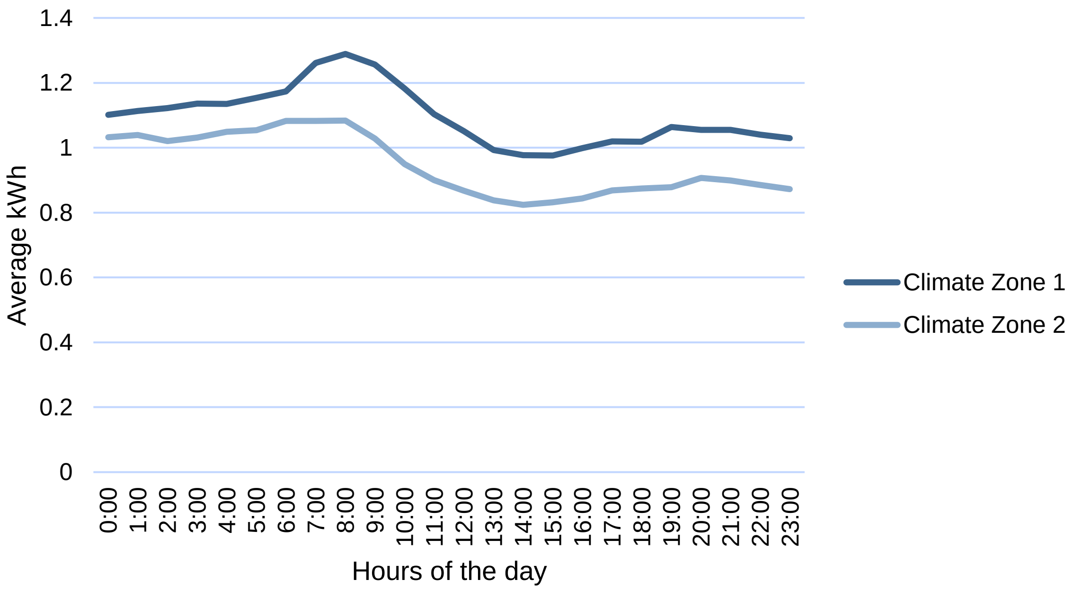


Figure 12: DHPs' Average Hourly Energy Consumption on Weekend Days in February 2020



Average Power Draw during the Peak Hours

Table 9 below lists the average power draw during the peak hours, providing insights on how DHPs consume energy during the peak hours.

Table 9: DHPs' Average Power Draw during the Peak Hours

	Climate Zone 1	Climate Zone 2
Average kW	1.57	1.33
Margin of error	**±0.18**	**±0.17**
Margin of error (%)	**11.2%**	**12.6%**

The average power draw in both zones may seem low, given that the average heating capacity for Climate Zone 1 is 20,000 Btu/h (5.9 kW) and for Climate Zone 2, 25,000 Btu/h (7.3 kW). However, the heating capacity has been obtained at the rated condition of 8.8°C; this capacity becomes lower as the ambient temperature decreases. For instance, for the DHP models listed on the Air-Conditioning, Heating, and Refrigeration Institute website that have an HSPF of 10 or higher and a rated output between 9,000 and 36,000 Btu/h, their average ratio of heating capacity at -8.8°C to the heating capacity at 8.8°C is 63%. In the peak conditions (between -10°C and -20°C), that capacity is likely to further decrease. If a DHP has a rated heating capacity of 5.9 kW, a capacity of about half this value at -15°C and a COP of 2, it consumes about 1.5 kW at -15°C if it operates at full load. This value of 1.5 kW is close to the average power draw observed during the peak hours, thus indicating that most DHPs do operate most of the time in peak conditions. In fact, 95% of all the DHPs consumed some electricity (meaning they operated for at least a portion of the hour) over all 26 peak hours. It is, however, worth mentioning that there are some variations among DHPs: some may have a heating capacity at low temperatures that is much closer to their rated capacity (particularly cold-climate DHPs, which are designed for optimal operation at temperatures below 10°C), whereas some DHPs stop operating at temperatures below -10°C or -15°C.

