DHP Controls Coordinated Research Project Evaluation

Final Report

Prepared for Energy Trust of Oregon

Submitted by Evergreen Economics

June 23, 2022

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MEMO

Date: 7/18/2022
To: Energy Trust Board of Directors
From: Dan Rubado, Sr. Project Manager – Evaluation
Mark Wyman, Sr. Program Manager – Residential
Subject: Staff Response to the DHP Controls Coordinated Research Project Evaluation

This report details the implementation and findings from a study that Energy Trust's Residential program conducted to investigate the use of smart, wall-mounted controls with ductless heat pumps (DHPs) as retrofits in single-family homes. This project was partially spurred by Oregon Public Utility Commission Order 19-301, which recommended Energy Trust work with PGE to test the combined energy saving and demand response capabilities of smart DHP controls. In addition, the Residential program was interested in learning if DHP energy savings could be improved by installing better controls after prior evaluation research showed somewhat disappointing results for DHP retrofits. This previous work indicated DHPs with wall-mounted controls might achieve higher savings than those using standard remote controls. The program team hypothesized that a wall-mounted smart control would allow occupants to better utilize their DHPs and, in turn, rely less on inefficient secondary heating systems, such as zonal electric (baseboards and wall heaters) and electric forced air furnaces, improving overall HVAC energy performance.

This study was designed to rigorously quantify the energy savings resulting from adding a smart control to an existing DHP system. Energy Trust also collaborated with PGE to include a test of the demand response capabilities of the selected device. Past program participants with DHPs were recruited for the study and then randomized into treatment and control groups. Treatment group customers were sent a free device along with install instructions. Two primary installation scenarios were investigated—DHPs in homes with backup zonal electric and electric forced air furnace heating systems. Homes with a mix of secondary heating systems, including non-electric ones, were also included incidentally. The program team implemented the study smoothly and did an excellent job recruiting study participants during a challenging time, managing all of the study logistics and following up to provide customer support to those having difficulty. The controls vendor was a supportive partner throughout the study and was able to fulfill orders in a timely manner, provide customer support and share data to enable a thorough evaluation of the results.

Unfortunately, only about three-quarters of treatment group participants installed and set up the devices, and only 45% still had a device installed one year later. Problems with installation and setup, Wi-Fi connection, using the device and controlling DHP operation were commonly mentioned by customers in a survey about their experiences with the device. There were compatibility issues as well, especially with older DHP systems, which the controls weren't designed for. As a result of these problems, customer satisfaction with the devices was very low and overall satisfaction with customers' DHP systems dropped among the treatment group.

In homes with DHPs and zonal electric backup heating, installing a smart DHP control caused electricity usage to increase by about 660 kWh per year and increased electricity demand during utility peak periods. Similar results were seen in homes with mixed or non-electric secondary heating systems. For homes with DHPs and electric forced air furnaces, installing a smart control for the DHP saved about 400 kWh per year, but the impact on electricity demand during utility peak periods was mixed. While the results for homes with electric furnaces offered a glimmer of hope, the savings were still relatively low, customer satisfaction was still a major issue, and this application is far too rare to build a market around. It is possible to connect some DHP controls with smart thermostats that control electric furnaces and prioritize heating with the DHP, using the furnace only as a backup system. This installation scenario was not incentivized and was not observed during the study. This type of multi-system networked controls could yield higher energy savings, but it would be unlikely to work as a self-installed measure.

This study demonstrated controlling only one heating system in homes using two or more systems is not an effective strategy for improving the energy performance of the home. These findings are the latest in a body of research on energy performance in homes with zonal electric heat that show gaining effective control of multiple independent heating systems is difficult and expensive. It also may be that improved controls for DHPs and secondary systems are not a key issue for efficiency programs to solve. DHPs are installed and used in a wide variety of applications, not all of which are ideal for maximizing energy savings, and improved controls may not increase savings in many situations. This study provided robust and comprehensive information about self-installed smart DHP controls, so Energy Trust is not pursuing further research at this time. Given the disappointing results and the documented challenges, Energy Trust will not be providing incentives for smart DHP controls.

It is possible that DHP controls may cost-effectively save energy in different scenarios, but this is contingent on integrating the controls of multiple heating systems so they can be networked with the smart DHP controls to allow for optimal staging of the heating equipment. While this is especially the case for homes with backup zonal electric heating, a more easily achievable target may be homes with DHPs and electric forced air furnaces, where integrating a single smart thermostat for the furnace with a DHP control could result in significantly improved savings. This and other integrated control strategies would likely require professional installation to ensure controls were installed and networked together properly to deliver the desired functionality and energy performance. Unfortunately, using a professional installer to install and integrate smart DHP controls with other smart controls on secondary heating equipment is likely to be expensive, and the savings results—while promising—are uncertain.

If utility demand response programs find value in targeting electric resistance heating systems and can install controls on all heating systems in a home, that could pave the way for a more successful application of DHP controls to improve energy efficiency. As noted above, DHP controls would have a better chance of saving energy if they controlled multiple systems and they would be more worthwhile if they provided multiple types of electricity grid benefits. For instance, smart line voltage thermostats for baseboards and wall heaters could theoretically interface with smart DHP controls and reduce reliance on inefficient resistance heat by placing more heating load on the DHP. While this type of retrofit would be expensive, if it provides significant demand response benefits to the utility, in addition to saving energy, and costs can be shared between multiple parties, it may be economically feasible. As mentioned above, smart thermostats for electric furnaces could be configured to interface with DHP controls to provide improved whole home performance and demand response benefits.

1 Executive Summary

In 2020, Energy Trust of Oregon led a coordinated research project to evaluate the impacts of smart ductless heat pump (DHP) controls in electrically heated single-family homes. These smart controls were theorized to improve the cost effectiveness of DHPs by reducing the reliance on less efficiency secondary heating systems.

The 679 study participants with existing DHPs were randomly assigned to a treatment group or a control group, with the intention of maintaining a balanced split by backup heating system type (electric forced air furnace, zonal electric, and non-electric heat). All 341 participants assigned to the treatment group were sent a smart control thermostat to self-install. Within the Portland General Electric (PGE) Smart Grid Test Bed (comprised of three small geographic regions), all 26 participants were assigned to the treatment group and asked to participate in multiple demand response events called by PGE on system peak days in summer and winter.

The evaluation consisted of:

- Nine **in-depth interviews** with staff from Energy Trust, PGE, CLEAResult (the program implementer), and the thermostat vendor to document the study design and implementation;
- A **participant web survey** (with n=466 respondents) to assess customer satisfaction, document the customer perspective on DHP controls, and provide context on how these devices were used; and
- **Billing analysis** to estimate the achieved energy and demand savings by season, hour-of-day, and day-of-week.

Summary of Findings and Recommendations

The low thermostat installation rates, high uninstall rate, and low customer satisfaction suggest that it is too early for this technology to be offered to the general population of customers with existing DHPs. While professional installation and education may reduce the incidence of these issues, it is likely not a cost-effective solution. Specifically,

- Only 73 percent of the treatment group **successfully self-installed** the thermostat and 38 of these people **decided to uninstall** it within the first year; and there were
- Low rates of **customer satisfaction** with the thermostat, which led to lower rates of satisfaction with the DHP itself.

In terms of energy and demand savings, the thermostats had mixed success:

- The smart thermostat for the DHP saved an **average of 399 kWh** (3%) over one full year for customers with an electric forced air furnace (eFAF) as their secondary heat, but they *increased* energy usage for customers with non-electric heat (Oddballs) and zonal electric heat (by 260 and 663 kWh, or 2% and 5%).
- The thermostats consistently ***increased*** **peak demand** in absence of the demand response program intervention.
- The smart thermostats successfully **reduced demand during demand response events**, though the impacts were small and highly variable across customers and events.

At a minimum, the thermostat manufacturer will need to improve the stability of the device's Wi-Fi connection, providing users with a notification when the devices have remained disconnected for an extended period. This may improve customer satisfaction while also increasing the number of thermostats that are available to receive a demand response event signal.

2 Introduction

Evergreen Economics and Driftless Energy (the Evergreen team) was hired by Energy Trust of Oregon (Energy Trust) in December 2020 to evaluate the impacts of the smart ductless heat pump (DHP) controls installed as part of the DHP Controls Coordinated Research Project implemented by CLEAResult. Smart DHP controls are theorized to improve the cost effectiveness of DHPs by reducing the reliance on secondary heating systems.[1]

This study was designed to produce rigorous estimates of the energy savings, timing of savings, and peak demand impacts of the smart DHP controls. Portland General Electric (PGE) has commissioned a separate evaluation to assess the demand response functionality of these devices and event participation by customers enrolled in the PGE Smart Grid Test Bed.

Coordinated Research Project

All participants in the coordinated research project were required to meet the following eligibility criteria:

- Their primary residence was a single-family home located in Oregon heating zones 1 or 2.
- They received electric service for their primary residence from PGE or Pacific Power.
- They had a DHP installed in their main living space for at least a year without any wall-mounted controls.
- They had no plans to move or make significant changes to their home in the following year.
- They agreed to all terms of the study.

As this was a randomized control trial, study participants were randomly assigned to a treatment group or a control group as shown in Table 1, with the intention of maintaining a balanced split by backup heating system type. The electric forced air furnace (eFAF) group was challenging to recruit and ended up much smaller than expected, with a large group of "oddballs" that have non-electric supplemental heat. The 341 participants assigned to the treatment group were sent a smart control thermostat with access to a dedicated installation support line. As these units were self-installed, it was expected that not all the devices would be installed, activated, and fully utilized by

[1] Smart controls could improve DHP performance above the standard remote controls by allowing residents to shift load to the DHP and use it more easily than backup heat sources. This was supported by small sample (n=11) subgroup findings in a 2019 DHP study that found slightly (but not significantly) higher savings among those with wall mounted DHP controls. Cadmus. 2019. *Residential Ductless Heat Pump Study*. Prepared for Energy Trust of Oregon. https://www.energytrust.org/wp-content/uploads/2019/10/Residential_Ductless_Heat_Pump_Study_Report.pdf

participants. Within the PGE Smart Grid Test Bed (comprised of three small geographic regions), all 26 participants were assigned to the treatment group. The demand response test subgroup experienced multiple demand response events called by PGE on system peak days in winter and summer. PGE commissioned a separate evaluation to measure the success of these demand response capabilities.

Table 1: Original Targets and Participants Recruited

		N Targeted		N Participants, as of 1/22/21	
	Study Group	**Treatment**	**Control**	**Treatment**	**Control**
Backup Heating System Type	Zonal Electric (Zonal)	200	200	180	177
	Electric Forced Air Furnace (eFAF)	200	200	62	63
	Oddballs*	N/A, no target		99	98
	Subtotal	**400**	**400**	**341**	**338**
Total		**800**		**679**	

* There were no explicit targets for oddball participants with non-electric supplemental heat. These homes use wood (n=120), gas (n=59), propane (n=14), or oil/kerosene (n=3), and five said they do not have any other heating system. The most common equipment type was a fireplace/stove (n=170). Some of the oddballs also have electric backup heat (11%), and most (80%) use their DHP as the primary cooling equipment in the home.

One device was provided to each customer in the treatment group, controlling one DHP head. Some participants requested more devices. Most customers who inquired were told that they could buy another device if they wanted, but a few were sent a second device. The thermostat vendor's typical customers have one device for each DHP head. CLEAResult instructed participants to install the device near whichever DHP head was in the "main living area."

The devices act as traditional wall mounted thermostats, replacing the standard remote control and displaying a clear temperature setpoint. The DHP controls were hypothesized to increase the energy savings and cost effectiveness of DHP systems by reducing reliance on less efficient secondary heating systems. The device uses an infrared (IR) signal to control the DHP, which means that the device can theoretically control the DHP without being connected to Wi-Fi or the thermostat vendor's mobile application.

Evaluation Objectives

The main objective of this evaluation was to estimate the annual electricity savings attributable to the use of smart DHP controls in electrically heated single-family homes for three scenarios, defined by the type of supplemental heating used in the home. Secondary evaluation objectives included the following:

- Determine the timing of electricity savings by season, hour-of-day, and day-of-week;
- Document the study design and actual implementation from the perspective of the program administrators, smart controls vendor, and participants; and
- Assess the overall success and future potential of DHP controls in terms of energy efficiency, demand reduction, demand response, and customer satisfaction.

3 Methods

This section provides details on our methods for data collection and analysis.

3.1 Interviews with Staff and Vendors

Evergreen interviewed Energy Trust, CLEAResult, and PGE staff as well as the device vendor to document the research project process and inform the development of data collection instruments. We consulted with Energy Trust and CLEAResult study leads to confirm the highest priority interviews.

We interviewed two Energy Trust staff members and three CLEAResult staff members in March 2021, roughly two months after completing customer enrollment. The interviews covered the following topics:

- Design of the research project;
- Implementation details and changes;
- Participation processes;
- Coordination with the smart controls vendor;
- Current challenges and concerns; and
- Emerging plan for smart DHP controls.

We also interviewed two staff members from the PGE Smart Grid Test Bed and two from the smart controls vendor in August and September 2021, after the first demand response events were called.[2] These interviews provided insights into the successes and challenges from the thermostat vendor's perspective, coordination between Energy Trust and PGE, product functionality and the mechanism for energy savings, long-term plans for product development, and forecasted market share.

The final interview guides are provided in Appendix A.1 Energy Trust, CLEAResult, and PGE Staff Interview Guide and Appendix A.2 Vendor Interview Guide.

[2] Our interviewees from the smart thermostat vendor included the CEO/co-founder and the head of customer support/training.

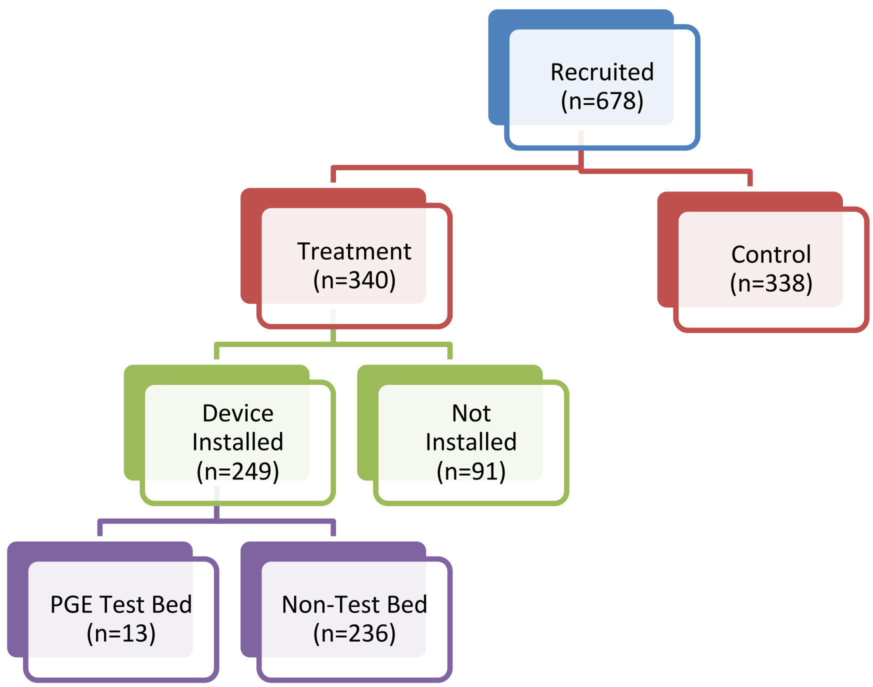
3.2 Participant Web Survey

Evergreen surveyed participants to document research project implementation, assess customer satisfaction with the devices, and provide additional context for how these devices were used in homes with secondary heating systems.

3.2.1 Survey Topics

The survey included four different pathways with variations in questions for the control group (n=338), treatment group with smart controls installed (n=249), those assigned to the treatment group but with no device installed (n=91, uninstalled or never installed), and PGE Smart Grid Test Bed demand response participants (n=13 with installed devices and n=5 without). The total number of participants in each group is shown in Figure 1.

Figure 1: Survey Pathways



Source: Device status as reported by the vendor as of April 27, 2021.

