BONNEVILLE POWER ADMINISTRATION

2023 Residential ASHP/VSHP Impact Evaluation Final Report

April 29, 2025

1 EXECUTIVE SUMMARY

This report presents results from impact evaluation activities conducted on 2020-2022 residential air source heat pump (ASHP) and variable speed heat pump (VSHP) conversion measures for the Bonneville Power Administration (BPA), addressing the following measure groups:

1. ASHP conversions in heating zones 2 and 3
2. VSHP conversions in all heating zones (1, 2, and 3)

The goal of this evaluation was to conduct billing regression analyses of BPA's residential ASHP and VSHP conversions. The primary objectives of this evaluation were to:

- **Estimate savings** of the measures with the goal of developing savings estimates for ASHP conversions in heating zones 2 and 3 and VSHP conversions in all heating zones
- **Identify drivers** of savings to better understand the variation in savings for these measures.

1.1 METHODOLOGY

This evaluation represents the population of residential ASHP and VSHP conversions with completion dates between October 1, 2019 and September 30, 2022. The sample design targeted a 90/10 confidence level and precision and was developed based on projects entered into the IS2.0 database. While not used in sampling for the billing analysis, Evergreen did append Performance Tested Comfort System (PTCS) registry data to analyze drivers of savings.

The sampling was conducted to optimize utility customer billing data collection and to satisfy Regional Technical Forum (RTF) minimum sample size guidelines for planning measures.

Once data collection from utilities was completed, Evergreen Economics used two statistical methods to assess energy savings. The first approach was based on post-only with comparison group (POCG) regression models to evaluate the impact of installing these measures. The second method was based on variable-based degree-day analysis (VBDD) to examine the distribution of changes in electricity use among participants. Evergreen also conducted a drivers analysis using the VBDD outputs to identify potential reasons for variance in savings.

1.2 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The findings are separated into billing regression analysis findings and drivers analysis findings. The billing analysis estimates the impact of installing the measures, while the drivers analysis explores differences in savings by home characteristics.

1.2.1 BILLING REGRESSION ANALYSIS FINDINGS

The overall results for BPA's residential ASHP and VSHP impact evaluation showed evaluated savings coming in below BPA-reported savings, and Table 1 shows overall realization rates (the ratio of evaluation savings to BPA-reported savings) of:

- ASHPs in heating zones 2 and 3: 45%
- VSHPs in heating zone 1: 58%
- VSHPs in heating zones 2 and 3: 38%

Table 1: Evaluated annual change in electricity use (in kWh) after installation

<table>
<tr><th>Measure</th><th>Heating Zone</th><th>Home Type</th><th>Program Population</th><th>BPA-Reported Savings (kWh)</th><th>Evaluated Savings (kWh)</th><th>Realization Rate</th></tr>
<tr><td rowspan="3">ASHP Conversion</td><td rowspan="3">HZ 2/3</td><td>SF</td><td>232</td><td>1,188,068</td><td>570,200</td><td>48%</td></tr>
<tr><td>MH</td><td>113</td><td>491,069</td><td>191,763</td><td>39%</td></tr>
<tr><td colspan="4">Subtotal</td><td>45%</td></tr>
<tr><td rowspan="6">VSHP Conversion</td><td rowspan="3">HZ 1</td><td>SF</td><td>895</td><td>3,468,029</td><td>2,329,544</td><td>67%</td></tr>
<tr><td>MH</td><td>246</td><td>957,160</td><td>254,879</td><td>27%</td></tr>
<tr><td colspan="4">Subtotal</td><td>58%</td></tr>
<tr><td rowspan="3">HZ 2/3</td><td>SF</td><td>144</td><td>789,481</td><td>265,319</td><td>34%</td></tr>
<tr><td>MH</td><td>31</td><td>153,260</td><td>86,321</td><td>56%</td></tr>
<tr><td colspan="4">Subtotal</td><td>38%</td></tr>
</table>

Evergreen compared evaluated savings to the best available unit energy savings (UES) values, and used values provided by ProCost calculations that are derived from RTF data.[1] The RTF updated its savings estimates in 2021 based on new evaluation data, reducing them by about half. Because of this action, the RTF's savings values for these measures are much lower than BPA's reported savings that were based on savings assumptions from before 2021, and more in line with the evaluated savings. Note that BPA has subsequently updated its savings estimates to the more current RTF UES values.

Therefore, the ratio of the evaluated savings divided by the RTF values was higher than the evaluated realization rates, but still under 100 percent for two of the three measure categories. Table 2 compares the evaluated savings to the 2021 RTF UES values and presents realization rates based on the more current RTF values. As shown, the realization rates are closer to 100 percent.

[1] These values were from ProCost v5.8 retrieved from the RTF website.

Table 2: Realization rates

<table>
<tr><th>Measure</th><th>Heating Zone</th><th>Home Type</th><th>BPA-Reported Savings Realization Rate</th><th>2021 RTF UES Values Realization Rate</th></tr>
<tr><td rowspan="3">ASHP Conversion</td><td rowspan="2">HZ 2/3</td><td>SF</td><td>48%</td><td>132%</td></tr>
<tr><td>MH</td><td>39%</td><td>65%</td></tr>
<tr><td colspan="2">Subtotal</td><td>45%</td><td>110%</td></tr>
<tr><td rowspan="6">VSHP Conversion</td><td rowspan="2">HZ 1</td><td>SF</td><td>67%</td><td>100%</td></tr>
<tr><td>MH</td><td>27%</td><td>36%</td></tr>
<tr><td colspan="2">Subtotal</td><td>58%</td><td>86%</td></tr>
<tr><td rowspan="2">HZ 2/3</td><td>SF</td><td>34%</td><td>76%</td></tr>
<tr><td>MH</td><td>56%</td><td>88%</td></tr>
<tr><td colspan="2">Subtotal</td><td>38%</td><td>78%</td></tr>
</table>

Evergreen's evaluation team corroborated the lower RTF values for the measures. The team identified a few potential reasons why electric savings for these heat pump conversions may have been lower than expected for ASHPs and VSHPs:

- End use customer snapback (increased use of efficient appliance for comfort)
- Addition of air conditioning
- Contractor design choices
- Displacement of non-electric heat (bulk fuels)

However, additional data collection including a participating customer survey would need to be conducted to confirm whether these issues are present (and the incidence of them) among customer installations. However, one recent evaluation[2] and other regional documentation[3] support these hypotheses.

1.2.2 DRIVERS ANALYSIS FINDINGS

The drivers analysis showed that pre-period electricity usage was the greatest indicator of energy savings—on average, participants that used more electricity in the pre-period experienced the greatest reductions in electricity use after the installation of an ASHP or VSHP. Additionally, for single-family homes in heating zone 1, participants that did not have air

[2] Bonneville Power Administration. *2018-19 Residential HVAC Impact Evaluation Final Report*. https://www.bpa.gov/-/media/Aep/energy-efficiency/evaluation-projects-studies/2018-19-bpa-res-hvac-impact-evaluation-final-report.pdf

[3] Northwest Energy Efficiency Alliance. Revised 2019. *Residential Building Stock Assessment II*. https://neea.org/img/uploads/Residential-Building-Stock-Assessment-II-Single-Family-Homes-Report-2016-2017.pdf

conditioning as part of their previous HVAC system on average increased their electricity use after installation of an ASHP or VSHP.

1.3 CONSIDERATIONS FOR FUTURE RESEARCH

Evergreen offers the following considerations for BPA and the region regarding additional data collection that may support viewing heat pump savings more broadly (and possibly informing updates to savings estimates and program benefits).

- Consider conducting an end-use customer survey to explore the potential issues and incidence of reasons for reduced realized savings. If the survey confirms the issues associated with lower-than-expected savings, BPA could also consider updating savings assumptions to account for broader issues around baseline and total fuel savings:
    - Reconsider baseline assumptions for heat pump measures for homes that do not already have AC, since many may have planned on installing central AC in the future.
    - Consider documenting as additional program energy savings the reduction in natural gas and bulk fuel usage associated with heat pump installations for homes that have natural gas and/or bulk fuel heating sources.
    - Consider documenting as program benefits the increases in household occupant comfort and safety that are associated with the use of more efficient heat pumps.

2 INTRODUCTION

Consistent with the RTF guidelines, BPA aims to achieve 90 percent coverage of its energy efficiency portfolio through impact evaluation in a four-year period.[4] When selecting which programs to evaluate in a given year, BPA balances the objectives of portfolio coverage, strategic research needs, timely feedback, annual budgets, and the cost and effort required.

BPA conducted impact evaluation planning in 2019-2020 to determine what evaluation activities had occurred previously and what evaluation needed to occur in the next four years to satisfy BPA's policy of evaluating measure savings equivalent to 90 percent of its energy efficiency portfolio every four years. The outcome of this effort was the 2020-2021 evaluation plan,[5] which categorized the portfolio into unique domains, which are components of BPA's program portfolio that are grouped by similar delivery approaches for the purposes of evaluation (including by utility type, measure type, and sector).[6] Aligned with the priorities identified in the 2020-2021 evaluation plan, this report documents the results of the evaluation of BPA's residential ASHP and VSHP conversion measures.

2.1 BACKGROUND

BPA, along with its public power utility partners, acquires savings from a portfolio of energy efficiency programs and measures, including UES measures utilizing a constant savings value for each measure application.

In 2020, Evergreen completed an impact evaluation of BPA's 2018–2019 residential HVAC program offering. At the time the billing data were collected for the study, the program population for VSHP and ASHP conversions was limited, particularly for heating zones 2 and 3. Based on this prior impact evaluation and other research, the RTF approved ASHPs for heating zone 1 as "proven" based on sufficiently robust sample sizes and evaluation results and identified ASHPs in heating zones 2 and 3 and all VSHPs as "planning" measures due to a lack of sufficient sample sizes and evaluation of the savings in the field. The RTF research strategy for these measures requested a pre-post consumption analysis for representative samples of ASHP and VSHP conversions split by heating zone and single-family (SF) versus manufactured homes (MH) in the following categories (Table 3).