5.4 Result Analysis

Considering the significant differences in energy and peak demand savings observed between Climate Zone 1 and Climate Zone 2, Econoler compared various parameters regarding the participants in each of the two zones to find possible explanations for those findings. It is interesting to note that another heat pump study, conducted in the Northwest of the United States, showed similar differences in savings between climate zones.[5] Indeed, this billing analysis study included participants from coastal, milder climates as well as participants from a colder, continental climate. Savings were found to be 25% higher in the milder climate, and when the individual units were metered, there was very little difference in overall heat production.

[5] Ecotope, *Ductless Heat Pump Impact & Process Evaluation: Billing Analysis Report (Report #13-262),* report prepared for Northwest Energy Efficiency Alliance, 2013.

The main difference between these two zones is, of course, the climate. Econoler established the distribution of the days covered by the metering study (from January 1, 2020 through March 31, 2020) by determining the average daily outdoor temperature experienced by each participant. The results are presented for each zone and group, as shown in Table 10 below.

Table 10: Distribution of Average Daily Temperatures by Climate Zone and by Group in January through March 2020

Climate Zone	1		2	
	Treatment	Control	Treatment	Control
Percentage of Days with Daily Average Temperature below -5°C	61%	60%	37%	37%
Percentage of Days with Daily Average Temperature below -10°C	23%	22%	8%	8%
Percentage of Days with Daily Average Temperature below -15°C	4%	4%	0%	0%

In both climate zones, the distribution is very similar between the treatment group and the control group, again validating that the two groups are comparable. However, the difference in the average daily temperature distribution between the two climate zones is clear: in Climate Zone 2, only 37% of the days had an average temperature of -5°C or lower whereas it was about 60% in Climate Zone 1. Climate Zone 1 also had a few days with average temperatures below -15°C, while this never occurred in Climate Zone 2. Because a DHP's heating capacity and COP usually decline as the outdoor temperature drops, this may explain why the savings are lower in Climate Zone 1 than in Climate Zone 2. The opposite effect may occur as the outdoor temperature rises above the point where a house has significant heating load; if little heat is needed to maintain the setpoint temperature in the house, the potential for savings decreases even if the DHP's capacity and COP are higher. Therefore, the savings could be higher in Climate Zone 1 in the shoulder seasons when the heating load in Climate Zone 2 is too low for DHPs to reduce the heating-related electricity consumption by a large amount. The results of this metering study in the coming months are expected to confirm this assumption.

Econoler believes that the difference in outdoor temperature was the main reason for the lower savings in Climate Zone 1, because other parameters with an impact on energy usage are similar between the two zones. For instance, the average house size of the treatment group and the control group is slightly larger in Climate Zone 2. The usage of woodstoves was also low in both zones, after the adjustments had been made to the control group in Climate Zone 1 (as described in Section 3).

The lower temperatures that Climate Zone 1 had probably explain the only other substantial difference between the two zones, which is the average heating capacity of the installed DHPs. Although houses are slightly smaller in Climate Zone 1, their DHPs have a substantially larger average heating capacity (25,000 Btu/h compared to 20,000 Btu/h of those in Climate Zone 2). This situation is consistent with the expectation that the maximum heating load is higher by about 17% if the DHPs are expected to operate at a temperature as low as about -15°C rather than at -10°C[6]; DHP installation contractors may choose to significantly oversize DHPs' rated capacity to compensate for the decreased capacity expected at very low temperatures.

Econoler also attempted to use the DHPs' interval metering data to determine whether the DHPs' operating patterns could explain the differences between the two climate zones. First, the DHPs' electricity consumption was compared to the whole-house electricity consumption to see whether there was any correlation between (1) the DHPs that consumed more electricity (and probably generated more heat) and (2) the lower whole-house electricity consumption (indicating probably higher savings than the average of the treatment group). In both climate zones, no correlation was found. The possible reason might be that some DHPs consumed more electricity because they operated less efficiently, and the others consumed less electricity simply because they operated at lower partial load. Based on this finding, Econoler has concluded that studying DHPs' electricity consumption patterns would not help explain the difference in savings between the two climate zones.