The survey instrument is provided in Appendix B.1 Survey Instrument. In addition to the topics laid out in the evaluation objectives, we integrated the following topics into the participant survey:

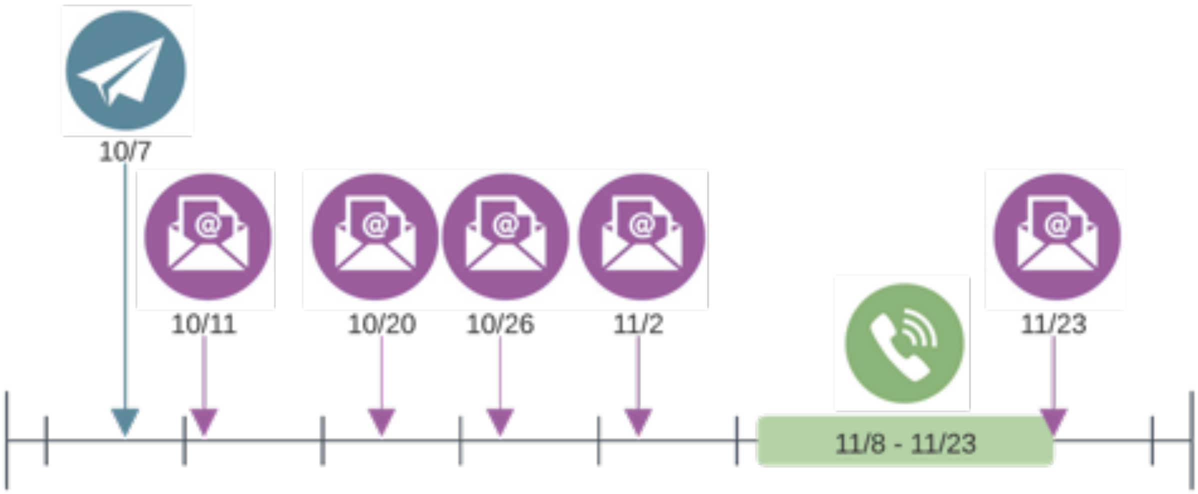
- Treatment group, with controls installed:
    - Confirm the device was installed and is still in use
    - Installation challenges

  - Where were the smart DHP controls installed? How much floor space does this serve (in square feet or percentage)? Is this the primary heating system for the whole home or just one zone?
  - Did you purchase any smart DHP controls in addition to the free device?
  - Did you use the device to set the DHP at a constant temperature, set up a schedule, or manually change the temperature settings regularly?
  - Did you set up the smart thermostat to connect with a central thermostat, occupancy sensor, or any smart home controls?
  - After installing the controls, did you notice any changes in your non-electric (natural gas, propane, fuel oil, wood, pellets) energy bills?
- Treatment group, no device installed:
  - Why did you change your mind about installing the device? What issues did you face with the installation?
- COVID-19 pandemic-related changes in occupant schedules (e.g., shift to remote education or working from home)
- Clarification questions about secondary HVAC systems:
  - Which of the following heating and cooling systems do you have that serve the same room(s) as the DHP? How are they controlled? In what scenarios do you use this system: all the time, when the DHP is not heating/cooling the space fast enough, when I am in the mood (e.g., fireplaces), rarely?

3.2.2 Recruitment

We launched the survey on October 7, 2021, and continued recruitment efforts for seven weeks, wrapping up recruitment on the day before Thanksgiving. Evergreen used three modes for the survey recruitment: mail, email, and phone. Evergreen mailed a survey invitation letter, followed by an email survey invitation and up to four email reminders (Figure 2). We also called non-respondents to remind them about the survey and to offer to conduct it over the phone, referring them to the web survey if preferred. If no one answered, we left a voicemail offering both of those options. We called each non-respondent twice, varying the time of day.

Figure 2: Survey Recruitment Timeline



CLEAResult provided Evergreen with examples of its email communications with participants so that we could use similar branding and messaging, increasing the likelihood that they associate the survey invitation with the coordinated research project. Even though participants agreed to complete the survey during the eligibility screening process, we offered a $10 incentive for completing the survey to improve response rates.

The letter, reminder emails, and phone scripts are provided in Appendix B.2 Recruitment Materials.

3.2.3 Disposition

We achieved a response rate of 76 percent for the control group and 61 percent for the treatment group, for an overall response rate of 69 percent (Table 2). Within the PGE Smart Grid Test Bed, 10 of the 18 contacts completed the survey (56%). A sample size of at least 69 responses was preferable for each analysis subgroup (e.g., zonal electric control, PGE Smart Grid Test Bed treatment DR-subgroup) as this was the minimum sample size required to detect statistically significant differences between the groups at 90 percent confidence with 10 percent precision. We exceeded this threshold by study group and group assignment (treatment versus control), though the sample was much smaller within the Smart Grid Test Bed and eFAF subgroups.

Table 2: Participant Survey Disposition

Study Group	Contacts			Completed*			Response Rate		
	Total	Treat	Control	Total	Treat	Control	Total	Treat	Control
eFAF	125	62	63	88	38	50	70%	61%	79%
Oddballs	197	99	98	137	63	74	70%	64%	76%
Zonal	356	180	176	241	108	133	68%	60%	76%
Total	**678**	**341**	**337**	**466**	**209**	**257**	**69%**	**61%**	**76%**
Smart Grid Test Bed		18	-		10	-		56%	-

* This does not count the n=8 participants (3 treatment and 5 control) who completed less than half of the survey questions.

In late October 2021, we observed that we had much higher response rates within the subset of the treatment group that had active devices (65% versus 32%), according to the status reported by the device vendor in April 2021. We modified the treatment group emails, prompting customers to respond even if they never successfully installed the smart thermostat. This additional outreach to customers with inactive devices (currently offline or never attempted setup) helped to reduce the gap in response rates. We requested an updated status for each device from the thermostat vendor in December 2021 to identify any additional devices that had been installed or gone offline. In the end, we received completed surveys from 87 percent of those with active devices and 55 percent of those whose devices were inactive (66% of those currently offline and 33% of those who never attempted setup), as shown in Table 3.

Table 3: Treatment Group Survey Disposition by Thermostat Status

Thermostat Status	Treatment		
	Contacts	Completed*	Response Rate
Currently Active	70	61	87%
Currently Offline	179	118	66%
Never Attempted Setup	91	30	33%
Total	**340**	**209**	**61%**

* This does not count the n=8 participants (3 treat and 5 control) who completed less than half of the survey questions.

3.2.4 Weights

Table 4 provides projection weights for each study group, with the treatment group further segmented by device status (as of December 2021). We combined treated customers who never attempted setup from the eFAF and Zonal study groups into a single group for weighting due to the small population size; oddballs were left alone because this group has unusual secondary heating systems. The control group had relatively stable response rates across the three study groups, so their weights were nearly identical and had little to no impact on the results.

Table 4: Survey Weights

Group Assignment	Device Status	Study Group	Participants	Surveyed	Response Rate	Weight (balancing)	Weight (projection)
Treatment	Currently Active	eFAF	13	13	100%	0.61	1.0
		Zonal	37	31	84%	0.73	1.2
		Oddballs	20	17	85%	0.72	1.2
	Currently Offline	eFAF	29	20	69%	0.89	1.5
		Zonal	102	64	63%	0.98	1.6
		Oddballs	48	34	71%	0.87	1.4
	Never Attempted Setup	eFAF	20	5	25%	2.05	3.3
		Zonal	40	13	33%		
		Oddballs	31	12	39%	1.59	2.6
Control	N/A	eFAF	63	50	79%	1	1.3
		Zonal	176	133	76%	1	1.3
		Oddballs	98	74	76%	1	1.3

3.3 Analysis of Energy Savings, Timing of Savings, and Peak Demand Savings

For these tasks, we used billing analysis to estimate the energy and demand savings attributed to the treatment of the smart DHP controls above and beyond any natural change observed in the control group of existing DHPs without smart controls for homes with each type of supplemental heat (separately):

1. Zonal electric (Zonal)
2. Electric forced air furnace (eFAF)
3. Oddballs (e.g., gas fireplace, pellet stove)

3.3.1 Data Cleaning and Exclusion Criteria

Table 5 provides a summary of every data source we utilized for this evaluation, fields provided, sample coverage (e.g., number of premises and date range), and how the data were used. After receiving each data source, we conducted data quality checks before preparing the data for analysis (e.g., flagging outliers, identifying and addressing missing values).

Table 5: Data Sources for the Evaluation

Data Source	Unique Fields	Coverage	Intended Use
Intake Survey	Customer and premise ID, HVAC system details, group assignment, survey responses	n=679	Customer and home characteristics for segmentation analysis
Advanced Metering Infrastructure (AMI) Usage Data	15- or 60-minute electricity consumption, billing rate code	n=669 premises Sep 2019-Jan 2022	Billing analysis, estimates of energy and demand savings, identifying sites with solar to exclude from the billing analysis
Demand Response Events	Identify date and time of each demand response event	39 events between Jun 2019 and Jan 2022	Flag usage during demand response events in the AMI data to exclude from analysis
Device User Summary	Device ID, first online date, customer contact information	n=352 devices	Link treatment group customers to device IDs, flag sites with fully installed and configured devices
Customer Relationship Management (CRM)	Premise ID, product code, date, *ex ante* savings, useful life	n=686 premises Feb 2000-Mar 2021	Identify solar and other measures installed during the study period
National Oceanic and Atmospheric Administration (NOAA) Weather	Hourly interval outdoor air temperature	n=31 stations Jan 2018-Jan 2022	Weather normalization (actual weather)
Typical Meteorological Year (TMY3) Weather	Typical weather conditions, based on historical outdoor air temperature	n=1,020 stations	Weather normalization (typical weather)

Participant Attrition

Table 6 shows the number of participants who were excluded from the analysis and the reason for their removal. Most notable were the number of homes with solar. Most of the dropped sites (n=42) were removed because they were flagged by their electric utility (PGE or Pacific Power) as having net-metered solar photovoltaic (PV) systems, which would pose problems for impact estimates from billing analysis. We flagged an additional 14 sites as solar sites, based on their hourly energy usage patterns during daylight hours.

It is also worth noting that 17 sites were removed because they had statistically significant non-routine events (NREs). These NREs were identified by using plots of the cumulative sum of model residuals for each participant site (individually) over time. Model residuals represent the difference between the actual energy use and the model prediction. A change in the slope of the cumulative sum of residuals is evidence of an event that is not captured in the model (i.e., a change other than weather, number of daylight hours, etc.), which can obstruct or exaggerate savings estimates.

In the end, we were able to retain 87 percent of participant sites for the billing analysis.

Table 6: Participant Attrition from Billing Analysis

Exclusion Criteria	Sites Dropped	Remaining Sites
Intake survey	-	679
Customer not linked to a distinct residential ID (by the utility)	1	678
No AMI data provided	5	673
Have net metered solar PV (sites with solar payment options and metered solar production were retained, but sites with only net energy metering were excluded)	42	631
Insufficient pre-period data (<12 months)	5	626
Had an account number change (i.e., no post data)	1	625
Additional sites flagged as apparent net metered solar PV	14	611
Had other statistically significant NRE (e.g., baseline NRE or a major change in addition to COVID in the post-period)	17	594

Table 7 compares the original count of participants who completed the intake survey against our final sample for the billing analysis by supplemental heating type and group assignment.

Table 7: Attrition by Group and Supplemental Heating Type

Supplemental Heating	Intake Survey			Billing Analysis		
	Total	Treatment	Control	Total	Treatment	Control
Zonal	356	179	177	320	166	154
eFAF	125	62	63	108	57	51
Oddballs	197	99	98	166	89	77
Unknown	1					
Subtotal	**679**	**340**	**338**	**594**	**312**	**282**

Day Exclusions

For the remaining 594 sites in the sample, we excluded the following days from the analysis:

- Peak Time Rebates (PTR), Smart Thermostat (ST), and Ductless Heat Pump Rewards demand response event days;
- The start and end of daylight savings (two days per year);
- The day the control was installed in the home;
- U.S. bank holidays;
- Days with incomplete meter observations (i.e., less than 24 hourly or 96 quarter-hourly readings per day);
- Days with incomplete weather observations (i.e., less than 23 hourly readings per day); and
- AMI data for the control group after December 27, 2021 (when their smart thermostat devices were shipped).

These exclusions removed 54,872 observations from the daily models (10%).

Identifying Outliers

Evergreen also identified outliers in hourly kWh energy consumption (i.e., individual observations) or those with unusual energy consumption patterns. An outlier was defined as any kWh reading that was more than three times the distance of the interquartile range (IQR) from the median interval measurement, based on the full time span of hourly interval AMI data for each site.[3] Almost every site had at least one flagged outlier, with the most extreme site having 14 percent of

[3] This definition of an outlier is based on CalTRACK rule 2.3.6. The IQR is a measurement of variability. The rank-ordered data are divided into four equal parts called quartiles. The IQR measures the distance between the first and third quartiles, corresponding to the 25th and 75th percentiles, containing the middle 50 percent of observations.

its AMI data flagged (this was still sufficient to proceed with modeling) and the average site having 2.5 percent of its AMI data flagged. We manually reviewed all sites in the sample with time-series plots to assess if the outlier flag was too sensitive (false positives).

Baseline models were estimated with and without these flagged outliers to assess the relative model fit; we concluded that these **outliers (2.5% of the total hourly observations and 0.3% of the daily observations) did not have a statistically significant impact** on the estimated energy savings; for this reason, **outliers were retained** in the models presented in this report.

3.3.2 Billing Analysis

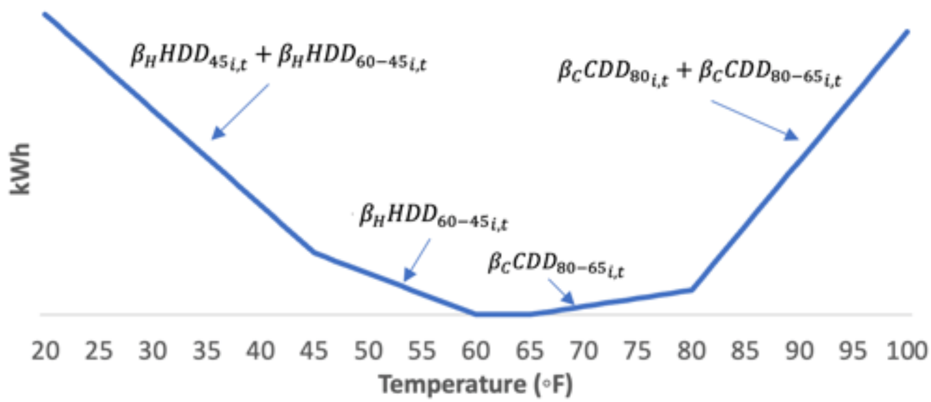
We used billing analysis to estimate energy and demand savings attributed to the treatment of the smart DHP controls above and beyond any natural change observed in the control group of existing DHPs without smart controls.

Daily Regression Model

We used the model specification in Equation 1 to estimate overall kWh energy savings for homes with each type of supplemental heat separately. The regression includes a series of day-of-week and seasonal indicator variables to help control for variability in energy usage that is not related to temperature, such as energy usage for cooking and lighting. This model includes heating degree days (HDD) and cooling degree days (CDD); we re-estimated the model with a range of base temperatures for CDD and HDD, to determine which yielded the best fit.[4] The best fit came from separating HDD into multiple terms, one measuring HDD from a base of 45 degrees and a second to capture HDD from a base of 60 degrees capped at 15 degrees (i.e., the heating load to bring a 45 degree room up to 60 degrees). This second term makes sense for heat pumps, because the kWh required to heat from more moderate temperatures is much lower than to heat from extremely low temperatures, as DHPs may operate less efficiently at low temperatures and/or the low temperatures motivate customers to use secondary heating systems, leading to more energy per unit of heat produced. When we expanded from the heating season to annual models, a similar split degree-day term yielded a good fit for CDD as well, which may have been caused by a declining coefficient of performance (COP) as outside temperatures rose. Figure 3 provides an example of how these four degree-day terms work together to predict the relationship between energy usage and outdoor air temperature. The models generally estimate flatter slopes, smaller incremental energy usage required to heat and cool the home at moderate temperatures, and steeper slopes (more incremental energy usage) at extreme temperatures.

[4] We calculated heating degree-hours (HDH) from hourly outdoor air temperatures, and then took the average of these hourly values to create a single heating degree-day (HDD) value for each weather station on each day in the study period. By calculating this metric from hourly temperatures instead of daily averages, we can identify days that require some cooling in the midday as well as heating in the early morning or evening. We re-estimated the model with a range of base temperatures (between 40 and 75 degrees Fahrenheit) to determine which yielded the best fit.

Figure 3: Heating and Cooling Degree-Day Example



The coefficients on $Treat$, $CDD * Treat$, and $HDD * Treat$ control for any difference between the treatment and control groups prior to the installation of smart DHP controls. The coefficients on $Post$, $CDD * Post$, and $HDD * Post$ are intended to absorb the impact of the COVID-19 pandemic and any other changes over time that are shared across the treatment and control groups. We tested the inclusion of additional interaction terms, dropping any that were not statistically significant and that did not improve the model fit. We estimated a distinct model for homes with each type of supplemental heat separately (i.e., the same specification but a different set of coefficient estimates for Zonal versus eFAF).