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[4] Regional Technical Forum. 2020. *Regional Technical Forum Operative Guidelines for the Assessment of Energy Efficiency Measures*: https://nwcouncil.app.box.com/v/2020RTFGuidelines (see Section 5.2.1).

[5] Evergreen Economics. *Bonneville Power Administration 2020-2021 Evaluation Plan*. Prepared for Bonneville Power Administration. https://www.bpa.gov/-/media/Aep/energy-efficiency/evaluation-projects-studies/bpa-2020-21-impact-evaluation-plan.pdf.

[6] In 2022, BPA revisited its evaluation strategy and 2020-2021 evaluation plan and refined the rolling evaluation approach that was recommended in the prior evaluation plan. BPA condensed and streamlined the domains into four major measure categories, with an updated plan to begin one study per year on a rolling basis across the four-year period. (See: https://www.bpa.gov/-/media/Aep/energy-efficiency/evaluation-projects-studies/2023-2024-bpa-ee-evaluation-strategy-presentation.pdf.)

Table 3: RTF research strategy requested sample size for conversions

Heat Pump	Home Type	RTF Requested Minimum Sample Sizes	
		HZ1	HZ2/3
ASHP	SF	NA (proven)	100
	MH	NA (proven)	75
VSHP	SF	100	100
	MH	75	75

2.2 EVALUATION OBJECTIVES

Heat pumps continue to be an important measure for BPA and its customer utilities. Therefore, to support a better understanding of the savings of this measure in the field as well as regional research needs, the evaluation sought to estimate energy savings for the RTF-identified HVAC measures with the goal of proving savings.

The objectives of this evaluation were to:

- Provide billing analysis to support RTF planning measures of ASHP conversions in heating zones 2 and 3 and VSHP conversions in all heating zones. This includes the following:
    - Measure-level realization rates
    - Measure-level and site-level evaluated savings
    - Comparison of claimed savings to evaluated savings
- Provide VBDD analysis to calculate site-level Unit Energy Consumption (UEC) to support measure planning
- Provide drivers analysis regression modeling

3 METHODOLOGY

This section summarizes the methods used by Evergreen Economics to conduct this evaluation. The section is organized by the following topics: Database Categorization, Sample Design, Billing Analysis, Drivers Analysis, and COVID-19 Considerations.

3.1 DATABASE CATEGORIZATION

During the scoping of this task, BPA staff shared concerns that the Performance Tested Comfort System[7] (PTCS) registry may not accurately categorize some heat pumps as being either an ASHP or a VSHP. With a VSHP, the compressor can operate at a speed that most efficiently meets household heating or cooling needs (i.e., the compressor speed varies). In comparison, the compressor in a traditional ASHP operates at a single speed, resulting in the compressor either operating at full capacity or being off. There are also two-stage ASHPs, which contain two compressors (one to meet light demand and one to meet heavy demand), but the speed of the operating compressor is not *variable* and so it should not be categorized as a VSHP. Two-stage ASHPs can sometimes be miscategorized as variable speed, even though they do not share the same technology nor operate with the same degree of energy efficiency.

To categorize the installed measures, Evergreen pulled make and model information from PTCS registry data and manually matched the proper heat pump type back to the registry, reviewing whether the heat pumps installed were truly variable speed or if they were two-stage/single-stage ASHPs.[8] Table 4 shows that 98.5 percent of ASHPs and 83 percent of VSHPs were accurately reported in the data pulled from PTCS.[9] The team used the variable "HeatPumpStage" and categorized ASHPs as "Non Variable Speed" and VSHPs as "Variable Speed."

Table 4: PTCS categorization of heat pumps

	PTCS-Reported ASHPs		PTCS-Reported VSHPs	
	N	**%**	**N**	**%**
Correctly Reported	8,322	98.5%	5,150	83%
Incorrectly Reported	125	1.5%	1,039	17%
TOTAL	**8,447**		**6,189**	

[7] Note that at the time this report was developed, PTCS was no longer an active part of BPA's program portfolio.

[8] Evergreen included measures that were listed as "PTCS Heat Pump Air Source" in MeasureType, between 2020 and 2022 for MeasureEntered date, and where HouseType included EXIST or MANU (excluded NEW).

[9] Note that 406 out of the 3,294 heat pump make and model combinations listed in the PTCS registry were not reviewed due to low frequency of the make/model combination or missing information. These 406 combinations that appeared infrequently or were missing information accounted for 686 of the 20,991 installations (3%).

These results show that nearly all the heat pumps reported in the PTCS registry as being an ASHP were indeed an ASHP (only 1.5% were misidentified as being a VSHP). Most heat pumps classified as a VSHP were also correctly classified; however, misclassification of heat pumps as being variable speed was much more likely, as findings show 17 percent of heat pumps classified as a VSHP were actually an ASHP (generally a two-stage unit).

3.2 SAMPLE DESIGN

Evergreen used IS2.0 data for sampling. The sample included measures reported to IS2.0 in fiscal years 2020 through 2022. The measure type was a "deemed measure," and the Technology/Activity/Practice was filtered to include only entries labeled "Air-Source Heat Pump with PTCS," "Air-Source Heat Pump without PTCS," "Variable Speed Heat Pump with PTCS," or "Variable Speed Heat Pump without PTCS." Heating zone information was pulled from the Reference Number, and home type was presented in Key Characteristic 1. Finally, conversions were determined by Key Characteristic 2. Table 5 shows the sample of available ASHP/VSHP conversions.

Table 5: Population of ASHP/VSHP conversions

	Home Type	HZ1	HZ2/3
ASHP	SF	NA	232
	MH	NA	113
VSHP	SF	895	144
	MH	246	31

To streamline utility customer and billing data collection, analysis focused on the 19 utilities with more than 30 VSHP conversions in the period from 2020 through 2022 and those with more than 30 ASHP conversions in heating zones 2 and 3. Evergreen added three utilities to meet RTF minimum sampling requirements for heating zone, heat pump type, and home type.

Table 5 shows the maximum possible number of sample points available, while Table 6 shows the maximum number of sample points available after streamlining the list of utilities.

Table 6: Filtered population of ASHP/VSHP conversions

	Home Type	HZ1	HZ2/3
ASHP	SF	NA	191
	MH	NA	93
VSHP	SF	673	123
	MH	204	25

Evergreen's evaluation exceeded the minimum sample sizes requested by the RTF (shown in Table 3 at the beginning of this report)—except for VSHPs for manufactured homes in heating zones 2 and 3 (Table 7).[10] The team explored alternative model specifications that combined manufactured homes and single-family homes to estimate the effect that installation of VSHPs in manufactured homes has on electricity savings relative to installation in single-family homes.[11]

Table 7: Filtered population of ASHP/VSHP conversions compared to minimum

Measure	Heating Zone	Home Type	Population	Filtered Population	RTF Minimum
ASHP	HZ 2/3	SF	232	191	100
		MH	113	93	75
VSHP	HZ 1	SF	895	673	100
		MH	246	204	75
	HZ 2/3	SF	144	123	100
		MH	31	25	75

3.2.1 DRIVERS ANALYSIS SAMPLE

The Evergreen team drew the sample from the IS2.0 heat pump installation data and appended additional variables from PTCS data.[12] BPA provided both data sets in June 2023. The IS2.0 data includes all measures that BPA uses to reimburse utilities and report savings, while the PTCS registry includes installation data entered directly by contractors. Therefore, Evergreen built the sample on the IS2.0 data but supplemented with PTCS data where possible to include more variables for the drivers analysis. Not all measures in IS2.0 were PTCS measures. The team found that 90 percent of conversions in IS2.0, and 95 percent of the sample, were indicated as “With PTCS.” For more detail on measures with and without PTCS entries, see Appendix A.

3.3 BILLING ANALYSIS

Evergreen conducted billing analysis using three main methods, which are detailed in this section:

1. Comparison group analysis
2. A post-only with comparison group regression model
3. The VBDD model

[10] Note that if Evergreen did not screen out utilities and included them all instead, the maximum sample size (increasing from 19 utilities to 81 utilities) for VSHP conversions in manufactured homes in heating zones 2 and 3 would go from 25 to 31. In Evergreen’s opinion, this does not justify applying alternate screening criteria.

[11] Evergreen could have run regression analysis on data from 25 homes; however, with a smaller sample size it would have become more challenging to confidently determine whether changes in energy usage are statistically significant. To improve the model’s accuracy and reliability, the team explored other models that used combined data from manufactured homes and single-family homes for VSHPs as incorporating more data helps the model’s performance.

[12] Evergreen included measures that were listed as “Deemed Measure” in MeasureType, between 2020 and 2022 for Fiscal Year, labeled as a conversion in Key Characteristic 2, and where Key Characteristic 1 was not “Single Family – New”.

3.3.1 COMPARISON GROUP ANALYSIS

Evergreen developed a comparison group for each energy efficiency measure evaluated through the billing analysis. The comparison group did not meet the standards for a control group under a randomized controlled trial (RCT) experimental design but did provide a baseline from which to measure the impact of installing each respective energy efficiency measure.[13]

Customers in a comparison group play an important role in the estimation of electricity savings impacts from an energy efficiency program. Without a comparison group, any change in energy consumption between the pre- and post-periods that is not associated with differences in electricity use in the pre-period or temperature (as represented by heating degree-day (HDD) and cooling degree-day (CDD)) is assumed to be due to the installation of the energy efficiency measure. However, changes in energy consumption between the pre- and post-periods may be due to one or more systematic factors outside of the model, such as changes in the economy, supply shocks within the regional electricity market, or society-wide changes in residential energy use.