Nevertheless, studying each house's DHP's electricity consumption as a function of the daily outdoor temperature allows for finding out when the DHP works and how its maximum electricity consumption varies with the temperature and a few interesting patterns were observed. Econoler analyzed a sample of DHPs which had particularly low electricity consumption and a sample of DHPs that had some of the highest electricity consumption levels. For most of the low-consumption DHPs, a similar pattern was observed, as shown in Figure 13 and Figure 14 below.

[6] Based on the fact that the heating load is proportional to the difference between the indoor temperature (assumed at 20°C) and the outdoor temperature, the ratio of the heating load for an outdoor temperature of -15°C against -10°C would be (20-(-15))/(20-(-10)) = 117%.

Figure 13: Low-consumption DHP Meter (D2BEA) Hourly Average Electricity Consumption as a Function of the Daily Outdoor Temperature

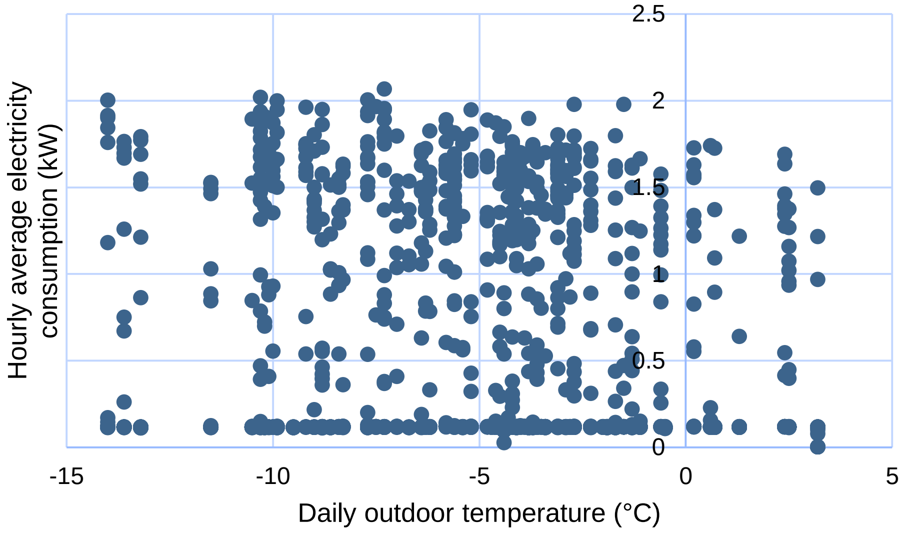
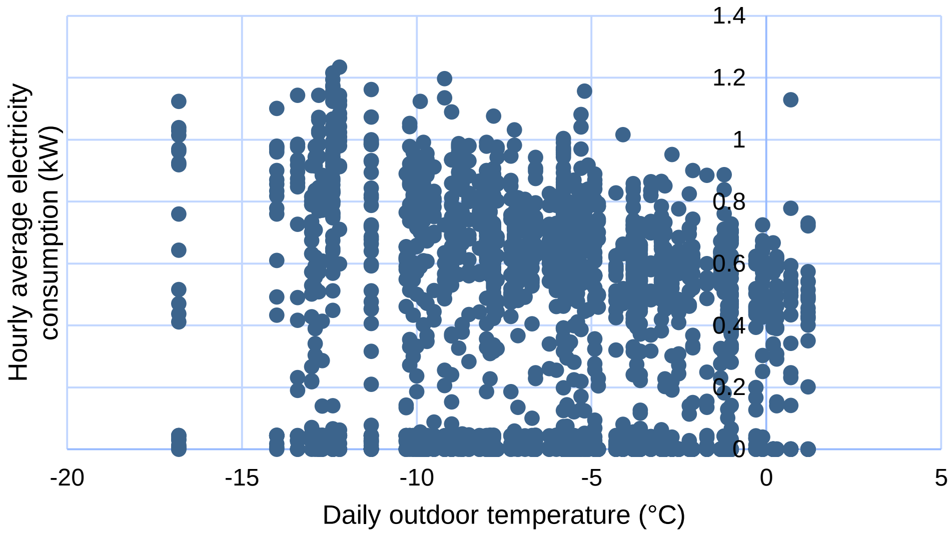