Equation 1: Daily Fixed Effects Regression Model

$$
\begin{aligned}
kWh_{i,t} = {} & \alpha_i + \beta_C CDD_{80_{i,t}} + \beta_C CDD_{80-65_{i,t}} + \beta_H HDD_{45_{i,t}} + \beta_H HDD_{60-45_{i,t}} \\
& + \sum_{DOW=1}^{6} \beta_{DOW} DOW_t + + \sum_{S=1}^{3} \beta_S Season_t + \beta_D Daylight_t \\
& + \beta_{DP} Daylight * Post_t + \beta_T Treat_t + \beta_P Post_t + \beta_{TP} Treat * Post_{i,t} \\
& + \beta_{CT} CDD_{80} * Treat_{i,t} + \beta_{CP} CDD_{80} * Post_{i,t} + \beta_{CTP} CDD_{80} * Treat * Post_{i,t} \\
& + \beta_{CT} CDD_{80-65} * Treat_{i,t} + \beta_{CP} CDD_{80-65} * Post_{i,t} \\
& + \beta_{CTP} CDD_{80-65} * Treat * Post_{i,t} + \beta_{HT} HDD_{45} * Treat_{i,t} + \beta_{HP} HDD_{45} * Post_{i,t} \\
& + \beta_{HTP} HDD_{45} * Treat * Post_{i,t} + \beta_{HT} HDD_{60-45} * Treat_{i,t} \\
& + \beta_{HP} HDD_{60-45} * Post_{i,t} + \beta_{HTP} HDD_{60-45} * Treat * Post_{i,t} + \varepsilon_{i,t}
\end{aligned}
$$

Where:

$kWh_{i,t}$ = Actual daily energy usage for customer *i* during time interval *t*

HDD_{45} = Heating degree-days calculated from a baseline temperature of 45°F

HDD_{60-45} = Heating degree-days calculated from a baseline temperature of 60°F, minus HDD from a baseline of 45°F (i.e., incremental heating degrees between 45° and 60°F)

CDD_{80} = Cooling degree-days calculated from a baseline temperature of 80°F

CDD_{80-65} = Cooling degree-days calculated from a baseline temperature of 80°F, minus CDD from a baseline of 65°F (i.e., incremental cooling degrees between 65° and 80°F)

$Treat$= Dummy variable (0, 1) for customers assigned to the treatment group

$Post$= Dummy variable representing the period after the smart DHP controls were installed and functional (a customized install date for customers in the treatment group and an assigned install date for the control group)

DOW = Day-of-week dummy variables (Monday-Saturday, omitting Sunday)

$Season$ = Season variable (spring, summer, and winter, omitting fall)

$Daylight$ = Hours of daylight (between dawn and dusk) during time interval t

α_i= Customer-specific fixed-effect (i.e., baseline consumption)

β_{TP}, β_{HTP}= Average daily impact and average incremental impact (for each additional HDD) of the controls on the energy usage in the post-period

ε = Random error assumed to be normally distributed

The estimated regression coefficients from this model, combined with normalized weather conditions from the Typical Meteorological Year (TMY3), produce estimates for normalized electricity savings (kWh) that result from being assigned to the treatment group, as shown in Equation 2.

Equation 2: Normalized Savings from the Intent to Treat (ITT)

$$\begin{aligned} Savings_{ITT} = {} & \hat{\beta}_{Treat*Post} * Days_{TMY3} + \hat{\beta}_{CDD_{80}*Treat*Post} \sum CDD_{(80)\,TMY3} \\ & + \hat{\beta}_{CDD_{80-65}*Treat*Post} \sum CDD_{(80-65)\,TMY3} + \hat{\beta}_{HDD_{45}*Treat*Post} \sum HDD_{(45)\,TMY3} \\ & + \hat{\beta}_{HDD_{60-45}*Treat*Post} \sum HDD_{(60-45)\,TMY3} \end{aligned}$$

Where:

$\hat{\beta}$ = Coefficients estimated in the regression model (for participants with a specific type of supplemental heating)

$Days_{TMY3}$ = Count of days in a TMY3 normalized weather-year

$\sum CDD_{(80)TMY3}$ = Sum of cooling degree-days during a TMY3 normalized weather-year calculated from base temperature of 80°F.

$\sum CDD_{(80-65)TMY3}$ = Sum of cooling degree-days during a TMY3 normalized weather-year calculated from base temperature of 80°F, minus CDD from a baseline of 65°F (i.e., incremental cooling degrees between 65° and 80°F).

$\sum HDD_{(45)TMY3}$ = Sum of heating degree-days during a TMY3 normalized weather-year calculated from base temperature of 45°F.

$\sum HDD_{(60-45)TMY3}$ = Sum of heating degree-days during a TMY3 normalized weather-year calculated from base temperature of 60°F, minus HDD from a baseline of 45°F (i.e., incremental heating degrees between 45° and 60°F).

To estimate the savings attributable to the smart DHP controls, we used a local average treatment effect (LATE) adjustment shown in Equation 3 to account for the proportion of the treatment group that completed the installation and setup of the DHP controls (completed install at some point, may include some that were later uninstalled). Note that in the survey sample, 73 percent of the treatment group self-reported having successfully installed the thermostat, but only 45 percent of the treatment group had the thermostat installed at the time of the survey (with the rest having been uninstalled). Our LATE adjustment considers smart thermostats that were ever installed (73% within the survey sample), as we would assume uninstalled thermostats are a natural phenomenon that would likely occur if this offering was expanded to a larger population.

Equation 3. LATE Adjustment

$$Savings_{Thermostat} = \frac{Savings_{ITT}}{n_{Thermostat}/n_{Treat}}$$

Where:

$n_{Thermostat}$= Number of customers who installed the smart DHP controls, based on installation date and status provided by the controls vendor

n_{Treat}= Number of customers who were assigned to the treatment group

Hourly Regression Model

The hourly model uses an ordinary least squares (OLS) regression with time-of-week indicators, heating degree-hours (HDH) and cooling degree-hours (CDH) to explain the variability in energy usage in terms of the day-of-week, time-of-day, and outdoor air temperature.[5] As shown in Equation 4, we added terms for the post-period and treatment group assignment to isolate the impact of the smart DHP controls above and beyond any change observed in the control group. Again, we estimated a distinct model for homes with each type of supplemental heat separately (i.e., the same specification but a different set of coefficient estimates for Zonal versus eFAF).

The interaction terms drastically increased the number of variables in the model, but they were statistically significant, suggesting that there were differences between the treatment and control groups in the pre-period and systematic differences in the heating slope during the post-period (including the COVID-19 pandemic), for which we needed to control. We tested additional

[5] Degree-day terms estimate a linear increase in energy usage for each additional degree below or above the baseline temperature (often 65 degrees Fahrenheit), when heating or cooling is likely required. We tested a range of baseline temperatures and selected the ones that yielded the best model fit.

interaction terms, and then dropped any that were not statistically significant and did not improve the model fit. Note that specifying separate models for occupied and unoccupied hours did not improve model fit.

Equation 4: Hourly Regression Model

$$
\begin{aligned}
kWh_{i,t} = {} & \beta_T Treat_i + \beta_P Post_t + \beta_{TP} Treat * Post_{i,t} + \beta_D Daylight_t \\
& + \beta_{DP} Daylight * Post_t + \sum_{S=1}^{3} \beta_S Season_t \\
& + \sum_{S=1}^{3} \beta_{SP} Season * Post_t + \beta_H H_t + \\
& + \sum_{TOW=1}^{48} \beta_{TOW} TOW_t + \sum_{TOW=1}^{48} \beta_{TOWP} TOW * Post_{i,t} \\
& + \sum_{TOW=1}^{48} \beta_{TOWT} TOW * Treat_{i,t} \\
& + \sum_{TOW=1}^{48} \beta_{TOWTP} TOW * Treat * Post_{i,t} + \beta_{HH} HDH_{45} \\
& + \beta_{HM} HDH_{60-45} + \beta_C CDH_{80} + \beta_C CDH_{65-80} + \beta_{HP} HDH_{45} * Post_t \\
& + \beta_{HP} HDH_{60-45} * Post_t + \beta_{CP} CDH_{80} * Post_t + \beta_{CP} CDH_{65-80} * Post_t \\
& + \beta_{HT} HDH_{45} * Treat_{i,t} + \beta_{HT} HDH_{60-45} * Treat_{i,t} + \beta_{CT} CDH_{45} * Treat_{i,t} \\
& + \beta_{CT} CDH_{65-80} * Treat_{i,t} + \beta_{HTP} HDH_{45} * Treat * Post_{i,t} \\
& + \beta_{HTP} HDH_{60-45} * Treat * Post_{i,t} + \beta_{CTP} CDH_{80} * Treat * Post_{i,t} \\
& + \beta_{CTP} CDH_{65-80} * Treat * Post_{i,t} + \varepsilon_{i,t}
\end{aligned}
$$

Where:

$kWh_{i,t}$ = Energy consumption for customer *i* during time interval *t*

$Treat$ = Indicator variable (0,1) for customers assigned to the treatment group

$Post$ = Indicator variable representing the period after the smart DHP controls were installed and functional (a customized install date for customers with smart DHP controls and an assigned install date for those without)

TOW = Indicator variables representing the time-of-week, 24 hours for two day types (weekdays vs. weekends)

HDH_{45} = Heating degree-hours calculated from a baseline temperature of 45°F

HDH_{60-45} = Heating degree-hours calculated from a baseline temperature of 60°F, minus HDD from a baseline of 45°F (i.e., incremental heating degrees between 45° and 60°F)

CDH_{80} = Cooling degree-hours calculated from a baseline temperature of 80°F

CDH_{80-65} = Cooling degree-hours calculated from a baseline temperature of 80°F, minus CDD from a baseline of 65°F (i.e., incremental cooling degrees between 65° and 80°F)

H = Relative humidity $(T_{Dew} - T)$

$Season$ = Season variable (spring, summer, and winter, omitting fall)

$Daylight$ = Indicator variable for daylight (between dawn and dusk) during time interval t

β = Coefficients estimated by the model

ε = Random error assumed to be normally distributed

The estimated regression coefficients from this model, combined with normalized weather conditions from the Typical Meteorological Year (TMY3), produce estimates for normalized electricity savings (kWh) for each time-of-week that results from being assigned to the treatment group, as shown in Equation 5.

Equation 5: Normalized Hourly Savings from the Intent to Treat (ITT)

$$HourlySavings_{ITT} = \hat{\beta}_{Treat*Post} + \hat{\beta}_{TOW*Treat*Post} + \hat{\beta}_{CDH_{80}*Treat*Post} \sum CDH_{(80)\,TMY3} + \hat{\beta}_{CDH_{80-65}*Treat*Post} \sum CDH_{(80-65)\,TMY3} + \hat{\beta}_{HDH_{45}*Treat*Post} \sum HDH_{(45)\,TMY3} + \hat{\beta}_{HDH_{60-45}*Treat*Post} \sum HDH_{(60-45)\,TMY3}$$

Just like the daily model, we used a local average treatment effect (LATE) adjustment to account for the proportion of the treatment group that completed the installation and setup of the smart DHP controls.

4 Findings

This section provides our findings from the in-depth interviews, participant survey, and billing analysis. We have organized this section by topic, integrating key findings from all tasks into one place to tell a cohesive story.

4.1 Staff, Vendor, and Participant Experiences

This section documents the project design and actual implementation from the perspective of the program administrators, implementers, smart controls vendor, and participants. All survey findings shown as percentages have been weighted, and counts are unweighted, unless otherwise noted.

4.1.1 Project Design and Implementation

Study Design

Improving smart DHP controls and optimizing the use of secondary heating systems was one of the strategies suggested by the program evaluation team to improve DHP savings.[6] As part of Oregon Public Utility Commission (OPUC) Order 19-301, which is part of the ongoing docket UM 1696, related to Energy Trust cost-effectiveness exceptions, the OPUC recommended in 2019 that Energy Trust collaborate with PGE to conduct a field test of smart DHP controls to test the combined energy saving and demand response capabilities.

Energy Trust did a thorough market scan to select the device based on its feature set, demand response capabilities, existing application programming interface (API), and price. They considered third-party devices that control DHPs with infrared (IR) sensors, offering integration with other smart home devices. These include Honeywell D6 Pro, Ambi Climate 2, Flair Puck, Sensibo Sky, ThinkEco, and Intesis Home; there are also three Original Equipment Manufacturer (OEM) products from Mitsubishi, Fujitsu, and Daiken. One of these devices were selected for the study. .

Energy Trust led discussions with PGE and Pacific Power while coordinating with the OPUC. PGE was heavily involved in the demand response portion of the study, coordinating between the device vendor and the distributed energy resource management systems (DERMs) provider (Virtual Peaker). Pacific Power was also involved, in a more limited role of providing data but not administering any demand response. Energy Trust led the design of the study and then contracted with CLEAResult to develop the implementation plan (e.g., recruitment, control and treatment

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[6] Jackson A and Walczyk J. 2019. R*esidential Ductless Heat Pump Study: Prepared for Energy Trust of Oregon*. Boston, MA; The Cadmus Group. Retrieved on 10/6/2020 from https://www.energytrust.org/wp-content/uploads/2019/10/Residential_Ductless_Heat_Pump_Study_Report.pdf

group assignments, delivery of controls), and Evergreen Economics led the development of an evaluation plan. The smart thermostat vendor's CEO worked with Energy Trust and PGE on the pilot for a year, prior to the start of the COVID-19 pandemic. Beyond just selling the units, they developed code to integrate the smart thermostats with Virtual Peaker.

Recruitment

Energy Trust developed a list of customers who had installed a DHP at least one year prior. The implementation staff started with email recruitment, then moved to direct mail when they needed to boost response rates. CLEAResult ran the email campaign using its new, automated email system—SalesForce Marketing Cloud. This meant the campaign could cater to individuals; if they did not open an email, a different one would be sent five days later, logging whether they reacted to it. The system enabled staff to be more strategic and reactive than in previous pilots.

PGE Smart Grid Test Bed recruitment was a separate activity with a co-branded version of the copy (these looked more like PGE materials than Energy Trust materials) sent directly from PGE, to comply with its privacy policy. Energy Trust only knew of approximately 70 contacts within the Smart Grid Test Bed that met the eligibility criteria. PGE expanded its recruitment for the Smart Grid Test Bed beyond Energy Trust's list of incentivized DHPs, looking at building permits for language that implied a DHP was present, but very few people were recruited that way. PGE implemented a separate email campaign and recruitment strategy to avoid sharing customer contact information with Energy Trust.

Recruitment was identified as the most significant challenge that the study faced by six of the seven staff we interviewed (the other interviewee thought the device installation was a bigger challenge than recruitment). Some specific challenges that Energy Trust and CLEAResult staff faced during recruitment were:

- Limited population of around 15,000 DHPs (eFAF was especially rare as a secondary system);
- The email on file for the DHP was not necessarily that of the person living in the home (data were less accurate the longer it had been since the install);
- High targets and a short timeline (~8 weeks) for recruitment— one staff member suggested that future studies budget more time and labor for one-on-one outreach to answer questions and help convince people to enroll;
- Time commitment to work through the intake survey (instead of a short opt-in followed by a longer survey to gather information);
- Other major events and campaigns coinciding with the study (e.g., wildfires, holidays, election season, COVID-19 pandemic); and
- Delays in getting gift cards, as these are harder to process than incentive checks (this issue could be avoided next time by ordering gift cards ahead of time).

The implementer, CLEAResult, was responsible for assigning participants to the treatment and control groups. The analysis lead set a random seed to generate group assignments for each wave of participants. Before finalizing the assignments, they took an average of the calendarized monthly electric usage data over the most recent nine months to confirm there was not a large imbalance in the electric loads between the groups.[7]

During the intake survey, all participants agreed to install the device if they were randomly assigned to the treatment group. For those within the PGE Smart Grid Test Bed, they were also asked to agree to the terms and conditions of the DHP Rewards Program, which would override their DHP temperature settings during system peak events in exchange for incentives. Unfortunately, there were many instances where participants changed their mind about the program after receiving the device.

After the initial recruitment stage, CLEAResult maintained communication with the pilot participants. This was planned early on to get ahead of questions and issues that might arise from customers navigating a new technology. CLEAResult designed emails for both treatment and control groups, reminding them that they were in the study. The treatment emails had a one in four open rate, which is very good for this type of campaign and implies that people wanted to learn more about the device or that they were facing issues with the device and were looking for answers.

Customer Support

The smart thermostat vendor's typical customer has multiple devices, one for each DHP head, whereas the participants in this study received a single device and were asked to install it in their main living space. One of the smart thermostats needs to act as the Wi-Fi bridge for the home, requiring a wired power source (not just the battery) for the device if it is serving as the Wi-Fi bridge. An outlet near the device is necessary, while staying within line-of-sight to the IR sensor on the DHP. The smart thermostat vendor built Wi-Fi bridge circuitry into a new widget ($15-20) that was commissioned for this study to give people the freedom to plug in the bridge and then have the smart thermostat positioned elsewhere. The smart thermostat vendor's CEO said that in hindsight, they would have suggested that Energy Trust purchase two smart thermostats for each participant.

[7] A full calendar year would have been preferable; scaling the requirement back to nine months was the only way to align all the participant sites without weather normalizing the baseline energy usage. If an imbalance was found between the two groups, the analyst would change the random seed, reassign the treatment and control groups, and then compare the average load again.

Energy Trust pre-provisioned the smart thermostat vendor with a library of the existing stock of DHP units (which each have slightly different frequencies of IR signals); the smart thermostat vendor used this list to request information from the manufacturers to calibrate the devices.