By including comparison sites in the billing regression model that are similar to participant sites with respect to geographic location, electricity usage, and participation in the same energy efficiency program (at either an earlier or later date), the evaluation accounted for the existence of any systematic external factors that might have affected electricity usage, as well as eliminate initial group differences as an explanation for post-installation changes in electricity usage by program participants. Assignment of a residential customer to the comparison group was not random, but rather determined based on one or more criteria (e.g., monthly energy consumption). Because of this, this report refers to the analysis as a quasi-experimental design, thereby acknowledging that the comparison group did not meet the standard of a control group within an RCT experimental design.

While all of the customers that installed one of the five energy efficiency measures offered through any of the 23 utilities that provided data for this project are program participants, for the purpose of the billing analysis, the team segmented customers into one of two groups based on the number of months of billing data before and after installation of the energy efficiency measure:

1. The "participant" group includes customers with at least 12 months of billing data prior to installation of the energy efficiency measure and at least 12 months of billing data after installation.
2. The "comparison" group includes customers with at least 24 months of billing data prior to installation of the energy efficiency measure or at least 24 months of billing data after installation of the energy efficiency measure.

Customers that did not meet either of these selection criteria were dropped from the billing analysis because due to not having enough months of electricity usage data to estimate the change in electricity use associated with a respective energy efficiency measure (and therefore did not meet the criteria of a "participant"), nor did they have enough billing data to act as a comparison home to a participant.

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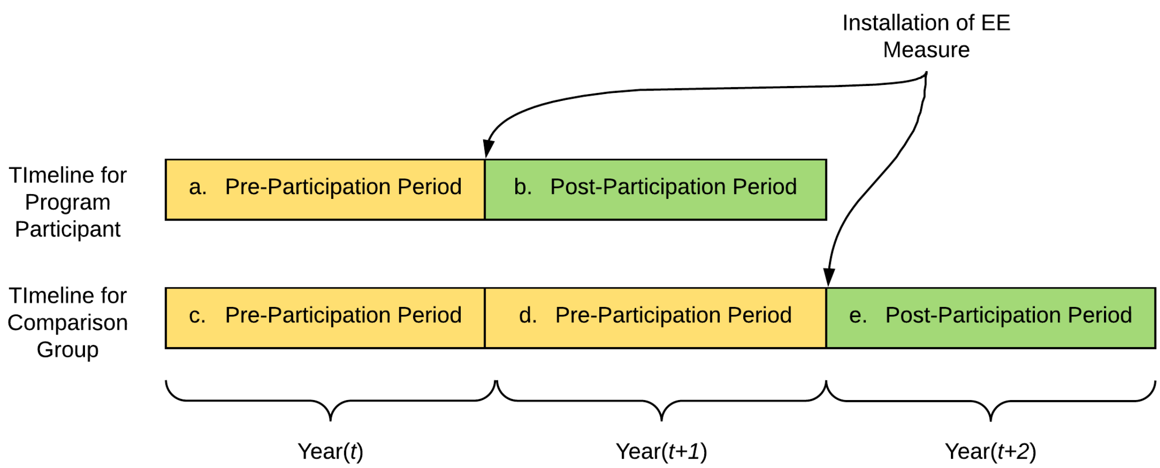
[13] It is important to recognize that because the evaluation is not based on an RCT (or similar) experimental design, the treatment and comparison groups are only approximately equivalent even though they may have very similar monthly electricity usage.

Figure 1 is a representation of how residential customers that participated in an energy efficiency program in one year can be used as a comparison for customers that participated in an earlier year. The first row in the figure represents the program participant to be evaluated, while the second row represents the comparison group.

Figure 1: Integrating comparison households into the experimental design



For the sake of simplicity, the figure shows a three-year period in which Year (*t*) represents the 12-month period immediately before a customer in the participant group installed the HVAC equipment. It also represents the first 12 months of the 24-month period before a customer in the comparison group installed the HVAC equipment.

Year (*t+1*) represents the 12-month period after the energy efficiency measure was installed in the home of the program participant (the post-participant period) and represents the 12-month period immediately before a customer in the comparison group installed the HVAC equipment.

Finally, Year *(t+2)* represents the 12-month period after the energy efficiency measure was installed in the homes of customers in the comparison group.[14] In this example, only data for billing periods in Year *(t)* and Year *(t+1)* are used for statistical modeling.

Evergreen matched each customer in the participant group to a customer in the comparison group based on how closely the monthly electricity usage of the two customers aligned during the 12 months prior to the participant installing the energy efficiency measure.[15]

3.3.2 POST-ONLY WITH COMPARISON GROUP (POCG) REGRESSION MODEL

Evergreen used a POCG regression model to evaluate the impact of installing any of the HVAC measures in the homes of residential customers that participated in one or more energy efficiency programs sponsored by a Northwest utility served by BPA. The POCG model is appropriate for study designs, such as impact evaluations of energy efficiency programs,

[14] When working with monthly billing data, as the evaluation team did for this project, the ideal is to have 12 months of billing data prior to installation of the energy efficiency measure and 12 months of billing data after the measure has been installed (and data for the comparison group for these same two 12-month periods).

[15] Evergreen chose the customer from the comparison group that minimizes the sum of squared errors in monthly electricity consumption.

where individuals self-select into the program and analysis of the energy impacts is conducted after ("post") installation of the measure. In addition, the customers comprising the comparison group are similar to participants in that they are from the same geographic area, are similar with respect to (monthly) electricity use, and they participated in the same or a similar energy efficiency program—either at an earlier or later date.[16]

The study considered numerous POCG model specifications of varying complexity before selecting the following specification:

$$kWh_{i,t} = \beta_1 CDD_{i,t} + \beta_2 HDD_{i,t} + \sum_{j=1}^{12} \beta_j Mt_t \times kWh_{i,t-12} + \sum_{k=1}^{12} \beta_k Mt_t \times kWh_{i,t-12} \times Pt_i + \varepsilon_{i,t}$$

Where:

$kWh_{i,t} = Average\ daily\ kWh\ of\ customer\ i\ in\ month\ t$ *of the post-period*

$CDD_{i,t} = Average\ cooling\ degree\ days\ for\ participant\ i\ in\ month\ t$

$HDD_{i,t} = Average\ heating\ degree\ days\ for\ participant\ i\ in\ month\ t$

$Mt_t = Indicator\ variable\ that\ equals\ 1\ for\ month\ t, else\ 0$

$Pt_i = Indicator\ variable\ that\ equals\ 1\ if\ customer\ i\ is\ a\ participant, else\ 0$

$kWh_{i,t-12} = Average\ daily\ kWh\ of\ customer\ i\ in\ month\ t\ of\ previous\ year$

$\beta_1, \beta_2, \ldots = Parameters\ to\ be\ estimated\ in\ the\ model$

$\varepsilon_{i,t} = Random\ error\ term$

By specifying the model with an array of monthly indicator variables (Mt_t) that interact with the pre-period electricity usage variable ($kWh_{i,t-12}$) and an indicator variable for participant (Pt_i), to the team estimated energy impacts for the program for each calendar month.

3.3.3 VARIABLE-BASE DEGREE-DAY (VBDD) REGRESSION MODEL

The VBDD modeling approach differs from the POCG regression model in that it fits individual regression models for each customer's pre-installation billing data and the customer's post-installation billing data. This means that this evaluation estimated two regression models for each customer in the participant group.

The VBDD model is specified as follows:

$$kWh_m = \alpha + \beta_1 CDD_{T,m} + \beta_2 HDD_{T,m} + \varepsilon_m$$

Where:

$kWh_m = Average\ daily\ kWh\ in\ month\ m$

$CDD_{T,m} = Average\ cooling\ degree\ days\ at\ reference\ temperature\ T\ in\ month\ m$

$HDD_{T,m} = Average\ heating\ degree\ days\ at\ reference\ temperature\ T\ in\ month\ m$

$\alpha = Estimated\ parameter\ representing\ daily\ baseload\ electricity\ usage$

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[16] This is in contrast to a designed experiment, such as RCT, where information is known on the individuals before they begin participating in the study and the subjects of the study are randomly assigned to either a participant or control group.

$\beta_1, \beta_2 = Parameters\ to\ be\ estimated\ in\ the\ model$

$\varepsilon_m = Random\ error\ term$

Using the estimated coefficients from each customer's pre- and post-period models, Evergreen computed the weather normalized average consumption for the pre- and post-periods. The team then computed the difference between the pre- and post-period weather normalized average consumption for each participant customer.[17]

The primary purpose of estimating VBDD models for program participants was to examine the distribution of changes in daily electricity use among participants. Whereas the post-only model provides estimates of the program level impact of installing a specific piece of equipment (as well as the impact for the average participant), the VBDD model simply measures the change in average daily electricity use for each participant while controlling for differences in temperature between the pre- and post-periods. Any change in electricity usage for an individual participant may be due entirely or in part to energy savings associated with installing the measure. However, because the VBDD model precludes the use of a comparison group, it is not possible to attribute a change in electricity use to the installation of the energy efficiency measure.

3.4 DRIVERS ANALYSIS

To conduct the drivers analysis, Evergreen used the VBDD model calculated during billing analysis. The output of the VBDD modeling process is the weather normalized change in electricity usage for each program participant between the pre-installation and post-installation periods, which serves as the dependent variables for the drivers analysis. These changes in electricity usage can be positive, negative, or zero.

The explanatory variables considered for the drivers analysis include average monthly electricity use prior to installation of the ASHP or VSHP, characteristics of the homes, previous HVAC equipment, and characteristics of the installed equipment (e.g., Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factor (HSPF)) to try to understand what factors impact savings. Table 8 shows the different variables considered for the drivers analysis. All variables except for pre-period usage, which was calculated using utility data, are from the PTCS registry.