Figure 14: Low-consumption DHP Meter (445C9) Hourly Average Electricity Consumption as a Function of the Daily Outdoor Temperature



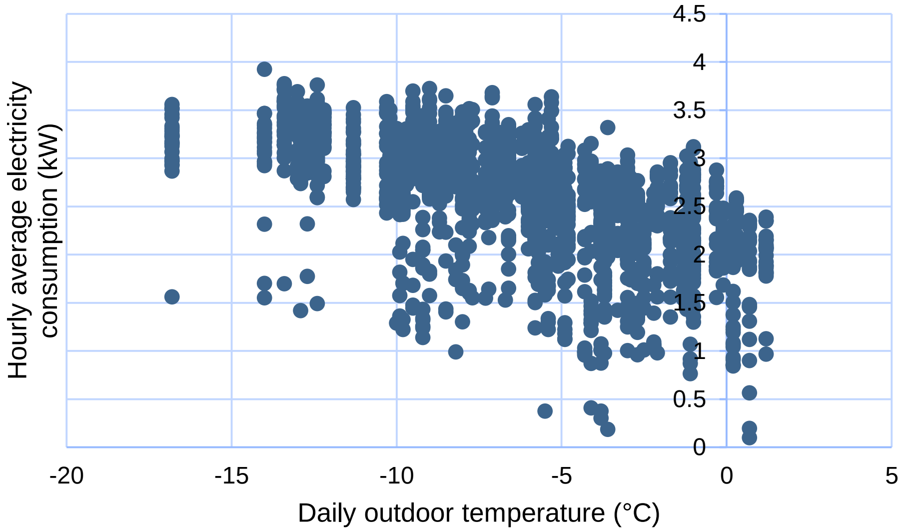
In both cases, the DHP appeared not to run at all or appeared to run for a small percentage of the time (as shown by the data points which are significantly below the maximum value for a given daily outdoor temperature), even on relatively cold days. This could be due to a unit that is oversized, or to control issues: for instance, if a backup heating system, like electrical baseboards, often covered most of the heating load. This assumption is not supported by the data collected on site when the meters were being installed, because the vast majority of participants had a much lower setpoint for their backup heating systems than for their DHP (including those two examples shown above).

Another assumption could be that DHPs are turned on and off or that their setpoint are changed frequently by the users. This type of user behaviour was observed in a metering study conducted in Massachusetts and Rhode Island and partially explained the low savings measured at some of the participating sites.[7]

The DHP featured in Figure 14 showed a more obvious increase of consumption as the outdoor temperature decreased, but its average hourly electricity consumption was still low, mostly under 1 kW, despite this DHP having has a heating capacity of 21,600 Btu/h (6.3 kW). This suggests that the DHPs do not run at their full capacity, even at the coldest temperatures for which they were sized. However, this cannot be confirmed because metering a DHP's electricity consumption alone does not provide information about its heat output or efficiency.

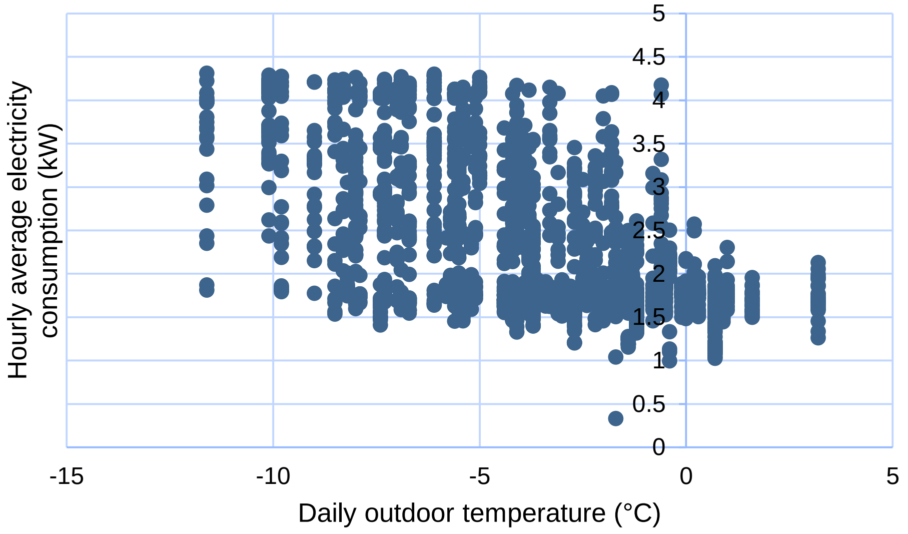
Those DHPs that consumed the most electricity also had one commonly observed operating pattern, as illustrated by the two examples respectively in Figure 15 and Figure 16 below.