Unfortunately, despite these hardware and firmware solutions addressed ahead of time, many customers still needed help with their installations.

The devices were mailed to customers, with instructions and information on who to contact for help. If it had not been for the COVID-19 pandemic, Energy Trust would have considered offering these devices as direct-install (the smart thermostat is usually installed by an HVAC tech, not self-installed). The smart thermostat vendor set up a new customer support line for installation help.

CLEAResult did not have direct access to device installation status and relied on the smart thermostat vendor to report back. There were some delays in getting this report set up, as some customers signed up for an account with the smart thermostat vendor with a different email, requiring some manual work to match orders to devices. The initial reports provided by the thermostat vendor in late 2020 showed an installation rate of around 50 percent, much lower than the 85 percent they had expected based on the installation rate of smart thermostats. In response, the smart thermostat vendor sent a troubleshooting email to customers who had not completed the installation to offer help. As many participants continued to lag with installation of their devices, CLEAResult and the smart thermostat vendor called participants to offer their support. As of December 16, 2021, 21 percent of devices were currently active, 53 percent were currently offline, and 27 percent had never attempted setup. In other words, 73 percent were installed at some point during the study, though many of these were later uninstalled.

4.1.2 Participants

Study Group

As shown in Table 8, every study group was represented in the survey respondent sample. These study groups were assigned according to their home's primary and secondary heating systems as reported during the intake survey. These classifications reflect the secondary heating systems present in the home, but not necessarily the same room(s) served by the DHP. Not all secondary systems will still be in use.

Table 8: Survey Respondents by Study Group (unweighted)

	eFAF	Zonal	Oddballs	Total
Treatment	38	108	63	**209**
Control	50	133	74	**257**
Total	**88**	**241**	**137**	**466**

The study groups do not reflect the secondary heating systems that survey respondents reported serving *the same room* as their DHP; these are the systems that would be directly impacted by a change in the smart DHP controls. Table 9 shows that many respondents reported having no other system conditioning the same rooms as their DHP, or that they had a different type of system entirely. Most commonly, respondents who were assigned to the Zonal study group reported not having any system in the same rooms as the DHP. This could be due to respondents considering their zonal heat as their primary system, but only using their DHP in rooms the zonal heat does not reach. Only 32 percent of survey respondents reported the same secondary heating system on the intake survey as on the follow-up survey, and **45 percent of respondents stated that they had no other heating system that serves the same room(s) as the DHP.** The high proportion of participants with no other heating system was surprising, as the program rules stated that the DHP must be installed in the main living space of the home, and it is unlikely that there was no previous heating source that served the main living space. It is feasible that the secondary system was decommissioned or removed after the DHP installation was complete. Another possibility is that respondents did not consider whether ductwork from a central system accesses the room that the DHP is in, which was our intent.

Table 9: Reported Secondary Heating Systems

Assigned at Intake	Reported in Survey					
	eFAF	Zonal	Oddballs	Mixed[8]	No Other System	Total
eFAF	17	9	10	6	46	**88**
Zonal	5	59	26	19	132	**241**
Oddballs	3	4	78	20	32	**137**
Total	**25**	**72**	**114**	**45**	**210**	**466**

Most respondent households were small, with 67 percent of homes reporting one or two people, 28 percent reporting three to five people, and less than 2 percent reporting six or more people living in the home. The remaining 3 percent did not respond to the question. About a third of all survey respondents had children in the home (33%), and slightly less than half of the respondents were working from home at the time of the survey (43%). About half of the homes were under 1,400 square feet in size (52%) and about a fifth were 1,400 to 1,799 square feet (22%). Larger

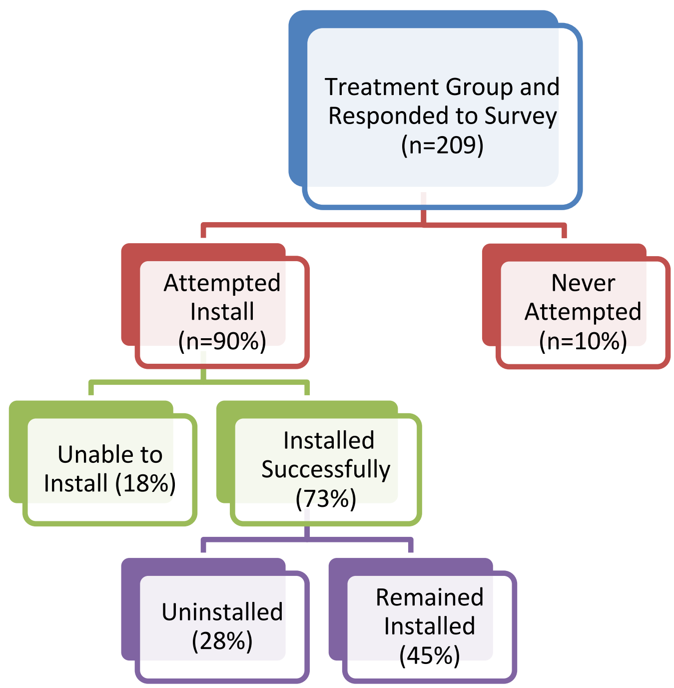
[8] If respondents reported more than one heating system in the same room as the DHP, and those heating systems were of different categories, they are categorized as "Mixed." For example, someone with a space heater and an electric furnace serving the same room as the DHP would be categorized as eFAF and Zonal, but have been reported here as Mixed.

homes were less common: 16 percent were 1,800 to 2,399 square feet, 5 percent were 2,400 to 2,999 square feet, 3 percent were 3,000 to 3,999 square feet, and less than 1 percent reported homes greater than 4,000 square feet.

Treatment Group

Of the survey respondents in the treatment group, **only about half reported that they had the thermostat installed at the time of the survey (45%, Oct-Nov 2021)** as shown in Figure 4. Many others reported that they uninstalled the thermostat after an initial successful install (28%), some reported they were never able to install the thermostat (18%), and a few reported that they never attempted to install the device at all (10%). Overall, 73 percent had the thermostat installed at some point, but 38 percent of those customers later decided to uninstall the thermostat (or 28% of everyone in the treatment group). Figure 4 illustrates the installation progress for respondents in the treatment group. Less than 1 percent installed more than one smart thermostat (n=4).

Figure 4: Treatment Group Thermostat Installation



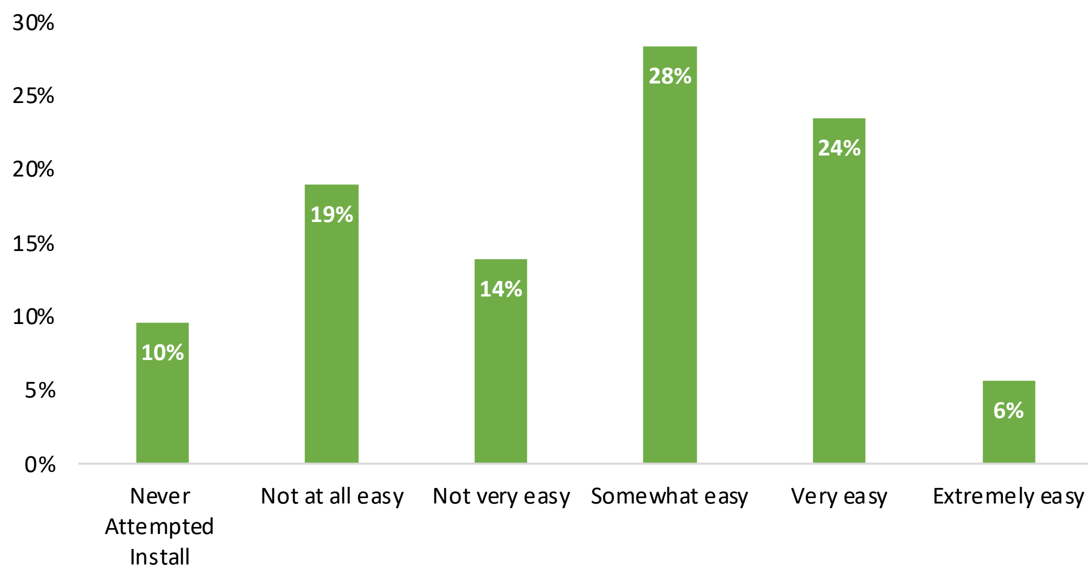
For those who initially installed the device but uninstalled it shortly after, the most common reasons were that the thermostat did not control the DHP properly (38%), there were Wi-Fi issues (30%), or they did not like using the smart thermostat app or the thermostat interface itself (13%). Most respondents who tried to install the device but were unsuccessful reported that they had issues connecting to and staying connected to Wi-Fi (40%) and that the thermostat was not working correctly (25%). Finally, the most common reason for the group of respondents that never attempted to install the device was that they no longer wished to participate in the study (59%) or that installation was too complicated (14%). Some reasons for not wanting to participate in the study included not wanting to install an app on their phone, not having the time to dedicate to installing the device, worry about demand response programs taking control of their thermostat and/or general skepticism of Wi-Fi connectivity to home devices, and a misunderstanding of the research project's intention when they first signed up.

The smart thermostat vendor's CEO felt that the study design was partly at fault for the low installation rate. They believed customers need more "skin in the game" if the offering is going to require self-install. Most uninstalled units were sent to participants who did not even try an initial setup, evidenced by the fact that they never registered the unit with the smart thermostat vendor (listed as step one in the installation instructions). He theorized that the intake survey incentive motivated people to enroll even if they were not committed to installing the device. While this incentive may have motivated some of the study participants to enroll, it should not negatively impact the analysis, as the treatment group was randomly assigned, and we use a LATE adjustment to estimate savings for the device while accounting for the proportion of customers who were assigned to the treatment group but never installed the device.

Installation Issues

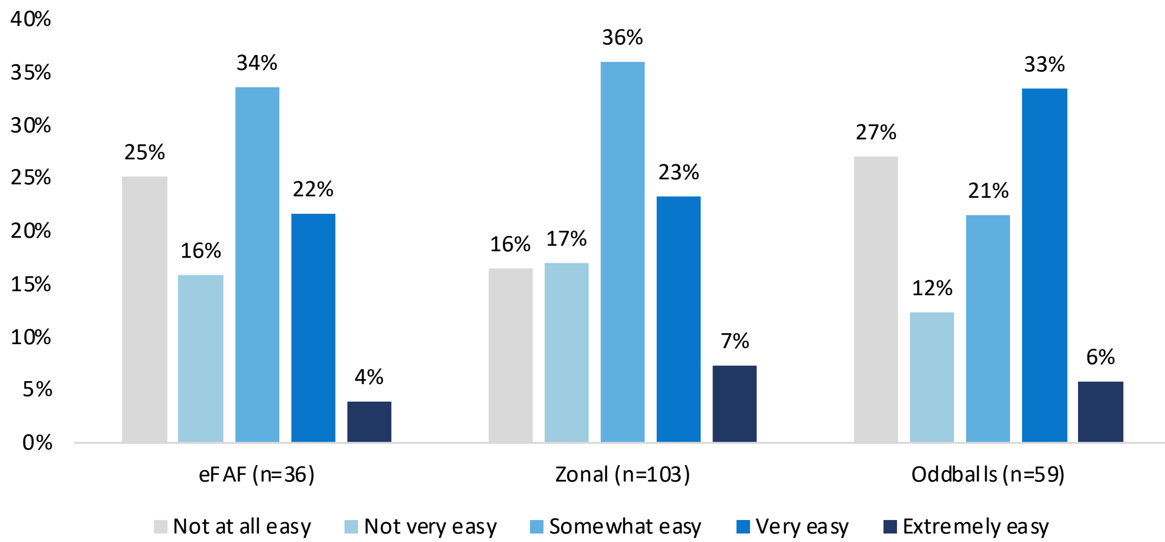
Survey respondents in the treatment group were divided on the ease of installing the smart thermostat, with more than half of all respondents (58%) reporting that the installation was at least somewhat easy and 19 percent saying it was not at all easy (Figure 5).

Figure 5: Ease of the Thermostat Installation (n=209)



Ease of installation differed slightly across study group. Oddballs more often reported that installation was either very or extremtly easy, compared to other groups, but Oddballs also reported that it was not at all easy most often as well (Figure 6).

Figure 6: Ease of the Thermostat Installation by Study Group



Of those who responded that the installation was not very or not at all easy (n=66, 32%), the most-cited reason was Wi-Fi connectivity issues (50%), followed by confusing instructions (21%), and that the smart thermostat did not control their DHP well or at all (12%). Other responses were that there were hardware issues (4%) or that their DHP model was not available as an option on the app during set up (4%).

For those who initially installed the smart thermostat (n=169), most were able to successfully install the vendor's Wi-Fi bridge device as well (93%); only a few were unsuccessful at installing the bridge or did not attempt to (4% and 3%, respectively).

Device Features

As the smart thermostat vendor's CEO told us, "When customers normally buy the product, [they] want convenience, control, auto-away, scheduling, geofencing, [to] turn off all [of the DHP] heads at once. Customers get savvy and [are] into the automation and features." The other vendor representative said "most [of our] customers are highly technical and seek us out," suggesting that their typical customer may be a little different than the general population of DHP users. Both of the vendor representatives felt it was clear from the installation rates and customer support calls that the study participants were less technically savvy and less interested in the device's features than their typical customer.

Figure 7 shows respondents' awareness of the various smart thermostat features and their frequency of use. Respondents were aware of most of the device's features, ranging from 93 percent who were aware of the scheduling feature (7% unaware) to 84 percent who were aware of temperature sensing or the option to integrate with other devices (e.g., occupancy sensors).

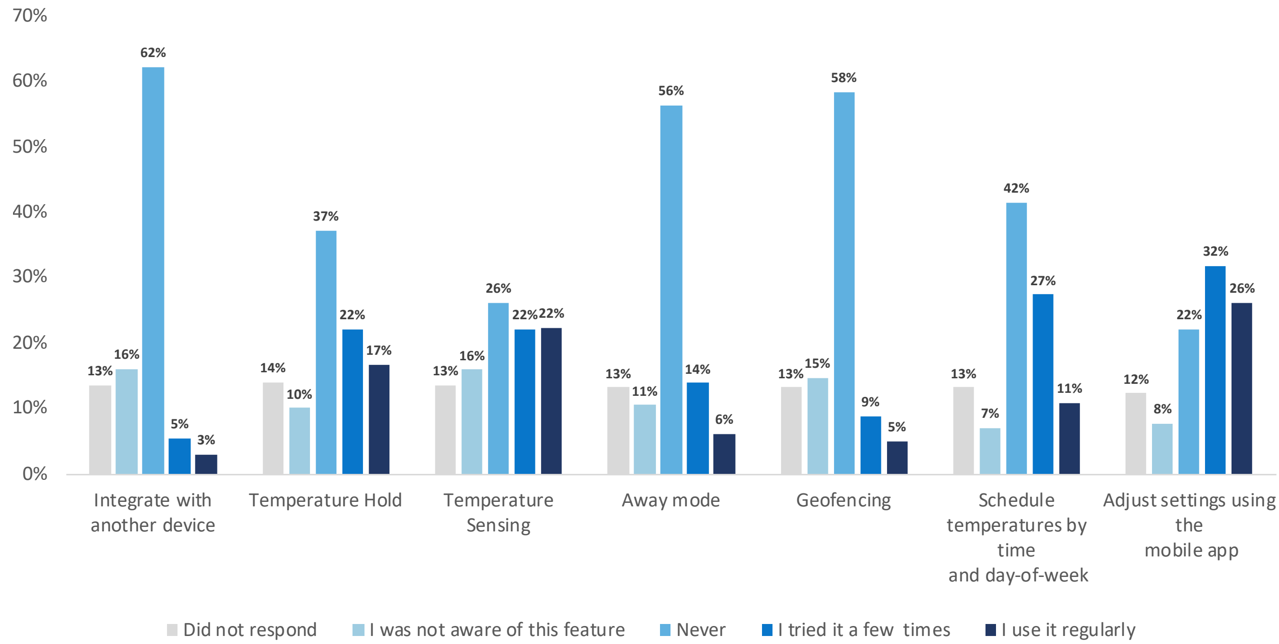
The temperature sensing feature could improve comfort and satisfaction, and unfortunately could also increase energy usage by measuring room temperature on the controls device instead of on air intake. Temperature sensing and adjusting settings via the mobile app were the most frequently used features (26% and 22% of respondents, respectively).

The smart thermostat offers an away mode that keeps the room with the device at the chosen temperature range (cycling heat on and off), and inactive mode is overridden if the temperature exceeds the pre-defined bounds (e.g., do not heat unless temperature drops below freezing). Away mode can be scheduled or activated in the mobile app.[9] Away mode could theoretically help cycle the DHP more often without going beyond the optimal temperature for maximum efficiency (versus simply turning the DHP off)—this is not a *set it and forget it* strategy but rather an option for optimization. Twenty percent of participants tried the Away feature, and 6 percent use it regularly.