Table 8: Drivers analysis variables

Variable	Description	Data Categories
Previous HVAC system did not have AC	Whether the system replaced by the heat pump had air conditioning.	1 if previous system did not have AC, else 0
Backup heat type	The type of backup heating. One site has a natural gas furnace, 7 have electric zonal, 15 have non-electric space heating, 519 have	1 if electric forced air, else 0

[17] Since each VBDD model is estimated using data for a single home (i.e., a "sample of one"), Evergreen did not differentiate the estimated change in daily electricity usage for each comparison home from the estimated change in daily electricity use for each participant home.

	electric forced air, and 397 have no backup heating.	
Home size	The heated area of the building in square feet.	Numeric value
Smart thermostat	Whether the home thermostat is an advanced smart thermostat based on BPA's Qualified Products List.[18]	1 if smart thermostat, else 0
Heating seasonal performance factor (HSPF)	A metric of heat pump heating efficiency. Higher HSPF ratings indicate greater efficiency.	Numeric value
Seasonal energy efficiency ratio (SEER)[19]	A metric of heat pump cooling efficiency. Higher SEER ratings indicate greater efficiency.	Numeric value
Pre-period usage	The average daily amount (in kWh) of energy usage in the pre-period.	Numeric value

3.5 COVID-19 CONSIDERATIONS

The VBDD models were estimated separately for each participant, and the estimated change in average daily electricity developed for each participant did not include any adjustment based on the inclusion of a comparison home. There was a concern that these *unadjusted* changes in average daily electricity use may have been impacted by provisions enacted in response to the COVID-19 public health emergency that led to many adults working from home and children attending school remotely from home. To test whether there was a "COVID effect" in which there was a systematic difference in electricity use in the pre-period and post-period, the team conducted the following analysis:

1. Evergreen created a frequency distribution of the pre-period start month for each participant (see Appendix B for the distribution).
2. The sample includes a randomly selection of 100 participants from this distribution.
3. The team randomly matched each of the 100 selected participants to a comparison home with the same overlapping 24 months of billing data. For each participant, the 24 months consisted of 12 months of pre-data and 12 months of post-data; for the comparison home, the 24 months would consist of 24 months of pre-data or 24 months of post-data.
4. For each randomly selected comparison home, the team conducted VBDD analysis (with the first 12 months representing the pre-period and the last 12 months representing the post-period).

[18] Bonneville Power Administration. Updated February 4, 2025. "Residential Advanced Smart Thermostat Qualified Products List". https://www.bpa.gov/-/media/Aep/energy-efficiency/document-library/smart-tstat-qpl.pdf

[19] Note that SEER/HSPF may not reflect the actual usage patterns of heat pumps, but directionally, they indicate relative efficiency. Neither of these variables were significant in the model.

5. The team computed the average daily change in electricity usage between the pre-period and post-period for each of the 100 comparison homes and then computed the mean and median of the differences.[20]
6. The team repeated steps 3 through 5 39 times (for a total of 40 random samples of 100 comparison homes).
7. The team then computed the mean and standard error of the means of the 40 random samples, which were 0.120 and 0.305, respectively.[21]

The mean estimated in step 7 (0.120) was the estimate of the average daily change (increase) in electricity use by the comparison homes between the pre- and post-periods. However, since the standard error, which is a measure of the variation in the estimated means, was greater than the estimated mean (0.305 vs. 0.120), the team found no statistical evidence that there was a change in average daily electricity usage by the comparison group between the pre- and post-periods. Stated another way, no "COVID effect" was found (either an increase or decrease) in electricity use by the comparison group and, therefore, found no reason to adjust the VBDD-based estimates of change in electricity use by the participant homes.

Note that the lack of a substantial difference in pre- and post-period usage may have been due to when the heat pumps were installed. Specifically, relatively few installations occurred in the early months of 2020 (at the onset of COVID) and so there was not a clean split of the timeframes for the pre- and post-periods. Instead, most installations occurred later in 2020 and in 2021, so that the pre-period is more characterized as "early COVID" and the post-period as "later COVID."

[20] Evergreen computed the differences as post-period minus pre-period, so positive differences represent an increase in electricity use between the pre- and post-periods and negative differences represent a decrease in electricity use.
[21] Evergreen also computed the median change in electricity use for each of the 40 trials, which ranged from -1.053 to 2.117.

4 FINDINGS

This section presents the findings from the residential ASHP and VSHP conversion impact evaluation of measures installed between 2020 and 2022.

The section is organized as follows:

- Billing regression analysis findings
- Drivers analysis findings

Appendix B provides site-specific savings estimation details.

4.1 BILLING REGRESSION ANALYSIS FINDINGS

This subsection provides the overall results for the billing regression analysis of residential ASHP and VSHP conversions installed between 2020 and 2022.

Evergreen estimated the change in electricity usage for residential customers that installed an ASHP or VSHP in 2020, 2021, or 2022. The team estimated models for participants by heat pump type (ASHP or VSHP), home type (single-family or manufactured homes), and heating zone (heating zone 1 or heating zones 2 and 3 combined).

Using a post-only (with comparison group) regression model as described in Section 3.3.2 the team estimates electricity savings from the installation of the measures.

The tables below display the billing regression findings by daily change in kWh by month. The “Statistical Significance Level” column represents the upper threshold likelihood that the observed results are due to random chance. For example, a value of 1 percent in the table (0.01 significance level) means that there is a 99 percent probability that the true value is non-zero. Values marked by “NS” indicate that the value is not statistically significant at the 0.01, 0.05, or 0.1 significance levels, meaning there is insufficient evidence to conclude that there is an observed change.

4.1.1 VARIABLE SPEED HEAT PUMPS

Of the 1,039 customers that installed a VSHP in single-family buildings to replace an electric forced air furnace, 564 met the criteria to be considered a participant for the purposes of modeling (459 in heating zone 1 and 105 in heating zones 2 and 3) (

Table 9). On average, customers in single-family homes in heating zone 1 reduced their electricity usage by 13.90 kWh per day (5,074 kWh per year). Customers in single-family homes in heating zones 2 and 3 reduced their electricity usage by an average of 6.92 kWh per day (2,526 kWh per year). The greatest electricity savings occurred during the winter months (December through March), with single-family homes in heating zones 2 and 3 experiencing an increase in electricity usage during the summer months of June through September.

Table 9: Billing regression analysis findings – VSHP single-family

Month	VSHP – HZ1 – SF		VSHP – HZ2/3 – SF	
	Daily Change in kWh	Statistical Significance Level	Daily Change in kWh	Statistical Significance Level
January	-25.46	1%	-13.33	1%
February	-24.47	1%	-16.96	1%
March	-20.50	1%	-16.09	1%
April	-15.28	1%	-8.69	1%
May	-8.20	1%	-1.24	NS
June	-4.90	1%	6.21	1%
July	-3.83	1%	6.81	1%
August	-4.65	1%	3.81	NS
September	-3.35	1%	2.89	NS
October	-9.56	1%	-7.76	1%
November	-19.75	1%	-21.77	1%
December	-26.90	1%	-16.95	1%
Average Daily Change in kWh	-13.90	1%	-6.92	1%
Average Annual Change in kWh	-5,074	1%	-2,526	1%
Average Annual Usage	22,294		25,468	
% Savings	-23%		-10%	

Of the 277 customers that installed a VSHP in manufactured homes to replace an electric forced air furnace, 170 met the criteria to be considered a participant for the purposes of modeling (149 in heating zone 1 and 23 in heating zones 2 and 3) (Table 10). On average, customers in manufactured homes in heating zone 1 reduced their electricity usage by 4.69 kWh per day (1,712 kWh per year). Customers in manufactured homes in heating zones 2 and 3 reduced their electricity usage by an average of 10.28 kWh per day (3,752 kWh per year). The greatest electricity savings occurred during the winter months (December through March), with manufactured homes in all heating zones experiencing an increase in electricity usage during the summer months of June and July.

Table 10: Billing regression analysis findings – VSHP manufactured homes

Month	VSHP – HZ1 – MH		VSHP – HZ2/3 – MH	
	Daily Change in kWh	Statistical Significance Level	Daily Change in kWh	Statistical Significance Level
January	-12.16	1%	-25.78	1%
February	-11.52	1%	-23.30	1%
March	-13.54	1%	-21.34	1%
April	-6.40	1%	-8.62	1%
May	0.03	NS	-2.06	NS
June	3.37	1%	1.47	NS
July	1.23	NS	1.99	NS
August	-0.34	NS	-0.52	NS
September	1.55	NS	-3.31	NS
October	-3.14	5%	-9.64	1%
November	-6.80	1%	-14.13	1%
December	-8.52	1%	-18.16	1%
Average Daily Change in kWh	-4.69	1%	-10.28	1%
Average Annual Change in kWh	-1,712	1%	-3,752	1%
Average Annual Usage	17,273		24,400	
% Savings	-10%		-15%	

4.1.2 AIR SOURCE HEAT PUMPS

Of the 345 customers that installed an ASHP in heating zones 2 and 3 to replace an electric forced air furnace, 257 met the criteria to be considered a participant for the purposes of modeling (172 in single-family and 85 in manufactured homes) (Table 11). On average, customers in single-family homes in heating zones 2 and 3 reduced their electricity usage by 9.08 kWh per day (3,314 kWh per year). Customers in manufactured homes in heating zones 2 and 3 reduced their electricity usage by an average of 6.18 kWh per day (2,256 kWh per year). The greatest electricity savings occurred during the winter months (December through March), with single-family homes in heating zones 2 and 3 experiencing an increase in electricity usage during the summer months of June and July. Conversely, manufactured homes in heating zones 2 and 3 experienced a decrease in energy usage in all months of the year.

Table 11: Billing regression analysis findings – ASHP

Month	ASHP – HZ2/3 – SF		ASHP – HZ2/3 – MH	
	Daily Change in kWh	Statistical Significance Level	Daily Change in kWh	Statistical Significance Level
January	-15.78	1%	-9.60	1%
February	-18.80	1%	-9.75	1%
March	-20.34	1%	-8.87	1%
April	-13.32	1%	-3.80	10%
May	-6.25	1%	-0.20	NS
June	-1.78	NS	-3.29	10%
July	4.44	5%	-6.95	1%
August	5.39	1%	-5.33	1%
September	0.97	NS	-2.58	NS
October	-10.05	1%	-2.70	NS
November	-15.70	1%	-9.29	1%
December	-17.78	1%	-11.91	1%
Average Daily Change in kWh	-9.08	1%	-6.18	1%
Average Annual Change in kWh	-3,314	1%	-2,256	1%
Average Annual Usage	24,425		21,474	
% Savings	14%		11%	

4.1.3 REALIZATION RATES

The overall results for BPA's residential ASHP and VSHP impact evaluation showed evaluated savings coming in below reported savings and showed overall realization rates (the ratio of evaluation savings to reported savings) of around 50 percent or less. Note that BPA's reported savings were based on savings results prior to 2021. The evaluated realization rates when compared to the more current RTF UES values are much higher.