Figure 15: High-consumption DHP Meter (D2BB9) Hourly Average Electricity Consumption as a Function of the Daily Outdoor Temperature



7 The Cadmus Group, Inc., D*uctless Mini-Split Heat Pump Impact Evaluation*, Report prepared for The Electric and Gas Program Administrators of Massachusetts and Rhode Island, 2016.

Figure 16: High-consumption DHP Meter (CC678) Hourly Average Electricity Consumption as a Function of the Daily Outdoor Temperature



In both cases, the DHPs never completely stopped running, even at relatively high outdoor temperatures. The lowest hourly electricity consumption is significant, especially in the second example. It is worth mentioning that the two DHPs have an average heating capacity of about 24,000 Btu/h (7.0 kW). The fact that they reached an hourly average of electricity consumption of 4 kW even at temperatures only slightly below 0°C could indicate that they did not operate efficiently. It is also worth mentioning that, surprisingly, both DHPs are high-efficiency models with the Region V HSPF value above 10 and less than two years of age. One of the common causes of poor DHP performance identified as part of the study by the Cadmus Group in Massachusetts and Rhode Island was the malfunction of the outdoor unit, due to improper clearance around the unit or snow accumulation. Additional site visits would be required during the winter to validate if that explanation might apply to some of the DHPs metered as part of this study.

CONCLUSION

This 2020 Winter Results report assesses the effectiveness of the study design and discusses the preliminary results based on the metering done over the first three months in 2020 (January through March).

Validating the control group and the treatment group involved making some adjustments to account for and compensate for the inadequate comparability between these two groups in terms of the number of occupants per household, the sizes of houses and secondary heating system usage. Despite the participants removed from the study for this purpose, enough participants remained in each group to allow for savings calculations. In addition, the missing data caused by temporary or permanent disconnection of the meters had a limited impact on the results because the missing data represented only a small percentage of all the hourly data of each month.

An analysis of the DHPs installed by the participants of the study showed that the vast majority of these DHPs were recent (less than 2 years old) and had an HSPF that would qualify them as high-efficiency DHPs.

Energy savings were calculated as the difference in electricity consumption between the electrically heated homes (the control group) and those homes with DHPs (the treatment group). For the three months from January through March 2020, the savings were found to be higher in Climate Zone 2 (with savings between 11% and 17% of the total electricity consumption) than in Climate Zone 1 (with savings between 7% and 10%). The average peak demand savings are defined as the savings generated over the 26 hours when peak conditions occurred over the period of January through March 2020. Significant average peak demand savings were found only in Climate Zone 2, with 0.78 kW or 13% of peak demand savings per home. The DHPs' energy consumption represents some additional load added to the grid if DHPs are installed to replace non-electrical heating systems. This DHP-related additional load was found to be quite small in peak conditions, at approximately 1.3 kW in Climate Zone 1 and at 1.7 kW in Climate Zone 2. However, these values are consistent with the sizes of the DHPs installed in the participating homes and the outdoor temperatures in the peak conditions.

An analysis of the differences in parameters between the two climate zones has revealed that the differences in outdoor temperature were the main reason for the lower savings in Climate Zone 1, because the other parameters' impacts on energy usage were similar for the two climate zones.