The smart thermostat vendor's CEO expected most of the energy savings to come from scheduling and geofencing; this differs from Energy Trust's theory that the savings would come from increasing customer reliance on the DHP, shifting away from less efficient secondary heating systems. As we discovered in the follow-up survey, 210 of the 488 respondents (45%) have secondary heating systems in the home (as reported on intake), but have no secondary heating system serving the same room as the DHP. In these homes, an increase in reliance on the DHP may not lead to a significant reduction in the heating load for any secondary systems. In these scenarios, savings would have to come from reduced heating load in surrounding rooms, and/or the geofencing and scheduling features of the device. Only 14 percent of participants tried geofencing, and 38 percent tried scheduling. Of respondents with experience using the scheduling feature (n=93), 29 percent were not at all satisfied with the feature, 14 percent were a little satisfied, 32 percent were somewhat satisfied, and 26 percent were very or extremely satisfied.

[9] There is no occupancy sensor onboard this device, but it can theoretically be connected to remote sensors if that feature is desired.

Figure 7: Awareness of Device Features and Frequency of Use (n=209)



4.2 Success and Future Potential of DHP Controls

This section provides our assessment of the overall success and future potential of DHP controls in terms of energy efficiency, demand reduction, demand response, and customer satisfaction.

4.2.1 Energy Efficiency

We used billing analysis to estimate the energy savings attributable to the smart DHP controls (in kWh), including a deep dive into variability in seasonal savings realized by customer segment (e.g., home size). See Section 3.3.2 for details on the billing analysis methods.

Table 10 shows the sample size, number of observations, and R-squared values of the final daily regression model. An R-squared value is a statistical measure of how close the data are to the fitted regression line. The R-squared value can range from 0 to 1, where the value of 1 means the model exactly matches the data feeding into the model. The R-squared values of the daily models ranged from 0.28 to 0.43, which is lower than we would expect. We ran various models, and the R-squared values observed in our final models were on the high end of what we observed from all the daily model variations. Removing daily outliers did not improve the R-squared values or have a statistically significant impact on the coefficient estimates. Despite the low R-squared values, most of the coefficients and resulting estimates of the savings impacts were statistically significant.

Table 10: Daily Regression Model Fit

Supplemental Heating	Sample Size			N Observations	R-sq
	Total	Treatment	Control		
Zonal	320	166	154	268,159	0.430
eFAF	108	57	51	88,795	0.425
Oddballs	166	89	77	137,058	0.275

Normalized electricity savings estimates from the smart DHP controls for the post-period were calculated by combining the estimated regression coefficients with the normalized weather conditions from TMY3 and applying a local average treatment effect (LATE) adjustment. Table 11 shows the average annual baseline energy usage, the LATE adjustment, normalized energy savings, percent of savings, and the number of observations that went into the model by supplemental heating type.

A LATE adjustment was applied to account for the proportion of sites assigned to the treatment group that never completed the device installation and setup. The LATE adjustment ranged from 0.67 to 0.77, indicating that roughly a third of the treatment group did not install the controls. The middle column provides the normalized and adjusted energy savings estimate with a 90 percent confidence interval.

Customers with **eFAF exhibited statistically significant energy savings of 399 kWh during the year or around 1.1 kWh per day (or 3.42% of annual usage) attributed to the smart DHP controls, whereas the Zonal and Oddballs groups exhibited a statistically significant *increase* in energy usage of 260 and 663 kWh, respectively** (shown in red text). The eFAF equipment may have more potential for savings from the smart DHP controls, as this is an inefficient central system that would be offset by increased reliance on the DHP. The Oddball group uses non-electric secondary heating, so we would expect to see an increase in kWh from the DHP in the billing data, with any reduced reliance on secondary heating impacting bills for other fuels – there was not much difference in secondary heating for delivered fuels between the treatment and control groups (we asked about these fuels in the survey; see Figure 8 for results).

Table 11: Normalized Annual Energy Savings from the Daily Model

Supplemental Heating	Average Annual Baseline Energy Usage (kWh)	LATE Adjustment (# device / # treat)	Normalized Annual Energy Savings (kWh, after adjustment)	Percent of Energy Savings	N Observations
Zonal	12,151	0.771	-260 ± 59	-2.1%	268,159
eFAF	11,656	0.667	399 ± 100	3.4%	88,795
Oddballs	13,366	0.685	-663 ± 93	-5.0%	137,058

Energy Savings by Customer Segment

Next, we explored the distribution of various customer segments by heating type to see if there might be a sufficient sample for a meaningful comparison of estimated energy savings. Table 12 presents the distribution of customers (in both the control and treatment groups) in our sample by segment using information collected from the intake survey administered by CLEAResult. Table 13 presents the distribution of customers in our sample using information collected from the follow-up evaluation survey administered by Evergreen; though we had a 69 percent response rate, analysis of the survey respondent sample was more limited and vulnerable to response bias.

Table 12: Characteristics of Homes in Sample by Supplemental Heating Type from the Intake Survey

Characteristic	Subgroup	Count of Participants by Study Group		
		Zonal	eFAF	Oddballs
Multihead	Yes	152	36	95
	No	161	72	71
Square Footage	Under 1,400	191	62	58
	1,400 to 1,799	61	27	50
	1,800 and above	59	18	57
Occupancy	1	74	33	25
	2	138	48	85
	3+	107	27	51
Heating Zone	1	287	89	144
	2, 3	31	19	22
Use DHP	<Everyday	19	10	46
	Everyday	292	97	115

Characteristic	Subgroup	Count of Participants by Study Group		
		Zonal	eFAF	Oddballs
Has Children	Yes	90	20	31
	No	230	88	135
Adult Working From Home	Yes	153	34	59
	No	164	74	103
Open Floor Plan	Yes	169	66	81
	No	105	25	64

Table 13: Characteristics of Homes in Sample by Supplemental Heating Type from the Evaluation Survey

Characteristic	Subgroup	Count of Respondents by Study Group		
		Zonal	eFAF	Oddballs
Heating Controls	On & off only	5	3	2
	Choose output level	18	2	6
	Choose single temp	30	13	12
	Programmable	12	6	5
Home During COVID	Same or less	21	7	19
	Little more	74	20	29
	Great deal more	116	45	59
Income	< 200% federal poverty level (FPL)	73	26	33
	200-400% FPL	106	25	49
	> 400% FPL	35	24	27
Education	Postgraduate degree	57	18	27
	College graduate	74	21	38
	Some college, AA degree or trade school	57	28	30
	High school graduate	16	5	12
Secondary Heating System in the Same Room as the	eFAF	Total = 19		
	Mixed	Total = 37		
	Oddballs	Total = 95		

Characteristic	Subgroup	Count of Respondents by Study Group		
		Zonal	eFAF	Oddballs
DHP (survey self-report)	Zonal	Total = 62		
	No other system	Total = 185		

We assessed that there may be a sufficient sample size to make a meaningful comparison of savings across the following customer segments: single versus multi-head systems, home size, heating zone, daily use of the DHP, homes that have children, homes with an adult working from home (WFH), income level, occupancy, floor plan, and amount of time spent at home during the COVID-19 pandemic.

Table 14 provides the normalized energy savings by supplemental heating type and selected customer segment. We omitted customer segments with fewer than 30 customers, as the sample is likely too small to draw meaningful conclusions from. We have shaded cells where the energy savings estimates differ significantly from the overall estimate. The segmentation analysis revealed some important differences across customers and a surprising lack of differences in other areas.

Important differences:

- eFAFs and Oddballs showed more energy savings in homes that were likely to be **occupied during the day** (adults working from home and children in the home), especially during the COVID-19 pandemic.
    - Homes that had at least one adult working from home showed more energy savings when compared to the homes where no adults were working from home, for the eFAF and Oddball heating type (results are opposite for Zonal).
    - Homes with children also showed more energy savings when compared to the homes where no children lived, for the Oddball and Zonal heating types.

Surprising lack of significant differences:

- Homes in **Heating Zone** 1 and homes that **used the DHP every day** either did not show significant savings or were not significantly different from the total, across all three heating types.

Inconclusive:

- **Single-head versus multihead systems** showed mixed results across the secondary heating types. Zonal results were not statistically significantly different from the overall results. For eFAF, single-head systems saved energy while multihead systems increased usage. For

Oddballs, multihead systems were one of the two segments that showed energy savings for that group.

- The **size of the home** had a varied impact on savings across the three types of supplemental heating.
    - For Oddballs, larger homes (those greater than 1,800 sq ft) showed some savings, while smaller homes (less than 1,800 sq ft) showed an increase in usage.
    - For eFAF, the smallest homes (less than 1,400 sq ft) showed a significantly higher amount of savings when compared to the overall eFAF segment.
    - For Zonal, the results did not follow a trend by house size. The largest homes (greater than 1,800 sq ft) showed some savings, but the small and mid-sized homes (less than 1,800 sq ft) showed an increase in usage. The mid-sized homes (between 1,400 and 1,800 sq ft) performed the worst.
- **Zonal** showed an increase in usage across every customer segment, aside from homes with children; however, those results were insignificant.
- Unlike the other groups, Zonal had better results (smaller increases in usage) for homes <u>without</u> at least one adult **working from home**. Either Zonal homes are different than eFAF and Oddballs, or the reason that the others showed better savings with adults working from home was due to a correlated characteristic and was not the reason that the controls were performing better.
- The **floor plan** type had mixed results between the supplemental heating types.
    - For the two heating types where the overall usage increased (Zonal and Oddballs), not having an open floor plan showed an insignificant amount of savings, and an open floor plan showed a significant increase in usage.
    - For eFAF (where the overall models showed some savings), the open floor plan showed a significantly higher amount of savings when compared to the overall eFAF segment.
- As part of the customer survey, respondents were asked about their **income level**. Zonal and Oddball customers who reported the lowest income level (below 200 percent of the federal poverty line [FPL]) showed some savings while Zonal and Oddball customers who reported an income level above 200 percent of FPL increased their usage.
- For eFAF, the amount of savings increased as the **home occupancy** increased. This relationship was inconsistent for Zonal and Oddball.

Table 14: Normalized Annual Energy Savings of Smart DHP Controls by Subgroup

Category	Sub-group	Zonal Norm Annual Energy Savings (kWh, after LATE adj)	n	eFAF Norm Annual Energy Savings (kWh, after LATE adj)	n	Oddballs Norm Annual Energy Savings (kWh, after LATE adj)	n
Overall		-260 ± 59	320	399 ± 100	108	-663 ± 93	166
Multihead	Yes	-306 ± 86	152	-1,149 ± 198	36	547 ± 124	95
	No	-378 ± 82	161	1,103 ± 112	72	-2,354 ± 138	71
Square Footage	<1,400	-202 ± 67	191	813 ± 115	62	-2,023 ± 143	58
	1,400-1,799	-896 ± 126	61		27	-619 ± 172	50
	1,800+	368 ± 181	59		18	350 ± 176	57
Heat Zone	1	-232 ± 62	287	326 ± 112	89	-704 ± 99	144
DHP Use	Everyday	-372 ± 61	292	440 ± 108	97	-497 ± 113	115
Has Children	Yes	72 ± 116	90		20	-231 ± 219	31
	No	-409 ± 69	230	178 ± 105	88	-802 ± 102	135
Adult WFH	Yes	-695 ± 86	153	687 ± 169	34	711 ± 157	59
	No	-29 ± 82	164	240 ± 123	74	-1,470 ± 120	103
Income	< 200% FPL	305 ± 165	73		26	230 ± 190	33
	200-400% FPL	-409 ± 119	106		25	-383 ± 222	49
	> 400% FPL	-735 ± 98	35		24		27
Occupancy	1	-27 ± 98	74	25 ± 170	33		25
	2	-748 ± 90	138	308 ± 133	48	-1,266 ± 126	85
	3+	436 ± 112	107		27	-872 ± 181	51
Floor Plan	Open	-464 ± 81	169	960 ± 132	66	-1,301 ± 161	81
	Not-Open	78 ± 103	105		25	-133 ± 159	64
Home During COVID	Great deal more	-368 ± 96	116	70 ± 152	45	-1,613 ± 222	59
	Little more	-552 ± 106	74		20		29
	Same or less		21		7		19

* We omitted customer segments with fewer than 30 customers, as the sample is likely too small to draw meaningful conclusions from.

Table 15 provides the normalized energy savings by supplemental heating type collected on the intake survey compared to the supplemental heating type collected in the follow-up survey. The intake survey grouped customers into supplemental heating type bins based on the secondary heating type ***in the home***, whereas the follow-up survey asked about the supplemental heating type for ***the room(s) served*** by the DHP. The follow-up survey found that a large group of these homes did not have any supplemental heating for the room served by the DHP (46%, or 185 out of 398). This comparison shows that the trend in savings is largely unchanged; the only group with energy savings are those with eFAF, with 399 kWh in savings among participants with an eFAF in their home (intake survey) and 1,121 kWh among the subset whose eFAF serves the same room as the DHP (Evergreen survey); however, this second estimate was based on a small sample of only 19 sites. As expected, homes with "No Other" supplemental heating group did not show any significant savings from the DHP; fortunately, this group did not *increase* their overall energy usage after installing the smart DHP controls either.

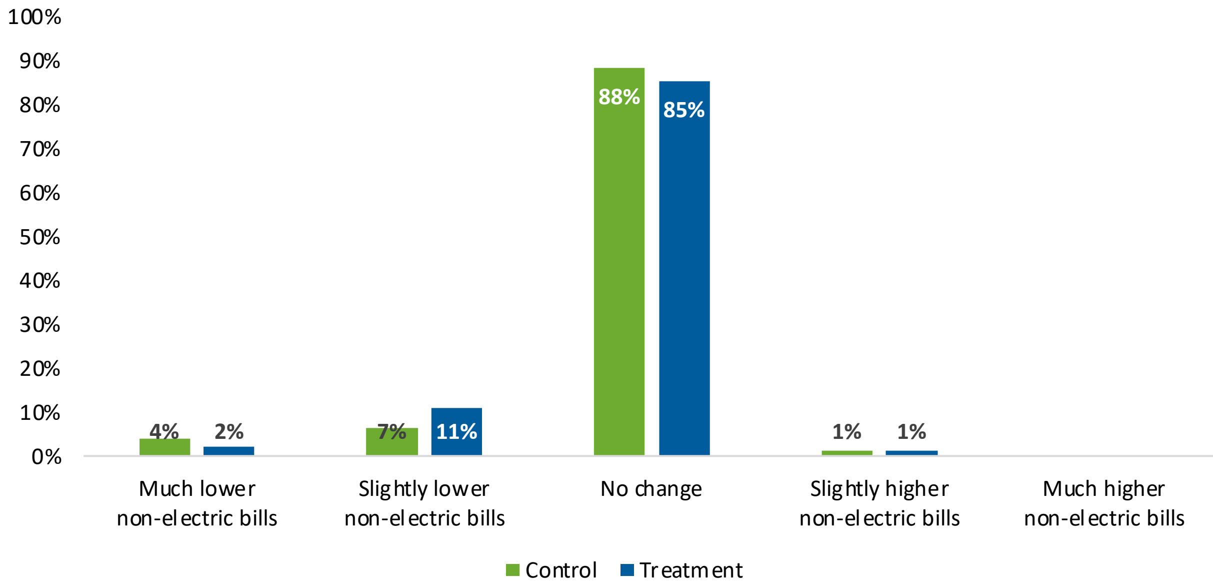
Table 14: Normalized Annual Energy Savings of Smart DHP Controls by Supplemental Heat Type

Supplemental Heating	Survey	Normalized Annual Energy Savings (kWh, after LATE adj)	n
Zonal	Intake	-260 ± 59	320
	Evergreen	-940 ± 124	62
eFAF	Intake	399 ± 100	108
	Evergreen	1,121 ± 223*	19
Oddball	Intake	-663 ± 93	166
	Evergreen	-877 ± 126	95
Mixed	Evergreen	-190 ± 186	37
No Other	Evergreen	-40 ± 75	185

* This savings estimate may not be reliable because it is based on only 19 sites.

Of the survey respondents who reported using non-electric heating systems in the same room as the DHP, most reported no change in their non-electric energy bills. As shown in Figure 8, most responded that their non-electric energy bills did not change, while some (13% in the treatment group and 11% in the control group) self-reported that their non-electric bills were much lower or slightly lower since 2020. Only a few reported slightly higher non-electric energy bills (1% of the treatment and control groups). There were no statistically significant differences between the treatment and control groups.