Table 12 shows evaluation results compared to both sets of savings assumptions, BPA's reported savings (based on savings results prior to 2021), and 2021 RTF UES values.

Table 12: Evaluated annual change in electricity use (in kWh) after installation

Measure	Heating Zone	Home Type	Evaluated Savings (kWh)	BPA-Reported Savings (kWh)	2021 RTF UES Values (kWh)	BPA-Reported Savings Realization Rate	2021 RTF UES Values Realization Rate
ASHP Conversion	HZ 2/3	SF	570,200	1,188,068	430,716	48%	132%
		MH	191,763	491,069	293,371	39%	65%
		Subtotal				**45%**	**110%**
VSHP Conversion	HZ 1	SF	2,329,544	3,468,029	2,320,480	67%	100%
		MH	254,879	957,160	714,609	27%	36%
		Subtotal				**58%**	**86%**
	HZ 2/3	SF	265,319	789,481	350,948	34%	76%
		MH	86,321	153,260	98,232	56%	88%
		Subtotal				**38%**	**78%**

The team also calculated the 90 percent confidence interval for average annual evaluated savings for each measure, heating zone, and home type. For all measure combinations, the BPA-reported savings value is outside (and above) the 90 percent confidence interval of the estimated evaluated savings. For four of the six measure combinations, the RTF savings fall within or below the 90 percent confidence interval of the estimated evaluated savings.

Figure 2 displays the evaluated savings and their associated 90 percent confidence intervals (the blue dot with the blue bracket) compared to the RTF UES values (green dot). As shown in the figure, UES values for three of the six categories fall within the confidence intervals; one is below (where the evaluated savings are statistically higher than the UES value), and the remaining two are above (where the evaluated savings are statistically lower than the UES value).

Figure 2: Confidence intervals for average annual change in electricity use (in kWh) after installation

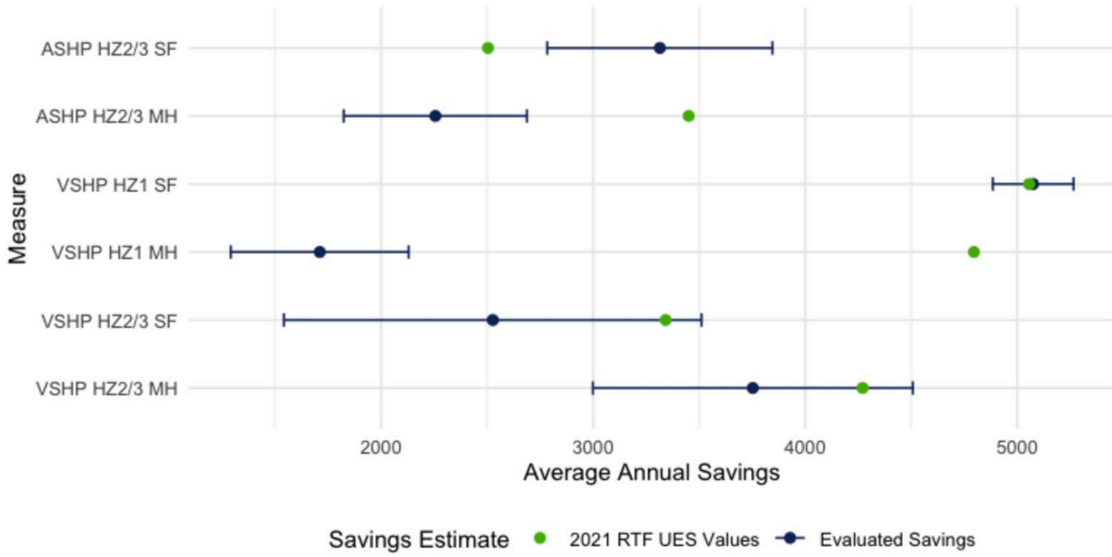

Table 13 provides the numeric values associated with the confidence intervals, with an asterisk and shading indicating savings values that fall within or below the evaluated savings estimates.

Table 13: Confidence intervals for average annual change in electricity use (in kWh) after installation

Measure	Heating Zone	Home Type	Evaluated Savings		BPA-Reported Savings	2021 RTF UES Values
			Lower Bound	Upper Bound	Value	Value
ASHP Conversion	HZ 2/3	SF	2,784	3,846	6,907	2,504**
		MH	1,824	2,688	5,777	3,451
VSHP Conversion	HZ 1	SF	4,885	5,266	7,556	5,056*
		MH	1,291	2,130	6,424	4,796
	HZ 2/3	SF	1,542	3,511	7,519	3,342*
		MH	2,999	4,508	6,663	4,271*

* Savings value is within the 90 percent confidence interval.

** Savings value is below the 90 percent confidence interval.

4.1.4 POTENTIAL REASONS FOR LOWER-THAN-EXPECTED SAVINGS

Based on past evaluations[22] and regional documentation,[23] Evergreen identified potential reasons for lower-than-expected savings, detailed below. However, without an accompanying customer survey for the participants involved, the team cannot confirm these findings with data collected by this study.

Snapback

Snapback occurs when an end user installs a higher efficiency measure and then uses it more to increase comfort or derive other benefits as a result of the lower operating costs. Snapback with the use of heat pump conversions typically occurs when the occupants heat and/or cool their home to more comfortable temperatures since the efficiency of the unit is so much greater than what they had before.

Addition of Air Conditioning

Based on program data, many participants did not have air conditioning before installing the evaluated heat pumps. By converting their previous heating system to a heat pump, end use customers essentially added cooling capability, which adds to overall energy usage, which may or may not be offset by the efficiency savings achieved by using the heat pump for heating.

BPA's 2018 evaluation of ductless heat pumps (DHPs) indicated that a substantial percentage of households that installed DHPs did not have AC beforehand, but reported that had they not installed a DHP, they would have planned to add central AC at a later date. If the baseline for heat pumps accounted for a central AC baseline for homes that did not already have cooling, heat pumps might show more realized savings as they offset future purchases and use of much less efficient central AC.

The UES values provided did not differ significantly by whether the baseline included AC or not. For example, ASHPs installed in single-family homes in heating zones 2 and 3 expected site savings of 2,842 kWh per year for homes with AC and 2,454 kWh per year for homes without AC. For VSHPs, the UES values were the same for homes with and without AC.

Contractor Design Choices

As a way to reduce customer complaints, contractors may favor comfort for the participant over efficiency. A past market study commissioned by BPA in 2019 found that contractors may "lock out" heat pump compressors at higher temperatures so that homes heat up faster, but may rely more on the less efficient electric resistance back up heat heating (which leads to less efficient equipment operation).[24] This means that heat pumps will not turn on until higher temperatures are reached when they should be allowed to operate until the internal thermostat tells them to stop (typically at 5ºF or lower). Electric resistance will turn on at higher

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[22] Bonneville Power Administration. 2018-19 Residential HVAC Impact Evaluation Final Report. https://www.bpa.gov/-/media/Aep/energy-efficiency/evaluation-projects-studies/2018-19-bpa-res-hvac-impact-evaluation-final-report.pdf

[23] Northwest Energy Efficiency Alliance. Revised April 2019. *Residential Building Stock Assessment II*. https://neea.org/img/uploads/Residential-Building-Stock-Assessment-II-Single-Family-Homes-Report-2016-2017.pdf

[24] Bonneville Power Administration. 2019. *Air Source Heat Pump Commissioning, Controls & Sizing Baseline Field Study Report*. https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2019-bpa-heat-pump-field-study-final-report.pdf

temperatures than intended (they typically should not operate at a temperature higher than 35ºF). While the participant is using the heat pump, the heat pump may be using less efficient heating using electric resistance, leading to lower savings. In addition, the heat pump may not be operating even when it is able to efficiently do so.

Based on the prior impact evaluation of DHPs, this anecdotally is done to provide higher temperatures at the register, which gives the impression that the system is doing well, even though a system may still be heating effectively at a lower supply temperature. Contractors may also oversize equipment. Their motivation is to have a satisfied customer and not have to go back to homes and address issues; for that reason, they typically err on the side of ensuring comfort over efficiency.

Displacement of Non-Electric Heat

The baseline equipment may include non-electric heating fuels such as wood and/or gas. If heat pump measures are used to offset some of the wood and/or gas heating, electric pre/post savings may show added load or negative savings. A customer survey could help clarify the use of wood and gas heating.

4.2 DRIVERS ANALYSIS FINDINGS

4.2.1 SITE-LEVEL RESULTS

Evergreen estimated the change in daily electricity usage for residential customers that installed an ASHP or VSHP in 2020, 2021, or 2022. Heat pump type (ASHP or VSHP), home type (single-family or manufactured homes), and heating zone (heating zone 1 or heating zones 2 and 3 combined) determined the site-level VBDD analysis. The estimates of pre- and post-installation energy usage from this site-level analysis were then used as inputs for the drivers analysis.

Figure 3 through Figure 8 in Appendix B shows the distribution of the change in average daily electricity use in kWh for each combination of heating zone, home type, and heat pump type.

4.2.2 DRIVERS ANALYSIS FINDINGS

Table 14 shows the regression results for the three models estimated.