The next step of this study will involve using a full year's worth of metering data to complete and update the load shapes and the energy consumption values calculated as part of the preparation of this winter 2020 results report. The full-year analysis will also look at the DHPs' impacts during the cooling season.

APPENDIX I
DATA-CLEANING

Econoler and Simptek performed several data-cleaning steps to ensure that the study results were accurate. The treatment-group participants each had both a whole-house meter and a DHP-circuit meter installed. The control-group participants each had only a whole-house meter installed. Those participants were removed from the analysis if their whole-house metering data was deemed insufficient, i.e., if too many data points were missing for a given metering period. However, those participants with sufficient whole-house metering data but insufficient DHP-circuit metering data were kept in the analysis for the purpose of savings calculations but were removed from the analysis of DHPs' energy consumption. The following paragraphs describe the data-cleaning steps taken to determine whether whole-house metering data was insufficient.

First, Simptek compared the February 2020 whole-house metered energy consumption with Newfoundland Power's utility bills to remove those participants with big differences, **resulting in the removal of 18 participants from the analysis**.

Second, the team investigated those DHP-circuit meters showing unusual consumption levels and found that there had been installation errors, resulting in the removal of 3 DHP-circuit meters. However, the 3 whole-house meters were kept in the analysis for the purposes of energy and peak demand savings calculations. **Therefore, this step did not result in the removal of any participants from the analysis.**

Third, Econoler analyzed the 5-minute interval metering data. Among the remaining participants, there were 490,906 missing 5-minute readings, accounting for 3.7% of the full data expected. Over half of the missing 5-minute readings occurred on February 29, 2020, which is explained by a technical issue happening to all the Neurio meters. As part of the analysis of the 5-minute interval data, anomalously high readings in the data were identified by Simptek. Whole-house readings indicating a demand higher than 24 kW and DHP-circuit readings indicating a demand higher than 12 kW were classified as anomalously high. A careful analysis revealed that many of the anomalous readings occurred immediately after a period over which no readings were recorded. In the event of a disconnection lasting less than 24 hours, the metering devices were expected to store the data and upload it once connection was re-established. Instead, in some cases, the readings obtained during the period of disconnection were blank and the first reading immediately after the connection was re-established was much higher than other metered readings, suggesting that energy consumption over the period of disconnection was aggregated into a single data point, which explains the relatively high volume of anomalous readings. If the missing data prior to an anomalously high reading spanned fewer than 6 readings (30 minutes), Econoler was able to extrapolate those results to be used at the hourly level. Otherwise, the anomalously high reading was excluded from the analysis. **This step did not result in the removal of any participants from the analysis.**

Fourth, Econoler removed from the analysis those participants who had two consecutive months with over 50% of the data missing. **This step resulted in the removal of 5 participants from the analysis.**

Finally, for 11 of the remaining participants, Econoler removed data for those months with 50% or more data missing. For example, if a participant had no missing data from January through February but had 60% of the March data missing, Econoler only excluded the data for March and kept the January and February data in the analysis. Since those months with less than 50% of missing data were kept in the analysis, **no participants were removed from the analysis following this step.**

As summarized in Figure 17 below, data-cleaning led to the removal of 23 participants from the analysis.

Figure 17: Sample of Participants after Data-cleaning

	Treatment Group		Control Group	
	Climate Zone 1	Climate Zone 2	Climate Zone 1	Climate Zone 2
Planned	n=65	n=65	n=65	n=65
Recruited	n=65	n=67	n=66	n=66
After Data Cleaning	n=61	n=61	n=60	n=59

APPENDIX II
CALCULATIONS OF LOAD SHAPES

Energy Savings Load Shapes for Heating

To obtain the energy savings load shapes for heating, data from the whole-house circuit meters of both the treatment group and the control group are used.

The following calculation steps are performed by using the data for each participant in both the treatment and control groups. These steps performed on the whole-house circuit meter data are essentially the same as those performed for the DHP electricity consumption load shapes.

1 The five-minute interval data points for each hour are added up, resulting in one value in kWh for each of the 8,760 hours in a year.