Figure 8: Changes in Non-Electric Energy Bills Since 2020 (n=139)



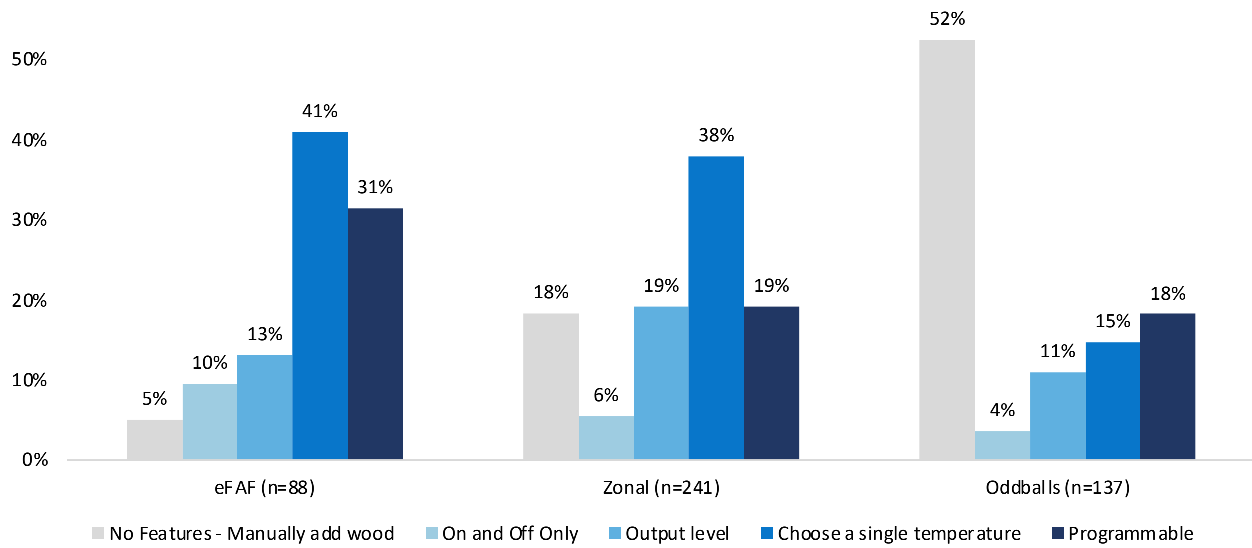
Based on survey self-reported usage, many respondents in both the treatment and control groups reported using their DHP the same or more since 2020 (Table 15). Unfortunately, the increased or sustained usage of the DHP (which is expected in the treatment group) does not appear to have translated into less usage of other heating or cooling systems. Those in the treatment group were more likely to use their other heating or cooling systems more often than those in the control group since 2020 (11% of the treatment group use their other **heating** systems more compared to only 4% of the control group; 27% of the treatment group uses their other **cooling** systems more compared to only 17% of the control group). This increase in heating and cooling within the treatment groups aligns with the billing analysis results for Zonal and Oddball, which found an increase in energy usage during the post-installation period (of treatment above and beyond the natural change observed in the control group).

Table 15: Change in HVAC Usage Since 2020

System	Assignment	Do Not Use	Use It Less	Use It the Same	Use It More
DHP (n=463)	Treatment	5%	5%	72%	18%
	Control		2%	77%	21%
Other Heating Systems (n=260)	Treatment	8%	26%	55%	11%
	Control	14%	25%	58%	4%
Other Cooling Systems (n=151)	Treatment	8%	16%	48%	27%
	Control	8%	9%	67%	17%

Figure 9 illustrates the type of controls attached to these secondary heating systems. **Households with eFAFs most often had programmable controls** (31%) when compared to Zonal and Oddballs (19% and 18%), and therefore would have automatically adjusted to changes in the room temperature caused by the DHP. As eFAFs are often central systems, they will not necessarily adjust the heat output for the whole home if the DHP only serves a portion of the space; the DHP will influence the temperature of the entire home to some degree, with the greatest impact if the DHP is operating in the same room as the eFAF thermostat. Fortunately, the research project rules stipulated that the participants install the DHP controls in the main living space, and thermostats for central systems are typically installed in the main living space.

Figure 9: Control Features by Study Group



4.2.2 Timing of Savings by Season, Hour, and Day

This section provides our estimates for the average impact of the smart DHP controls by hour-of-day, day-type, season, and the utility-defined peak hours, as well as a savings shape for the typical year (i.e., normalized calendar and weather conditions).

Table 16 shows the sample size, number of observations, and R-squared values of the final hourly regression models. The R-squared values of the hourly models ranged from 0.14 to 0.17, lower than the daily models. We tested inclusion of additional variables and interaction terms but saw no additional improvement in the explanatory power. Most of the coefficients were statistically significant or near the cutoff, indicating that we were able to extract a signal for the key impacts that we were trying to measure amidst the noise in the data.

Table 16: Hourly Regression Model Fit

Supplemental Heating	Sample Size			N Observations	R-sq
	Total	Treatment	Control		
Zonal	320	166	154	6,465,300	0.17
eFAF	108	57	51	2,146,249	0.15
Oddballs	166	89	77	3,310,377	0.14

Figure 10 shows normalized and adjusted hourly energy savings estimates with a 90 percent confidence interval by study group. The energy savings estimates from the daily model show significant energy savings for eFAF and negative savings (i.e., an increase in energy usage) for Oddballs and Zonal. The hourly model is consistent with the findings at the daily level and provides additional information into how these changes are distributed across hours of the day. Most of the savings for eFAF in the middle of the day between 8 a.m. and 5 p.m. (hour 8-17). They had some small increases in energy usage in the early morning hours and late evening hours, but these were not statistically significant. Oddballs had large and statistically significant increases in energy usage from midnight until noon, but some of these were offset by savings later at night from 8 p.m. to 9 p.m. Zonal had a smaller spike in energy usage from 6 a.m. to 10 a.m., but this was not offset by significant savings later in the day; instead, they were exacerbated by more small increases in energy using during the afternoon and evening hours from 3 p.m. until 9 p.m.

Figure 10: Estimated Annual Hourly Energy Savings

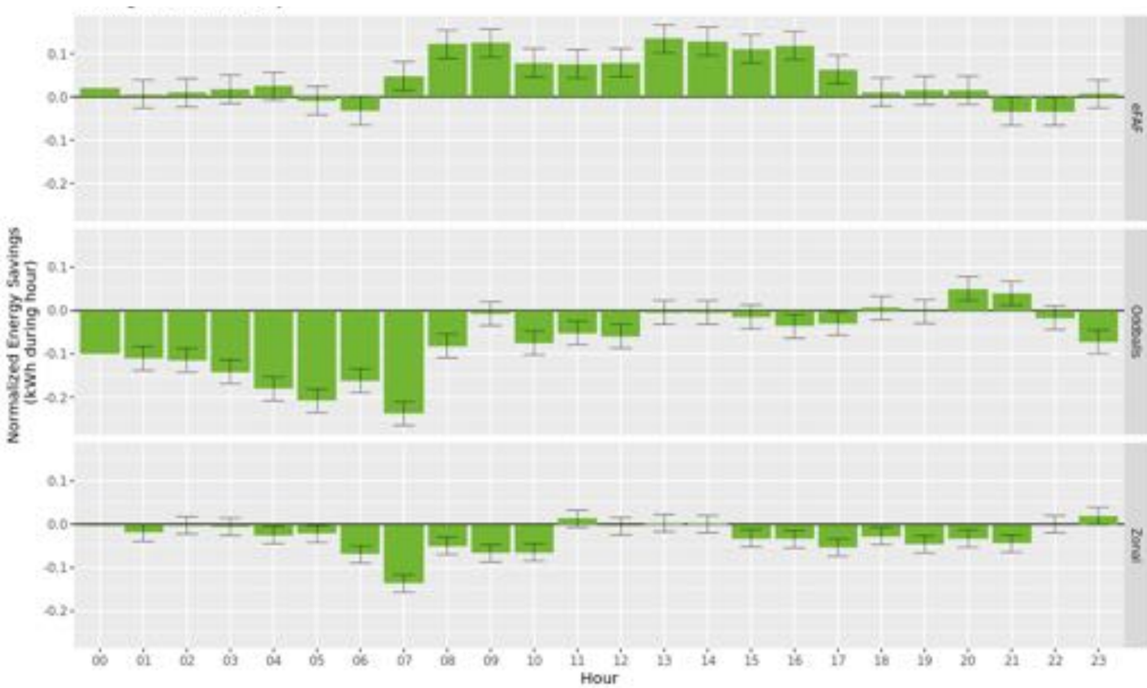
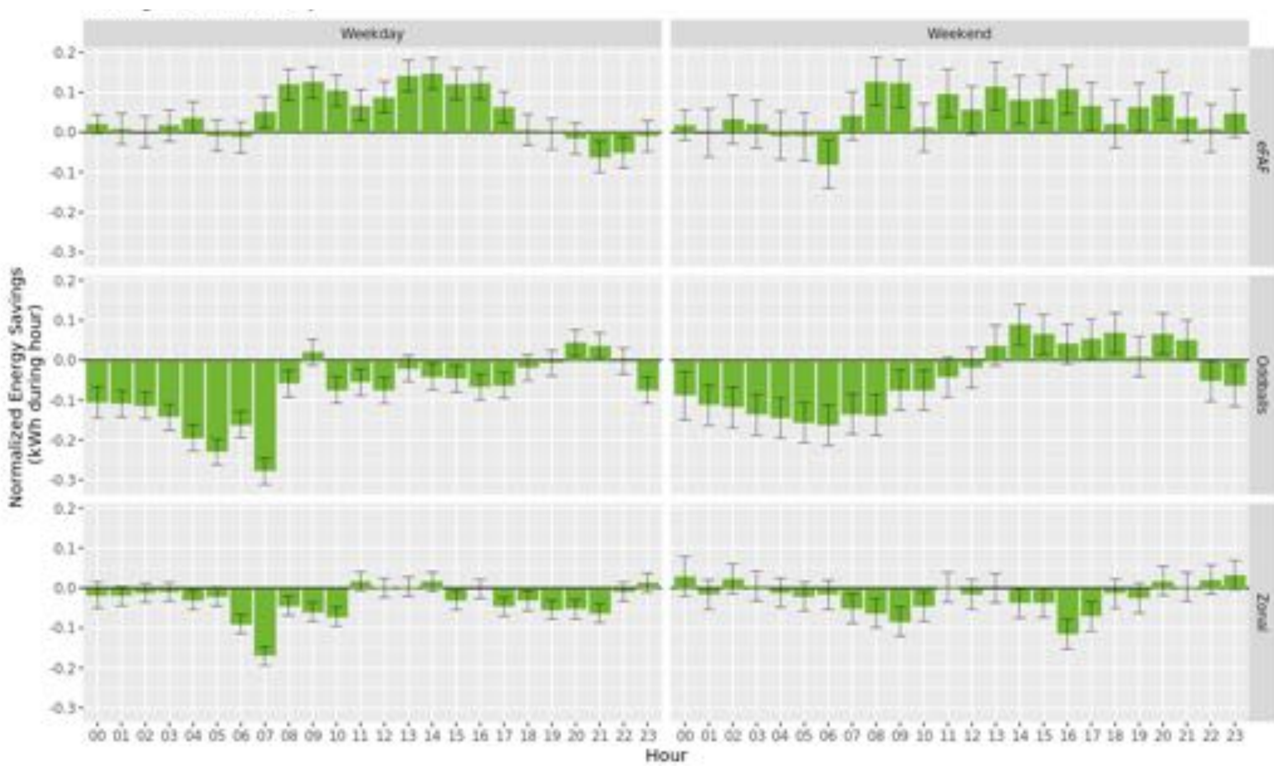


Figure 11 shows these same normalized and adjusted hourly energy savings estimates split out by day type. For both Oddballs and Zonal, the morning impacts of the smart DHP controls were more extreme on weekdays than on weekends. The increases in energy usage exhibited by Oddballs occur from 11 p.m. to 8 a.m. on weekdays (peaking at 7 a.m.), whereas energy usage increases from midnight to 10 a.m. on weekends; this seems reasonable, as occupants often have more varied schedules on weekends.

Figure 11: Annual Estimated Hourly Energy Savings by Day Type



A measure that does not provide statistically significant energy savings for the average day may still be worthwhile if it can produce savings during utility peak hours, when energy costs the most to generate. Figure 12 shows these same normalized and adjusted hourly energy savings estimates for weekdays, split out by season (summer: June-August, winter: December-February).

PGE's summer peak period is depicted with a red shaded area from 3 p.m. to 8 p.m. and Pacific Power's summer peak is depicted with a blue shaded area from 5 p.m. to 9 p.m. Customers with eFAF had significant energy savings during the first two hours of the PGE summer peak from 3 p.m. to 5 p.m., but no significant changes in energy usage during Pacific Power's peak hours of 5 p.m. to 9 p.m. Oddballs had significant savings during the last two hours of Pacific Power's peak, 8 p.m. and 9 p.m. Unfortunately, customers with Zonal heat show small yet statistically significant increases in energy usage during the summer peak for both PGE and Pacific Power.

PGE and Pacific Power's winter peak period is depicted with a purple shaded area on weekdays from 6 a.m. to 10 a.m. and from 5 p.m. to 8 p.m. Unfortunately, Oddballs and Zonal homes both exhibited significant increases in energy usage during the morning and evening peaks on weekdays in winter (December-February). Customers with eFAF systems did have significant savings during most of the morning peak, but had just one hour of significant savings in the evening at 5 p.m.

Figure 12: Estimated Hourly Energy Savings on Weekdays during Peak-Hours by Season

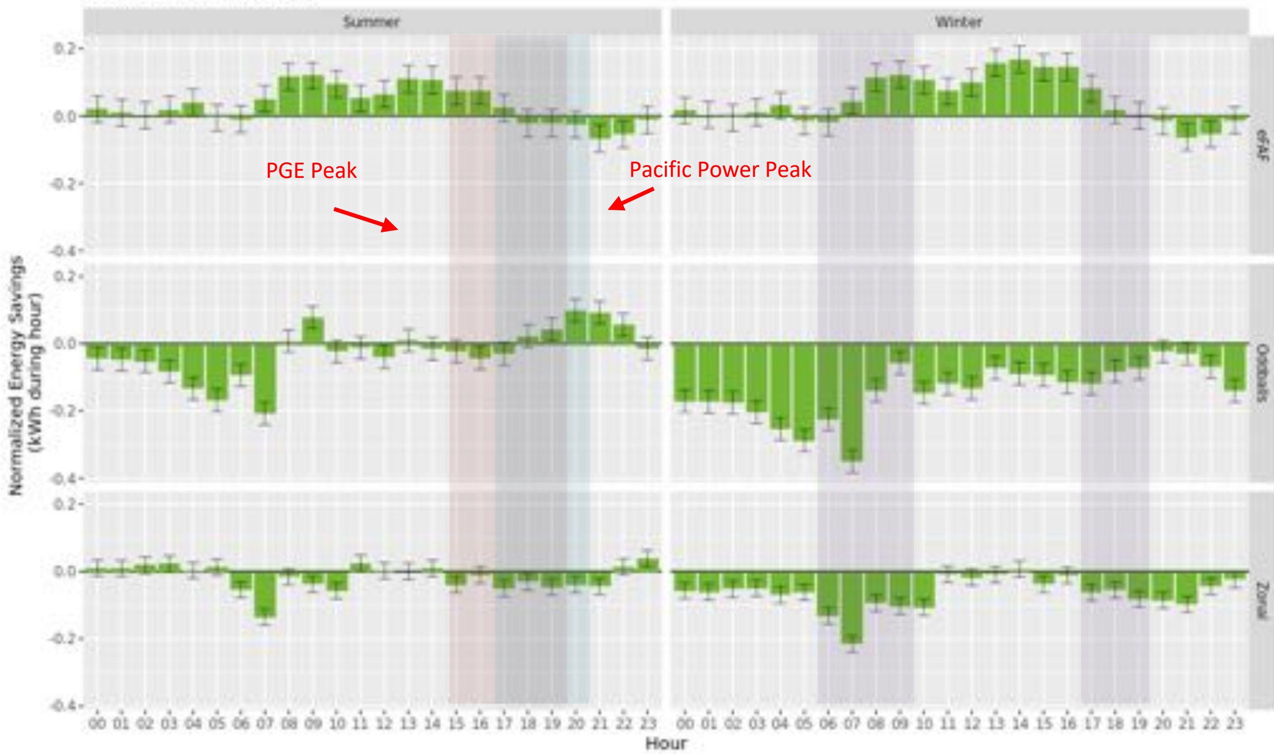


Table 17 provides an average of these hourly kWh savings on weekdays across the utility peak hours by study group. The positive savings exhibited by Oddballs towards the end of the summer peak period for both utilities were not enough to offset the negatives in the first few hours of the peak period.

Table 17: Average Hourly kWh Savings during Utility Peak Hours by Season

Study Group	Summer		Winter
	PGE	Pacific Power	PGE & Pacific Power
Zonal	-0.18	-0.17	-0.75
eFAF	0.13	0.13	0.36
Oddballs	-0.03	-0.04	-1.04

Figure 13 shows the comparable normalized and adjusted hourly energy savings estimates for weekends, split out by season (summer: June-August, winter: December-February).