1. Single-family homes in heating zone 1
2. Single-family homes in heating zones 2 and 3
3. Manufactured homes in heating zones 1, 2, or 3

For the three models, this evaluation found that pre-period electricity usage was a positive and highly statistically significant indicator of energy savings—on average, participants that used more electricity in the pre-period experienced the greatest reductions in electricity use from the installation of an ASHP or a VSHP. The estimated coefficients represent the estimated change in electricity usage in the post-period for each kWh of electricity a home used in the pre-period above the mean usage of all participants. For single-family homes in heating zone 1, this means that for each additional kWh of electricity used by a participant in the pre-period above the mean pre-period usage of all participants, savings were on average 0.41 kWh greater, holding all else constant.[25] For single-family homes in heating zones 2 and 3, the average impact on savings was 0.23 kWh, and for manufactured homes the impact on savings was 0.22 kWh.

For single-family homes in heating zone 1, Evergreen found that, holding all else constant, participants that did not have AC as part of their previous HVAC system, on average increased their electricity use after installation of an ASHP or VSHP. When the heat pump replaced a system without AC, single-family homes in heating zone 1 used an additional 2.76 kWh per day, compared to homes where the heat pump replaced a system with AC. This suggests that many program participants took advantage of the cooling ability of their new ASHP or VSHP; however, it should be noted that the appropriate baseline for this increase may not be “no cooling,” but rather another, less efficient, cooling system. The team found no statistical evidence that replacing an HVAC system without AC impacted electricity usage of single-family homes in heating zones 2 or 3, nor is there evidence of this in manufactured homes across the three heating zones.

The size of the home, the backup heating system, and the efficiency metrics—HSPF and SEER—were not statistically significant at the 0.1 significance level in determining energy savings.

Positive values in the coefficient indicate electricity savings, and negative values indicate increased electricity usage. The statistical significance of each estimated coefficient, which represents the strength of the correlation between the dependent variable and the respective explanatory variable, is indicated by the number of asterisks.[26]

[25] The converse is also true—for program participants with pre-period electricity usage below the average of all participants, for each kWh of electricity below the mean, electricity savings were on average 0.42 kWh lower, holding all else constant.

[26] Where one or two asterisks represents, respectively, the 0.1 or 0.01 level of significance.

Table 14: Regression model results

Variable	SF – HZ1		SF – HZ2/3		MH	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Constant	8.98	2.25	7.67	3.33	7.15	3.00
VSHP	NA	NA	-2.96	1.95	4.88	3.05
HZ1	NA	NA	NA	NA	-1.76	3.07
Previous system did not have AC	-2.76	1.56*	0.73	2.28	-0.25	2.25
Pre-period usage	0.41	0.03**	0.23	0.03**	0.22	0.04**
Average daily pre-period usage	60.81		68.38		54.17	
Sample size	452		276		253	
R Squared	0.39		0.15		0.15	
F Statistic	146.5		16.41		11.36	

Note: * indicates that the value is statistically significant at the 0.1 significance level and ** indicates significance at the 0.01 significance level.

4.2.3 ADDITIONAL SMART THERMOSTAT FINDINGS

The team also explored whether the presence of a smart thermostat was associated with higher or lower savings for the ASHP and VSHP measures. Smart thermostats were identified using PTCS data and model lookups. Thermostat model numbers included in BPA's Qualified Products List were labeled as "smart" for this analysis. Furthermore, the RTF's definition of connected thermostats aligns with BPA's Qualified Products List classification, which allows an easy comparison of expected values. The team's assumption was that having a smart thermostat may result in modest electricity savings for homes that had an ASHP installed through the program, but likely would have little impact on homes in which a VSHP was installed.

Instead, Evergreen found that holding all else equal, homes with smart thermostats that installed ASHPs in heating zones 2 or 3 in single-family homes had savings of 9.56 kWh/day (which translates to 3,489 kWh/year) greater than homes without a smart thermostat that installed ASHPs in heating zones 2 or 3 (n=161 sites, 25 of which have smart thermostats). This finding was statistically significant at the 0.1 confidence level. The thermostat analysis of the other measures was not statistically significant.

This finding for ASHPs in heating zones 2 and 3 is far in excess of RTF UES values for connected thermostats of 748.85 kWh/year for heating zone 2 and 604.63 kWh/year for heating zone 3.[27] For this reason, Evergreen believes the results are implausible and are likely due to another variable (or variables) that are predictors of higher savings that are also

[27] Regional Technical Forum. "Connected Thermostats". https://rtf.nwcouncil.org/measure/connected-thermostats/

correlated with having a smart thermostat. The analysis explored home size, efficiency metrics (HSPF and SEER), duct sealing, and serving utility as potential variables to help explain this effect but found no correlations.

5 KEY FINDINGS AND RECOMMENDATIONS

5.1 KEY FINDINGS

The overall results for BPA's residential air source heat pump and variable speed heat pump impact evaluation showed evaluated savings coming in below BPA-reported savings. Evergreen found overall realization rates (the ratio of evaluated savings to BPA-reported savings) of:

- ASHPs in heating zones 2 and 3: 45%
- VSHPs in heating zone 1: 58%
- VSHPs in heating zones 2 and 3: 38%

While these realization rates are lower than expected compared to BPA's claimed savings, these results are more in line with RTF savings values for these same measures (Table 15). (RTF savings assumptions are based on more recent data than BPA's reported savings.)

Table 15: Realization rates

Measure	Heating Zone	Home Type	BPA-Reported Savings Realization Rate	2021 RTF UES Values Realization Rate
ASHP Conversion	HZ 2/3	SF	48%	132%
		MH	39%	65%
	Subtotal		**45%**	**110%**
VSHP Conversion	HZ 1	SF	67%	100%
		MH	27%	36%
	Subtotal		**58%**	**86%**
	HZ 2/3	SF	34%	76%
		MH	56%	88%
	Subtotal		**38%**	**78%**

The drivers analysis showed that pre-period electricity usage was the greatest indicator of energy savings. On average, participants that used more electricity in the pre-period experienced the greatest reductions in electricity use from the installation of an ASHP or a VSHP. Additionally, for single-family homes in heating zone 1, participants that did not have AC as part of their previous HVAC system on average increased their electricity use after installation of an ASHP or a VSHP.

5.2 CONSIDERATIONS FOR FUTURE RESEARCH

To better understand the reasons for lower-than-expected savings for ASHP and VSHP conversions, Evergreen offers a consideration regarding additional data collection:

- **Consider conducting a customer survey** to explore the issues raised in this report that reduce realized savings, both to confirm and understand the magnitude of the various issues. The survey could explore more in-depth concurrent participation in other energy efficiency programs and behavioral habits of households. This evaluation appended PTCS data onto the regression models to estimate drivers of savings. In future evaluations, PTCS data will not be available, as the program has closed.

Evergreen also has some considerations for BPA regarding viewing heat pump savings more broadly, allowing BPA to consider more than pre/post electric savings benefits.

- **Reconsider baseline assumptions** for heat pump measures in homes that do not already have AC. There could be certain areas based on cooling degree days that assume eventual AC installation, so that the savings for homes that install a heat pump for heating and cooling are measured against less efficient AC versus no cooling.
- **Consider the reduction in supplemental heating** when evaluating the benefits of heat pump installations for homes that have bulk fuel heating sources. By only viewing the electricity savings (and excluding other fuel savings), total benefits may not be accurately assessed.
- **Consider increases in household occupant comfort and safety** that are associated with the use of more efficient heat pumps as additional program benefits. BPA and some of the utilities it serves are interested in serving low-income households with energy efficiency programs and services, some of which experience negative savings when they install high efficiency measures because they can now afford to heat and cool their home. This not only increases comfort but may also improve occupant safety and health. There may be other market segments and/or geographic areas where negative savings may be expected where health, comfort, and safety benefits should be explicitly considered.

APPENDIX A: MODELING RESULTS FROM POST-ONLY BILLING REGRESSIONS

Table 16 through Table 18 show the estimated coefficients and standard errors for each regression model, as well as the number of participants, sample size, adjusted R-square, and F-statistic.

Table 16: Modeling results for variable speed heat pumps in single-family homes

Variable	VSHP – HZ1 – SF		VSHP – HZ2/3 – SF	
	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	8.984	0.499	4.001	1.564
CDD	0.343	0.068	0.670	0.173
HDD	0.617	0.031	0.759	0.065
Pre-kWh * Jan	0.738	0.007	0.758	0.021
Pre-kWh * Feb	0.683	0.007	0.785	0.021
Pre-kWh * Mar	0.705	0.008	0.800	0.024
Pre-kWh * Apr	0.736	0.011	0.742	0.028
Pre-kWh * May	0.730	0.015	0.708	0.037
Pre-kWh * Jun	0.699	0.017	0.690	0.041
Pre-kWh * Jul	0.770	0.019	0.752	0.046
Pre-kWh * Aug	0.774	0.020	0.794	0.054
Pre-kWh * Sep	0.699	0.018	0.650	0.052
Pre-kWh * Oct	0.642	0.012	0.674	0.038
Pre-kWh * Nov	0.706	0.009	0.849	0.029
Pre-kWh * Dec	0.778	0.008	0.824	0.023
Part * Pre-kWh * Jan	-0.275	0.009	-0.123	0.023
Part * Pre-kWh * Feb	-0.260	0.008	-0.156	0.023
Part * Pre-kWh * Mar	-0.262	0.010	-0.180	0.028
Part * Pre-kWh * Apr	-0.272	0.014	-0.130	0.036
Part * Pre-kWh * May	-0.199	0.019	-0.026	0.049
Part * Pre-kWh * Jun	-0.132	0.020	0.150	0.055
Part * Pre-kWh * Jul	-0.107	0.022	0.172	0.059
Part * Pre-kWh * Aug	-0.133	0.023	0.101	0.068
Part * Pre-kWh * Sep	-0.089	0.022	0.069	0.063
Part * Pre-kWh * Oct	-0.177	0.016	-0.124	0.044
Part * Pre-kWh * Nov	-0.259	0.011	-0.250	0.032
Part * Pre-kWh * Dec	-0.298	0.009	-0.160	0.024
Participants	**459**		**105**	
Sample Size	**673**		**123**	
Adjusted R-Square	**0.68**		**0.72**	
F-Statistic	**1,547**		**345**	