2 The five-minute interval data points for each day are also added up, resulting in one value in kWh for each day in a year.

3 Each daily data point (from Step 2) is associated with the outdoor temperature at a given location and on that day by cross-referencing a historical weather database from Environment Canada (and NASA model data, where necessary, to fill in gaps).

4 A regression of all the daily data points as a function of the outdoor temperature is to be developed for each participant (based on the data points obtained from Steps 2 and 3). This regression uses the following equation: $kWh = \alpha + \beta \cdot T$, where T is the outdoor temperature in Celsius degrees.

5 Each hourly data point is to be normalized to be compatible with the electricity consumption during a typical weather year, using the following equation:

$$kWh_{norm_i} = kWh_i \times \left(\frac{\alpha + \beta \cdot T_{norm\,j}}{\alpha + \beta \cdot T_j}\right)$$

Where:

- i represents each hour of a year;
- j represents each day of a year;
- α and β are drawn from the regression obtained specifically for the participant;
- kWh_i is the recorded electricity consumption for each hour at the whole-house circuit meter;
- T_{norm_j} is the temperature expected for each day in a typical meteorological year (drawn from a separate database);
- T_j is the outdoor temperature at the given location for each day.

6 To obtain whole-house energy savings load shapes, the following calculation steps are performed to aggregate the individual results of all the subcategories in both the control group and the treatment group samples. Normalized data is aggregated at the monthly level. We will analyze the variations among the days of the week to establish the aggregated results to limit

random variations while keeping those variations that are statistically significant (for example, all the Mondays of each month can be grouped, or all the weekdays of each month). At least, we will keep different load shapes for each month. Each subcategory in the treatment group and the control group samples (Climate Zone 1 and Climate Zone 2) will have its own load shape.

7 DHPs' energy savings load shapes are obtained by subtracting the weather-normalized average electricity consumption load shape of the treatment group sample subcategory from the corresponding load shape of the control group.

DHPs' Electricity Consumption Load Shapes for Heating

To obtain the annual load shapes of DHPs' electricity consumption, the metered DHP electricity consumption data of all the participants in the treatment group is used. The following calculation steps are to be performed on the data for each participant:

1 The five-minute interval data points for each hour are added up, resulting in one value in kWh for each of the 8,760 hours in a year to limit the peaks and valleys caused by the equipment being turned on and off.

2 The five-minute interval data points for each day are added up, resulting in one value in kWh for each of the days in a year.

3 Each daily data point (from Step 2) is to be associated with the outdoor temperature at the given location on that day by cross-referencing a historical weather database from Environment Canada (and NASA model data, where necessary, to fill in gaps).

4 A regression of all the daily data points as a function of the outdoor temperature is to be developed for each participant (based on the data points obtained from Steps 2 and 3), using the following equation: $kWh = \alpha + \beta \cdot T$, where T is the outdoor temperature in Celsius degrees.

5 Each hourly data point is to be normalized to be compatible with the electricity consumption during a typical weather year, using the following equation:

$$kWh_{norm_i} = kWh_i \times \left(\frac{\alpha + \beta \cdot T_{norm\,j}}{\alpha + \beta \cdot T_j} \right)$$

Where:

- i represents each hour of a year;
- j represents each day of a year;
- α and β are drawn from the regression obtained specifically for the participant;
- kWh_i is the recorded electricity consumption of the DHP for each hour;
- T_{norm_j} is the temperature expected for each day in a typical meteorological year (drawn from a separate database);

› T_j is the outdoor temperature at a given location on each day.

To obtain the annual load shapes of DHPs' electricity consumption, the following calculation steps are to be performed to aggregate the individual results of all the subcategories in the treatment group sample.

6 Normalized data points are aggregated at the monthly level. We will analyze the variations among the days of the week to establish the aggregated results, thus limiting random variations while maintaining variations that are statistically significant (for example, all the Mondays of each month could be grouped, or all weekdays of each month). At least, we will keep different load shapes for each month. Each subcategory of the treatment group sample (Climate Zone 1 and Climate Zone 2) will have its own load shape.