Figure 13: Estimated Hourly Energy Savings on Weekends by Season

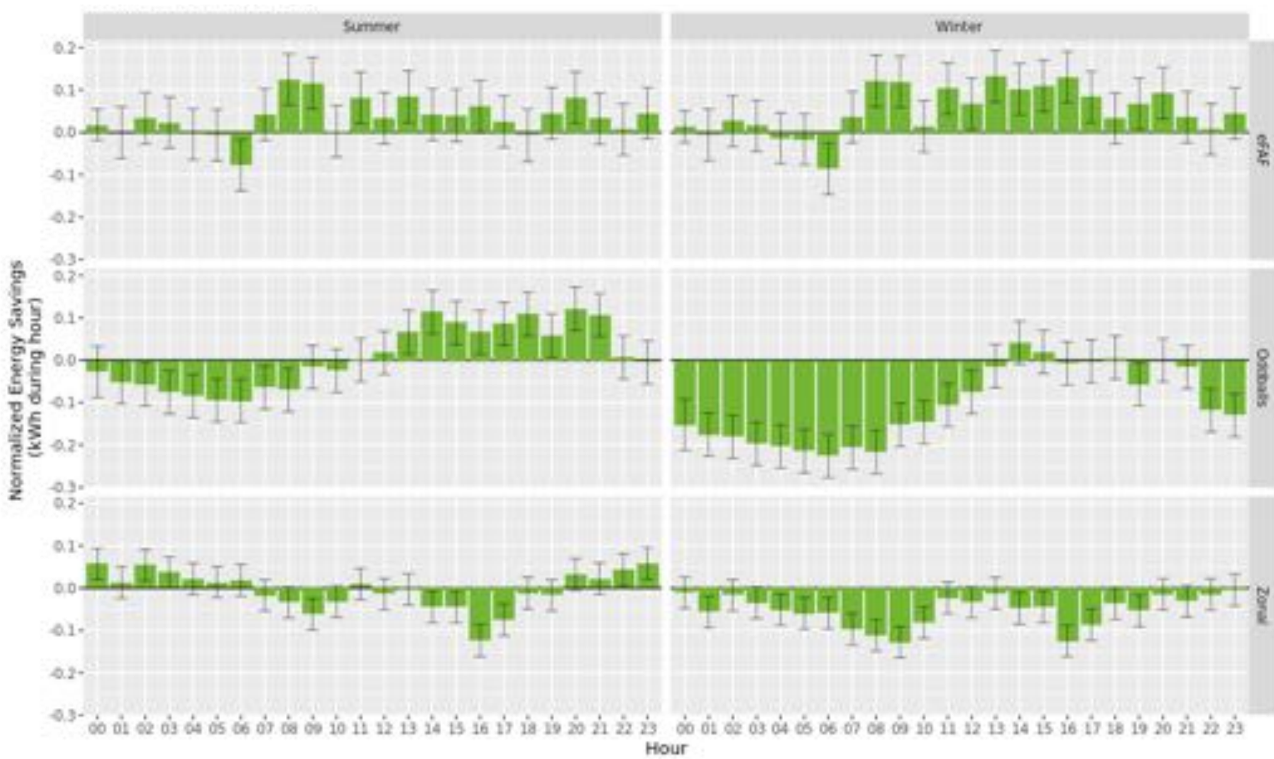
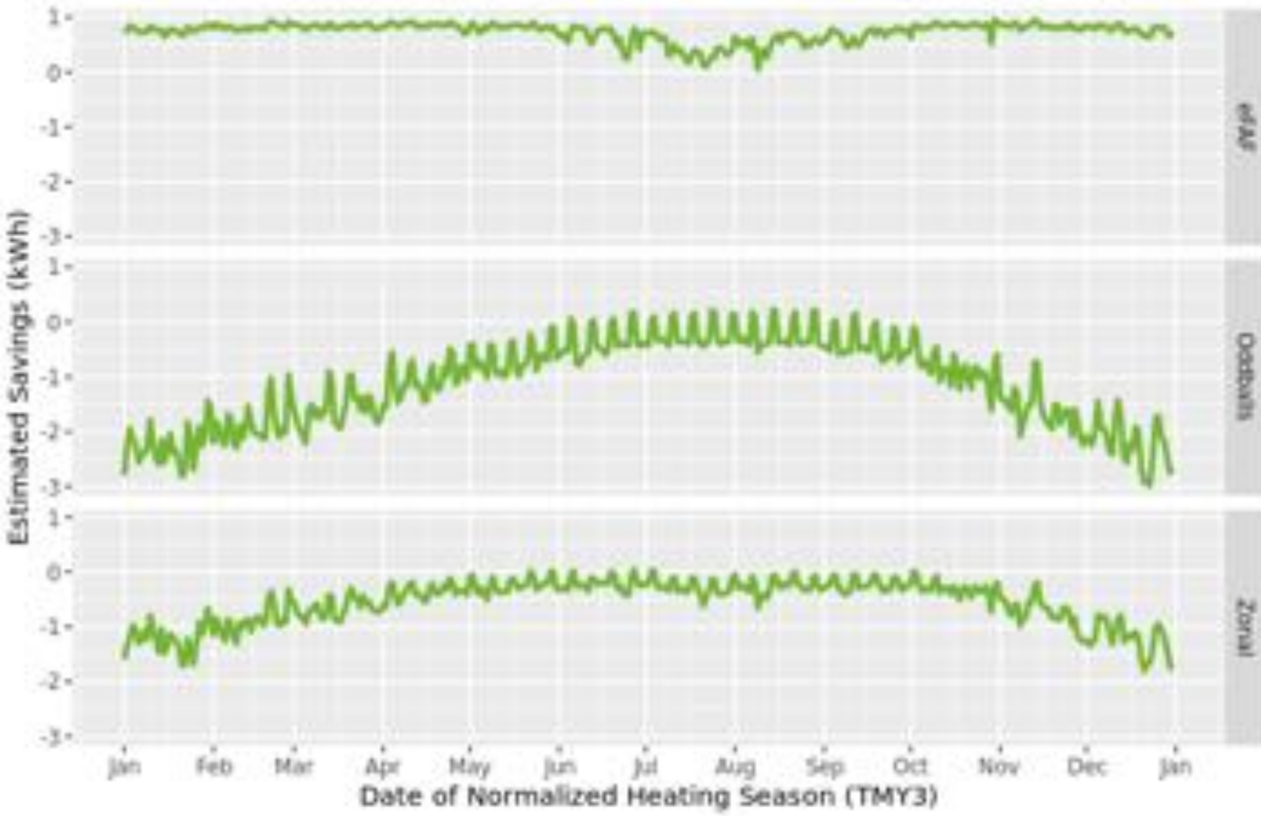


Figure 14 shows the daily savings shape for a normalized weather year (TMY3) for each study group, which represents the daily sum of hourly savings estimates. The eFAF savings are relatively stable, fluctuating between 0.05 and 0.95 kWh per day over the course of the year. There is a prominent dip in the min, max, and average daily savings during the summer months of July and August, with a more moderate dip in the surrounding months of June and September. Oddballs have large *increases* in daily energy usage above 2.8 kWh during the peak heating months of December and January, with much more modest *increases* in the middle of the year of around 0.22 kWh per day (during the cooling season), with the small positive savings between 0.14 and 0.22 kWh on a handful of days between June and September. Zonal follows a similar, though less prominent pattern, with a maximum daily *increase* in energy usage of 1.7 kWh in December and January and more modest *increases* in the middle of the year around 0.21 kWh per day, with small positive savings between 0.02 and 0.04 kWh on a handful of days between May and July.

Figure 14: Estimated 365 Savings Shape



4.2.3 Demand Reduction

Figure 15 provides the hourly energy savings estimates on the coldest weekday of the heating season in a normalized weather year (TMY3), as an estimate of the potential demand savings offered by DHP controls. PGE and Pacific Power's winter peak period is depicted with a purple shaded area from 6 a.m. to 10 a.m. and from 5 p.m. to 8 p.m. The direction of savings during the morning peak period on the coldest day of the year are like the average weekday, with eFAF exhibiting demand savings during the morning peak (0.09 kW at 8 a.m. and 9 a.m.) while Oddballs and Zonal increased their demand (with a max increase of 0.39 kW at 7 a.m. and 0.20 kW at 9 a.m.). However, the savings on this extremely cold day are much more modest, and the increases in energy usage are even more pronounced. Only eFAF exhibited some demand reductions of 0.06 kW at 5 p.m. during the evening peak, but these were not statistically significant. Based on the coldest day of the year, it appears that DHP controls are unlikely to deliver winter peak demand savings, at least without a formal demand response program (like the one being implemented in the summer for the smart DHP controls installed in the PGE Test Bed).

Figure 15: Estimated Peak Demand Savings During the Coldest Day of the Heating Season

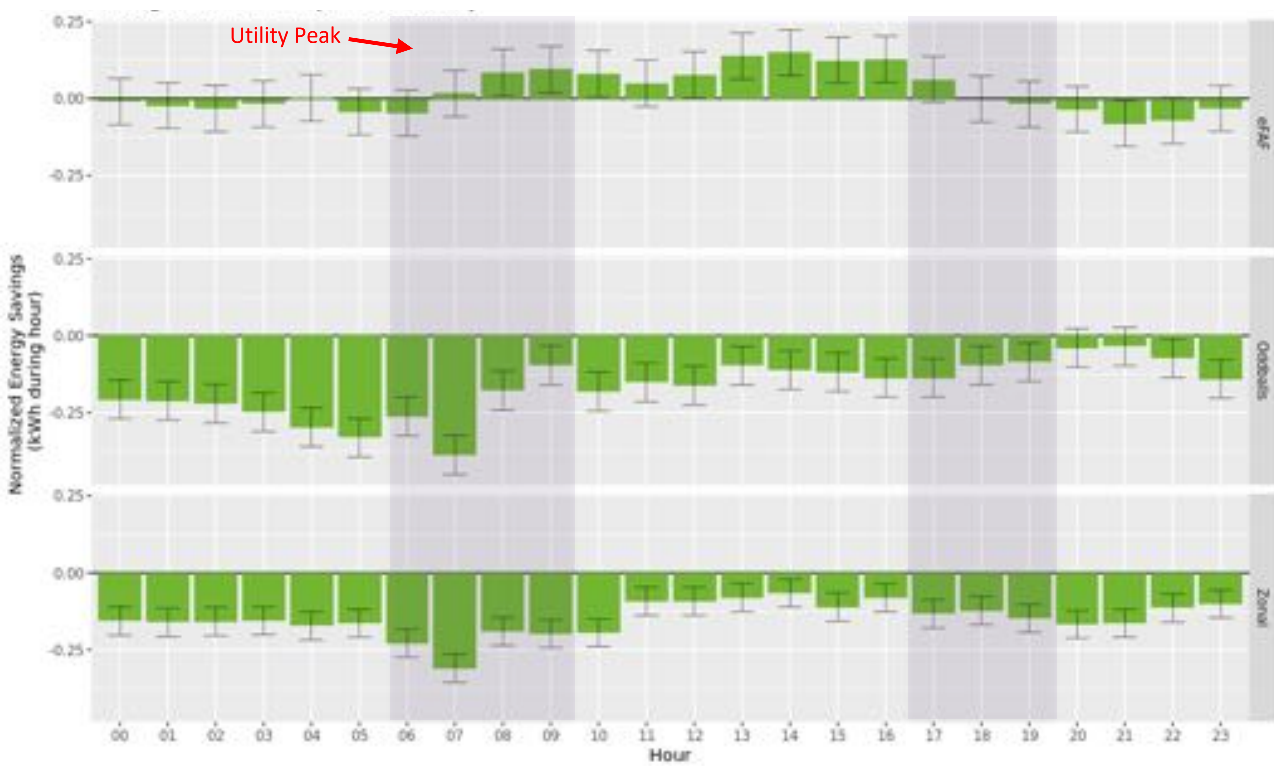


Figure 16 provides similar hourly energy savings estimates for the hottest weekday of the cooling season in a normalized weather year (TMY3), as an estimate of the potential demand savings offered by smart DHP controls. PGE's summer peak period is depicted with a red shaded area from 3 p.m. to 8 p.m. and Pacific Power's summer peak is depicted with a blue shaded area from 5 p.m. to 9 p.m. All three study groups increased their energy usage during the summer peak hours on the hottest day of the year, except for Oddballs from 6 p.m. to 8 p.m., which have statistically significant savings of 0.11 kW during the last hour of Pacific Power's peak period (this is after the end of PGE's peak). Again, it appears that smart DHP controls are unlikely to deliver summer peak demand savings and may instead make summer peak worse.

Figure 16: Estimated Peak Demand Savings During the Hottest Day of the Cooling Season

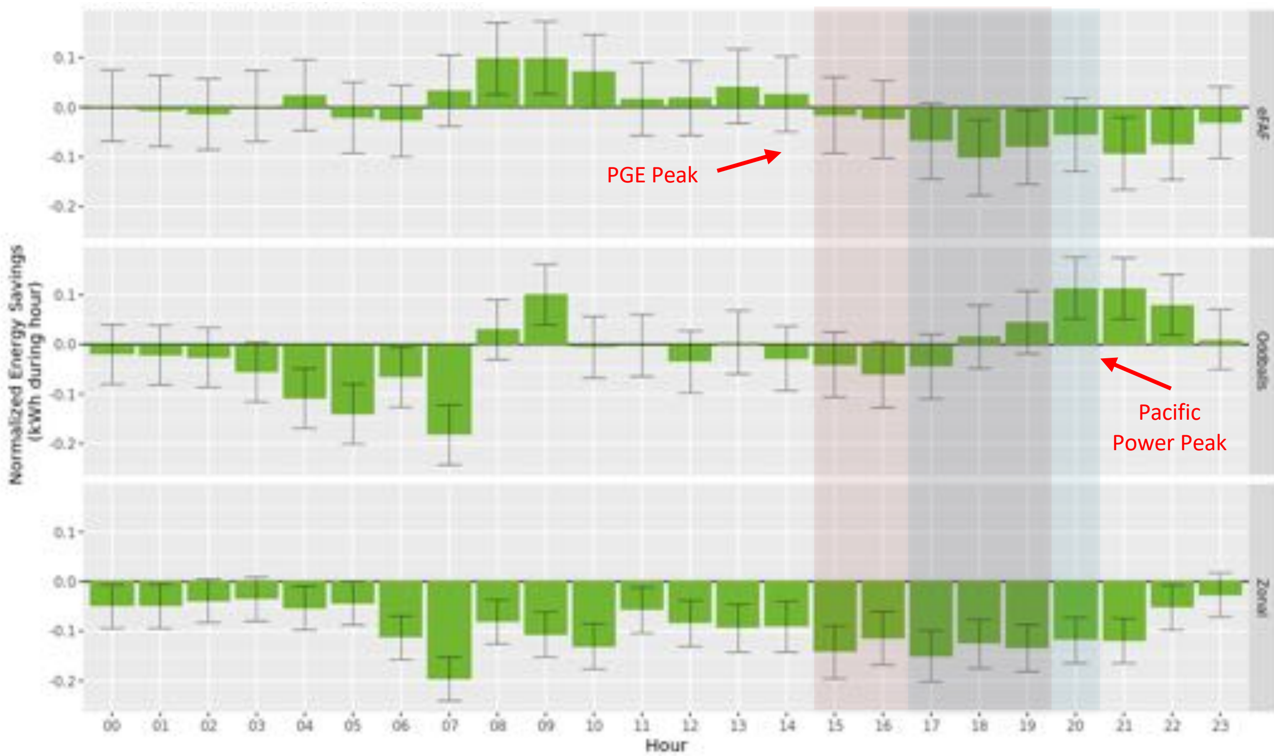


Table 18 provides the average hourly demand savings during the utility peak hours on the hottest and coldest days of the year. These smart thermostats increase load on average across all seasons and study groups except for the modest demand savings of 0.03 kW by Oddballs during Pacific Power's summer peak and eFAF during winter peak. In many instances, these devices pose a negative impact to grid stability. A demand response program may be able to shed load on event days relative to similar non-event days. However, it will be important for the program to assess whether the load shed was enough to offset the increased load incurred by these devices before motivating customers to purchase devices.[10] We provide such a comparison in the next section.

[10] If the device was purchased by the customer with no rebate, then the increased load is naturally occurring, and the program could claim event savings relative to similar non-event days. If the device is offered by the program at a discount, then they should only claim event savings in excess of the pre-thermostat baseline (as similar non-event days will have a higher demand after the thermostat is installed).

Table 18: Average Hourly Demand Savings during Peak Hours on the Hottest and Coldest Days

Study Group	Summer		Winter
	PGE	Pacific Power	PGE & Pacific Power
Zonal	-0.13 ± 0.05	-0.13 ± 0.04	-0.19 ± 0.04
eFAF	-0.06 ± 0.07	-0.08 ± 0.07	0.03 ± 0.07
Oddballs	-0.02 ± 0.06	0.03 ± 0.06	-0.18 ± 0.05

4.2.4 Demand Response

In late June 2021, PGE called the first demand response event, attempting to increase the temperature setpoint of connected devices in the Smart Grid Test Bed. PGE called the event and sent the event signal, but the smart thermostats did not appear to respond. It turned out that the dispatch worked and devices responded, but the response was not adequately logged in Virtual Peaker (the DERMs provider). This type of issue is common with new devices, as a demand response application programming interface (API) must be developed specific to the hardware that would enable fleet management and reporting. The PGE demand response test was the smart thermostat vendor's first ever demand response project, but now they have multiple demand response programs operating across the country and they are "learning quickly".