Table 17: Modeling results for variable speed heat pumps in manufactured homes

Variable	VSHP – HZ1 – MH		VSHP – HZ2/3 – MH	
	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	4.231	0.904	0.897	1.798
CDD	0.989	0.189	0.151	0.150
HDD	0.351	0.055	0.081	0.061
Pre-kWh * Jan	0.823	0.016	1.007	0.016
Pre-kWh * Feb	0.802	0.017	0.951	0.015
Pre-kWh * Mar	0.852	0.020	0.947	0.018
Pre-kWh * Apr	0.821	0.025	0.934	0.026
Pre-kWh * May	0.746	0.032	0.914	0.045
Pre-kWh * Jun	0.711	0.037	0.911	0.056
Pre-kWh * Jul	0.808	0.044	0.967	0.072
Pre-kWh * Aug	0.834	0.049	1.000	0.063
Pre-kWh * Sep	0.774	0.043	0.986	0.058
Pre-kWh * Oct	0.733	0.027	0.912	0.034
Pre-kWh * Nov	0.772	0.020	0.944	0.019
Pre-kWh * Dec	0.808	0.018	1.000	0.017
Part * Pre-kWh * Jan	-0.169	0.018	-0.249	0.026
Part * Pre-kWh * Feb	-0.165	0.019	-0.226	0.026
Part * Pre-kWh * Mar	-0.223	0.022	-0.249	0.031
Part * Pre-kWh * Apr	-0.142	0.029	-0.139	0.044
Part * Pre-kWh * May	0.001	0.038	-0.049	0.061
Part * Pre-kWh * Jun	0.117	0.042	0.039	0.066
Part * Pre-kWh * Jul	0.044	0.048	0.051	0.068
Part * Pre-kWh * Aug	-0.013	0.052	-0.013	0.069
Part * Pre-kWh * Sep	0.052	0.048	-0.086	0.069
Part * Pre-kWh * Oct	-0.073	0.033	-0.165	0.046
Part * Pre-kWh * Nov	-0.114	0.023	-0.159	0.031
Part * Pre-kWh * Dec	-0.120	0.019	-0.175	0.026
Participants	**149**		**23**	
Sample Size	**204**		**25**	
Adjusted R-Square	**0.67**		**0.86**	
F-Statistic	**429**		**388**	

Table 18: Modeling results for air source heat pumps

Variable	ASHP – HZ2/3 – SF		ASHP – HZ2/3 – MH	
	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	7.87	1.10	2.343	1.252
CDD	0.37	0.12	0.477	0.130
HDD	0.25	0.05	0.416	0.053
Pre-kWh * Jan	0.88	0.02	0.889	0.022
Pre-kWh * Feb	0.87	0.02	0.882	0.023
Pre-kWh * Mar	0.89	0.02	0.869	0.026
Pre-kWh * Apr	0.85	0.02	0.822	0.032
Pre-kWh * May	0.79	0.03	0.828	0.038
Pre-kWh * Jun	0.77	0.04	0.875	0.038
Pre-kWh * Jul	0.68	0.04	0.952	0.036
Pre-kWh * Aug	0.66	0.05	0.964	0.040
Pre-kWh * Sep	0.64	0.04	0.872	0.043
Pre-kWh * Oct	0.74	0.03	0.736	0.030
Pre-kWh * Nov	0.84	0.02	0.846	0.023
Pre-kWh * Dec	0.91	0.02	0.959	0.022
Part * Pre-kWh * Jan	-0.15	0.02	-0.111	0.025
Part * Pre-kWh * Feb	-0.19	0.02	-0.118	0.026
Part * Pre-kWh * Mar	-0.24	0.02	-0.129	0.031
Part * Pre-kWh * Apr	-0.21	0.03	-0.073	0.040
Part * Pre-kWh * May	-0.14	0.04	-0.005	0.049
Part * Pre-kWh * Jun	-0.04	0.04	-0.081	0.048
Part * Pre-kWh * Jul	0.11	0.05	-0.157	0.043
Part * Pre-kWh * Aug	0.14	0.05	-0.129	0.050
Part * Pre-kWh * Sep	0.02	0.05	-0.067	0.056
Part * Pre-kWh * Oct	-0.17	0.03	-0.051	0.040
Part * Pre-kWh * Nov	-0.18	0.02	-0.125	0.029
Part * Pre-kWh * Dec	-0.17	0.02	-0.139	0.025
Participants	**172**		**85**	
Sample Size	**191**		**93**	
Adjusted R-Square	**0.73**		**0.73**	
F-Statistic	**573**		**330**	

APPENDIX B: DISTRIBUTION IN CHANGE OF ENERGY USE

The following figures show the distribution of changes in average daily electricity use in kWh for each combination of heating zone, home type, and heat pump type. The change in energy use was calculated by subtracting pre-normalized annual consumption from post-normalized annual consumption. Therefore, negative values indicate savings (shown as green bars in the histograms), and positive values indicate increased usage (shown as red bars in the histograms).

Figure 3: Heating zone 1 manufactured homes VSHP (n=147)

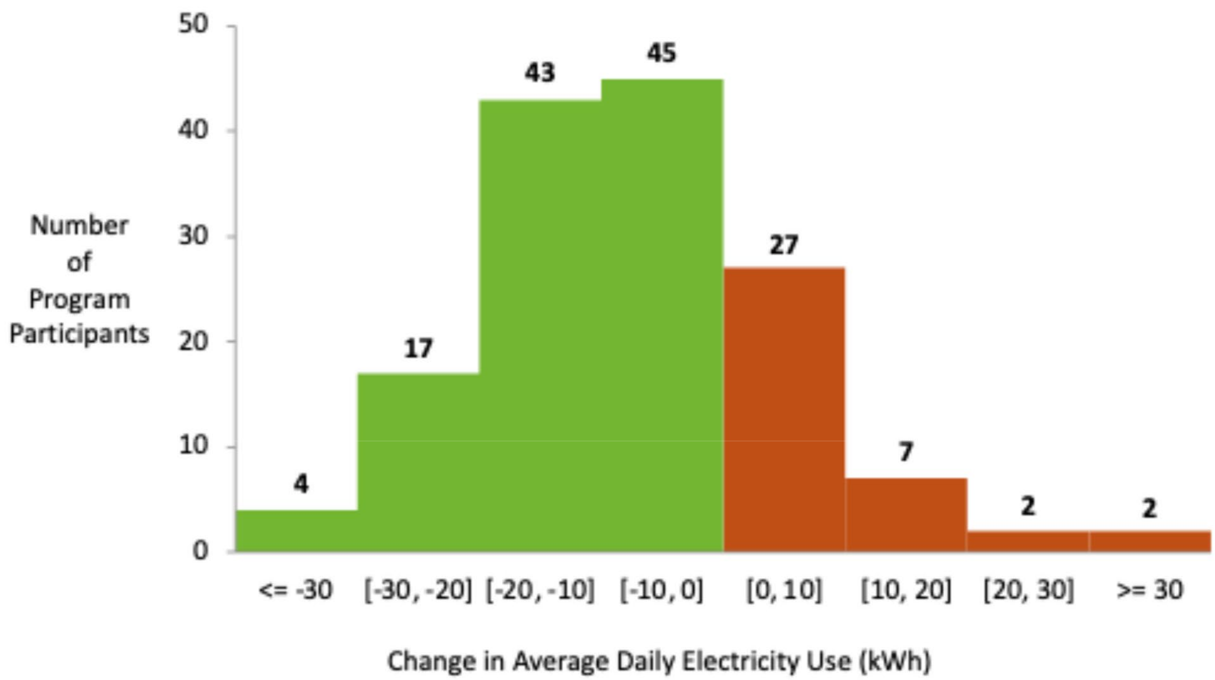

Figure 4: Heating zone 1 single-family VSHP (n=451)

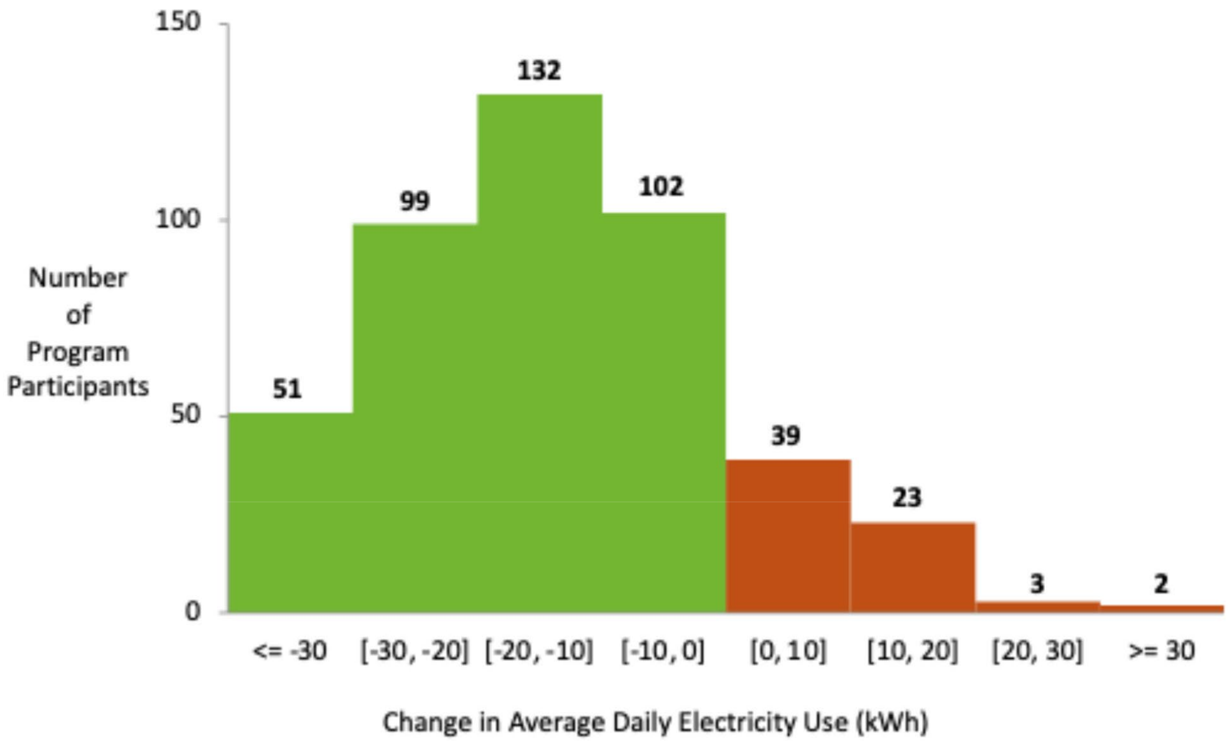

Figure 5: Heating zones 2 and 3 manufactured homes ASHP (n=83)

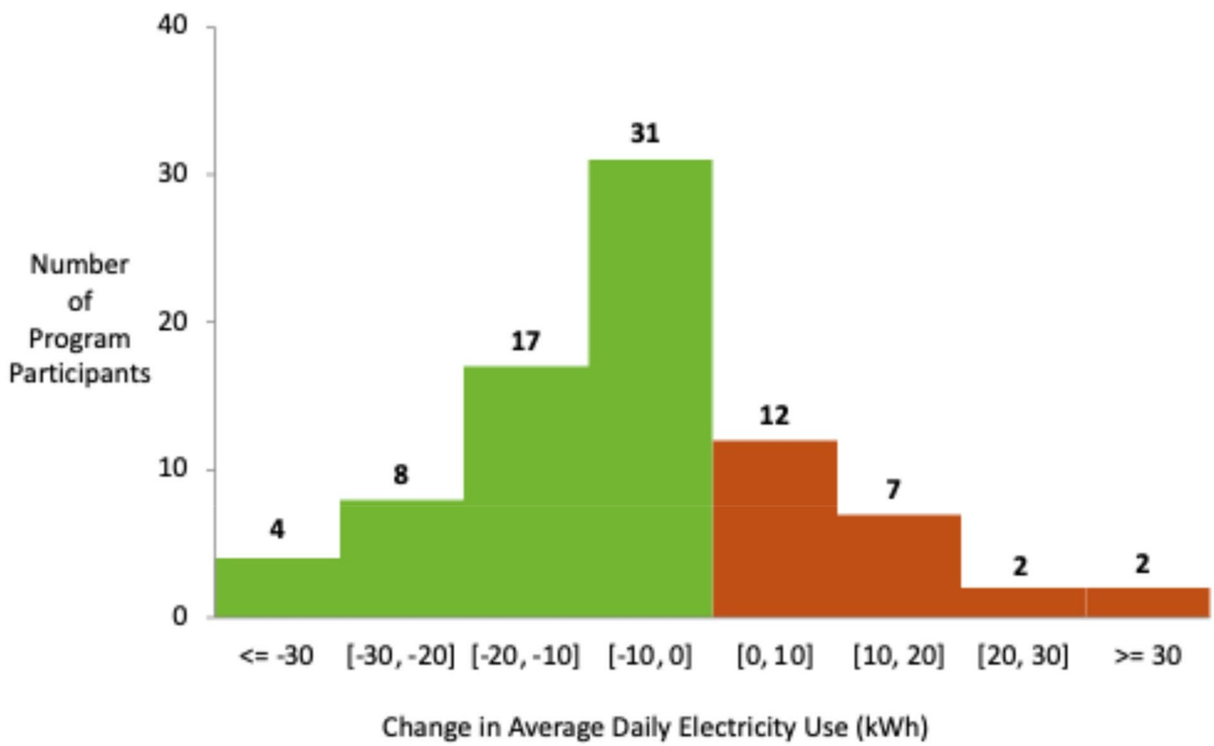

Figure 6: Heating zones 2 and 3 manufactured homes VSHP (n=23)

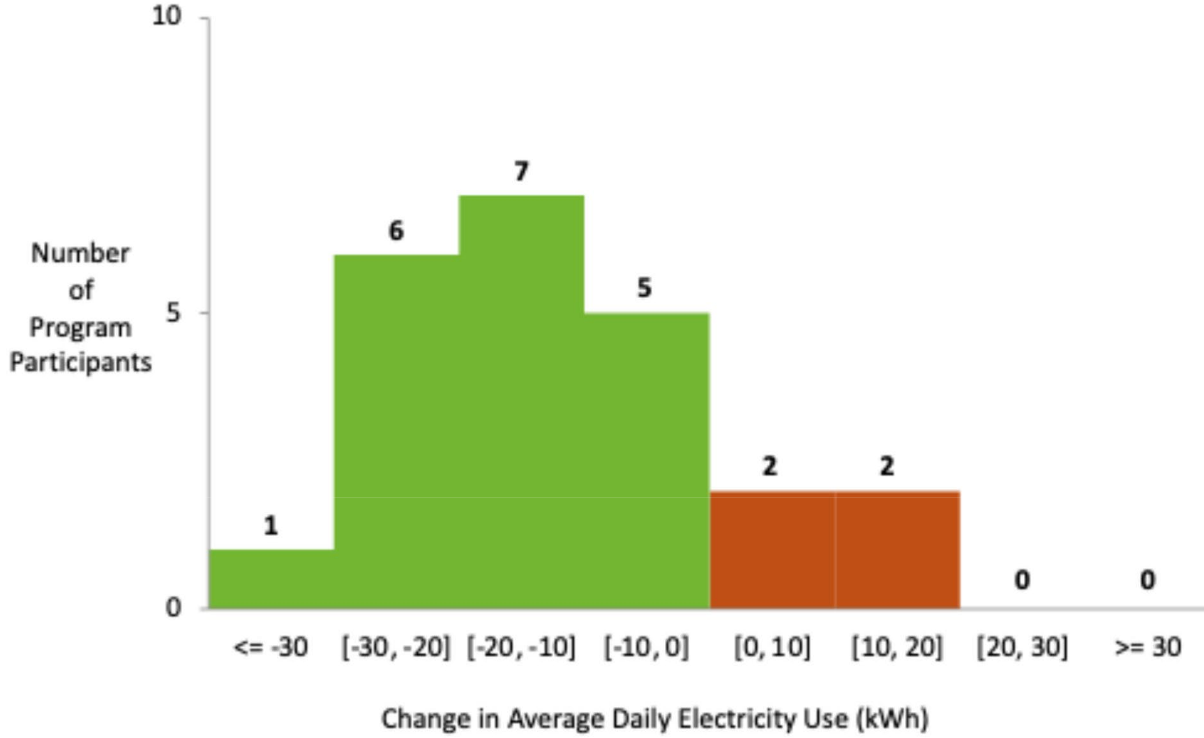

Figure 7: Heating zones 2 and 3 single-family ASHP (n=172)

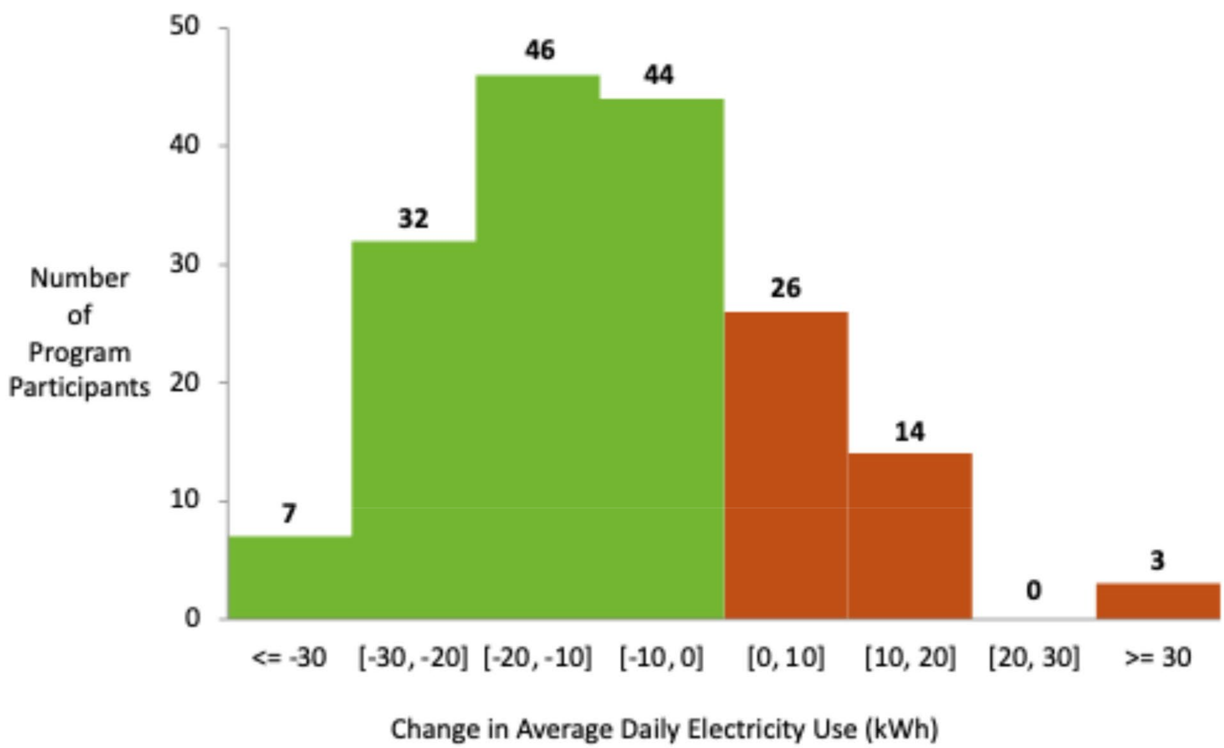

Figure 8: Heating zones 2 and 3 single-family VSHP (n=104)