PGE and the smart thermostat vendor were both confident that the devices would continue to respond to event signals after the issue was resolved. One staff member from Energy Trust was "highly confident" that the signal would transmit from PGE to Virtual Peaker to the smart thermostat vendor to the device, but they had "no idea" if that would curb load or just shift to the backup HVAC system. One of the staff from CLEAResult theorized that summer would be better than winter—referring to their experience with the Flex pilot, for which they had 80 percent participation in demand response events—though we may see more opt-outs, with more people home during the day during the COVID-19 pandemic. The smart thermostat vendor's CEO was "very confident [in the future success of the events] because the devices are responding."

PGE commissioned a separate evaluation to assess the demand response functionality of these devices and event participation by customers in the PGE Smart Grid Test Bed. This report was submitted on April 5, 2022.[11] We have provided some high-level results from this report below.

[11] Evergreen Economics. 2022. *Evaluation of Ductless Heat Pump Controls in the PGE Smart Grid Test Bed*.

Summary of Smart Grid Test Bed Evaluation

PGE's demand response events can occur in the summer between June 1 and September 30 and in the winter between December 1 and February 28. Events can last from one to four hours. Three hours prior to a demand response event, participants are notified by text and email that an event will occur. During events, the phrase "Energy Event" is displayed on the thermostat, and the thermostat is adjusted by one to three degrees Fahrenheit to reduce energy usage with minimal impact on home comfort. Customers can choose to override an event by physically rotating the smart thermostat dial or by dragging the blue temperature slider in the smart thermostat vendor's app; a confirmation message is displayed to remind participants that adjusting the temperature would cause them to opt out of the event. Our scope for the evaluation leveraged energy consumption data to estimate the demand response event savings for all devices that responded to events in 2021 and 2022.

We found evidence of load shifting during demand response events in both event seasons, with an average hourly impact of 0.33 kW in summer and 0.27 kW in winter. When we looked at individual participants and events, the savings varied greatly, from -1.18 to 2.32 kW in summer and from -3.63 to 1.47 kW in winter. There were some consistently high and low performers within each season. These estimated savings values are based on the very small number of devices that were connected and responded to the events (n=5 to 7 devices per event).[12] We did not identify any consistent characteristics in the survey that explain why some homes save more than others. That said, our findings do suggest that the smart DHP controls are capable of load shifting.

Customers in the Smart Grid Test Bed reported fewer challenges with the installation of the thermostat. All of the PGE Smart Grid Test Bed customers who responded to the survey reported that they were able to install the thermostat (n=10 of 10), compared to 73 percent of the 209 treated customers (38% of whom later decided to uninstall the thermostat) in the larger Energy Trust study who responded to the survey. Most of the PGE Smart Grid Test Bed survey respondents (n=8 of 10) said the thermostat was extremely or very easy to install, compared to 64 percent from the Energy Trust study.

The Smart Grid Test Bed respondents were generally satisfied (providing a rating of at least 4 out of 5) with the smart thermostat (n=5 of 10) and their ductless heat pump (n=9 of 10), compared to 24-27 percent (by study group) and 43 percent in the larger Energy Trust study. Only 20 percent of Smart Grid Test Bed respondents had zero challenges with the thermostat, with delays between the app or thermostat (n=5 of 10) and the DHP being the most common challenge (n=4 of 10).

[12] The reason why these devices were no longer connected or responding to events should be investigated; see report for additional discussion.

Before recruiting additional participants, we suggested that PGE explore the following:

- **Follow up with Virtual Peaker and the smart thermostat vendor to understand why so few homes responded to each event.** Most homes participated in only two of the six events, despite having installed devices and receiving event notifications. Only 7 percent of events were overridden, according to Virtual Peaker, so we presume that the rest of the devices did not respond because they were not active during the events. Wi-Fi connection has been a persistent challenge with the smart thermostat.
- **Request additional information from the smart thermostat vendor on how the temperature setpoint is chosen.** The way that the temperature setpoint is chosen may have an impact on participant comfort during the events; while uncomfortable temperatures may lead to greater load reduction, they could also motivate customers to override the event signal and stop shedding load entirely.
- **Set up a process for identifying customers who have moved into homes with existing devices** to avoid controlling devices of customers who have not agreed to participate.
- **Consider which hour is most important for load shedding.** For instance, during the summer, the highest savings were seen during the first hour of the event, then tapered off. If 6 p.m. is the most important hour to shed load in the summer, then the event could be called at 6 p.m. instead of at 5 p.m. to maximize impacts during the preferred hour.

Synthesis of Demand Response and Peak Demand Impacts

Table 19 provides an estimate for the net impacts, comparing the load shed during events against the increased load incurred by these smart thermostats.

The demand analysis for the energy efficiency evaluation found significant differences in hourly savings on the hottest and coldest days of the year by secondary heating type. Unfortunately, we do not know the secondary heating type for Smart Grid Test Bed participants who enrolled directly through PGE. If we assume the distribution is similar to the dual participants (the 10 customers in the Smart Grid Test Bed who enrolled through Energy Trust), then we would expect the hourly impacts shown in the first two columns. The columns provide the weighted average hourly peak demand savings during the utility event hours (5 p.m. to 7 p.m.) on the hottest and coldest days of the year; these are the savings that the utility would use for grid planning. Unfortunately, every single study group had an increase in energy usage during these event hours on extreme weather days. These smart thermostats pose a negative impact to grid stability without a demand response program, on event and non-event days.

The next two columns provide the event impacts from the demand response evaluation, these were estimated as the difference between peak demand on event days and similar non-event days (with the thermostat). Hence, the thermostat impacts estimated by the efficiency evaluation will be present on the non-event days used in the demand response evaluation.

What we really want to measure is the net impact of the demand response events above and beyond the thermostat impact; this is provided in the right-hand columns. A positive net impact suggests that the load shed during demand response events is sufficient to offset the increase in energy usage caused by the thermostats. We estimate positive net impacts for all hours of the summer events and the last two hours of the winter events (all except 5 p.m.).

Table 19: Average Hourly Peak Demand Reduction during PGE Event Hours on the Hottest and Coldest Days

Study Group	Thermostat Impacts* (actual vs. baseline)		Event Impacts (event vs. similar non-event days)		Net Impacts (event vs. baseline)	
	Summer	Winter	Summer	Winter	Summer	Winter
5 p.m.	-0.12	-0.12	0.47	-0.10	0.35	-0.22
6 p.m.	-0.10	-0.11	0.33	0.33	0.24	0.23
7 p.m.	-0.09	-0.12	0.21	0.57	0.12	0.45
Overall*	**-0.10**	**-0.11**	**0.33**	**0.27**	**0.23**	**0.16**

* A weighted combination of the three study groups, representing the known group assignment of dual participants in the PGE Smart Grid Test Bed and the Energy Trust study (n=7 Zonal, 2 eFAF, and 1 Oddball). While this is not comprehensive, we do not know the secondary heating type of all Smart Grid Test Bed participants who enrolled directly through PGE.

The demand response program impacts were large enough to offset the increase in demand caused by the smart thermostats in most instances. However, it is important to remember that the event impacts were based on a very small sample of participants and event days. If the reported customer satisfaction, cost, and opt-out rates are no worse than the existing programs (i.e., compare to PGE's alternatives), PGE should consider a larger pilot to provide more reliable estimates of event savings prior to scaling the program.

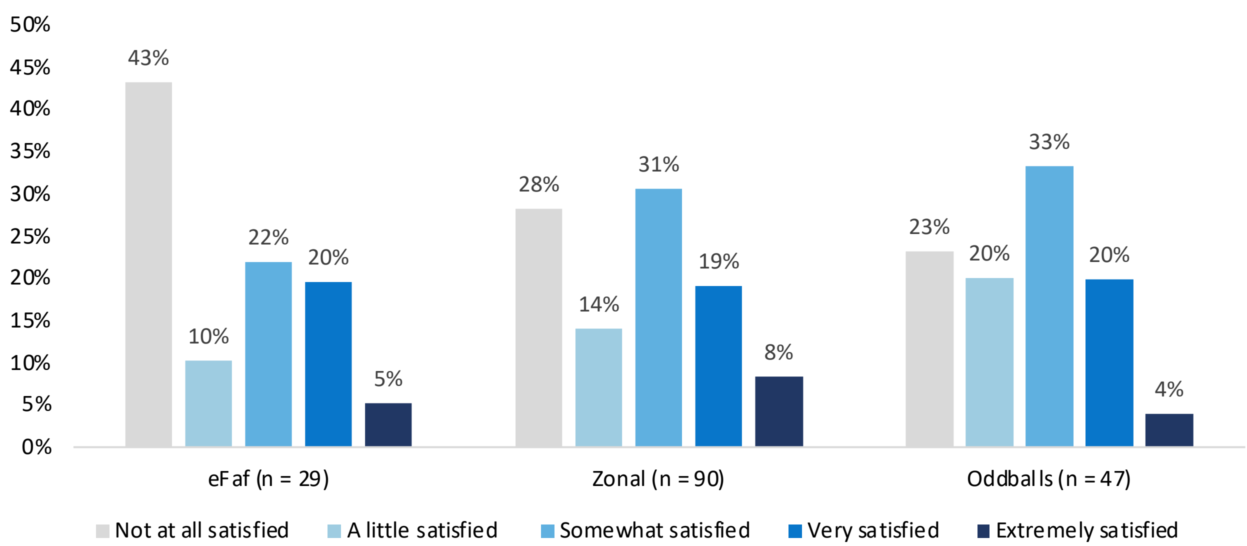
4.2.5 Satisfaction

Smart Thermostat

Energy Trust, CLEAResult, and PGE staff were hesitant to report on their level of satisfaction with the smart thermostat at the time of our interviews (i.e., after customer enrollment, prior to the heating season evaluation). Two people from Energy Trust said that they were generally satisfied, referring to impressions that it had been well received. The other four felt it was too soon to rate their satisfaction. Positive aspects of the device were the clean design and the remote app control, while negatives were the installation challenges (both in frequency and complexity). Their satisfaction with the device vendor was a bit higher, with all four people who had interacted with the smart thermostat vendor reporting being "very satisfied," "pretty satisfied" (n=2), or "satisfied so far." Some positive experiences they mentioned were the smart thermostat vendor's investment in product upgrades, order fulfillment (timelines and detail of reporting), customer support, and collaboration with CLEAResult on follow-up education materials. One person mentioned that "[the thermostat vendor] likely lost money on this project to try and improve their claims [about product usability]," seeing this as a great opportunity to market the device. All three staff who had experience sending requests to the smart thermostat vendor agreed that they were very responsive.

Participants who installed the smart thermostat were asked to rate their satisfaction with the device (Figure 17). Customer satisfaction with the device was lower than expected, with only 25 percent of eFAF, 27 percent of Zonal, and 24 percent of Oddballs very or extremely satisfied with the device. Many respondents said they were not at all satisfied with the smart thermostat device, ranging from 23 percent of Oddball participants up to 43 percent of eFAF participants being not at all satisfied.

Figure 17: Satisfaction with the Installed Smart Thermostat (Treatment Group after Install, n=166)



While the survey did not ask directly about why they were satisfied or unsatisfied, we did ask an open-ended question about what participants would change about the smart thermostat, if anything. Table 20 shows the eight common themes we found in their open-ended responses.

Table 20: Changes to the Smart Thermostat (n=116)

What would you change about the smart thermostat?	Percent of Respondents
Better temperature control	15%
Simplify instructions or improve installation help	15%
Improve the app or the device interface	12%
Better control of the DHP	11%
More sturdy construction of the thermostat	10%
Better internet capability	7%
Better options for set up location	5%
Device does not work at all	5%
Other	9%
Nothing	13%

When prompted, Energy Trust, CLEAResult, and PGE staff mentioned the following concerns about the smart thermostat:

- People are not installing the device (n=2);
- The casing for the device is plastic – Nest has saturated the market with a higher build quality (n=2);
- They may not be compatible with older DHPs and all manufacturers (n=2);
- Skepticism that the devices would be able to save energy (n=2); and
- Concerned that controlling the DHP without controlling secondary systems poses the risk that customers will curtail the DHP, leading to increased use of less efficient equipment (n=1).

Other customer complaints mentioned by Energy Trust, CLEAResult, and PGE staff during our interviews (shortly after recruitment ended, during the heating season) were:

- The device controlled the DHP in unexpected ways—turning it off and on too much or ramping up the temperature;

- Some participants mistakenly believed that Energy Trust was controlling their DHP, when it was simply the built-in automation of the device (n~3);[13] and
- The onboard thermometer was giving an inaccurate reading. The smart thermostat vendor explained that this can happen if the device overcorrects for the impact of heat generated by the device's power supply.

We asked respondents who had installed the smart thermostat whether they had any of the following challenges with the device, as shown in Table 21. **Only 18 percent of respondents reported no problems.** Not operating the heat pump properly, not maintaining a comfortable temperature, and delay between using the app and the DHP responding were the most common reported challenges (27 percent, 24 percent, and 24 percent, respectively). With respect to the delay between the DHP and changes made within the app (24% identified this as a challenge) or on the physical device (18%), the smart thermostat vendor's CEO explained that there is a three-second latency period before changes are reflected from physical intervention and a 24-seccond delay if the change is made in the app and the device is running off the battery. Customers can choose to alter the refresh rates of the device if they would prefer faster reaction times, but this comes at the expense of the battery life.

Table 21: Challenges with the Smart Thermostat after Install (n=191)

Challenge	Percent of Respondents
Not operating the heat pump properly	27%
Not maintaining a comfortable temperature	24%
Delay between using the app and the DHP responding	24%
Delay between using the thermostat and the DHP responding	18%
Difficulty using the mobile app	16%
Difficulty with the thermostat's user interface (physical device)	15%
Batteries running out	5%
Other	32%
None	18%

[13] One of the vendors gave an example of a customer who wrote in that they were upset that the thermostat vendor was controlling their thermostat. It turned out that he had accidentally turned on the temperature sensing feature.

Approximately a third of respondents said they had other challenges and were asked to elaborate on these challenges. Most written responses mentioned challenges staying connected to Wi-Fi (n=11). A few mentioned that the installation instructions were generally confusing (n=7). Other responses included that the smart thermostat did not work at all (n=2), the install location was challenging (n=2), there were scheduling issues (n=2), the unit was always on (n=2), and that they needed help with settings, other features, or the remote (n=3).

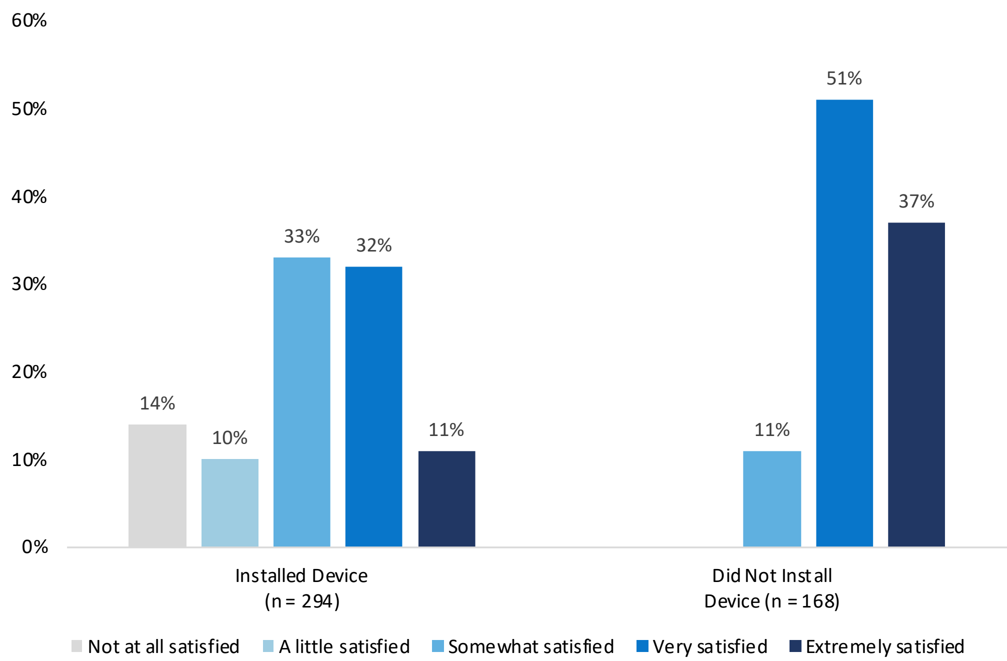
In response to the customer complaints about Wi-Fi connection, the smart thermostat vendor provided the following explanations for why these devices go offline:

- Organic disruptions in Wi-Fi connections – Wi-Fi is required to set up the device, but it is possible to control the device if the connection drops;
- Customers change the W-Fi password but forget to update the thermostat; they may not realize that it is offline because the display is unchanged; and
- Energy is only required to change the display (similar to a Kindle e-reader), which makes the batteries last a long time but also means that it is not obvious when the batteries die.

Ductless Heat Pump

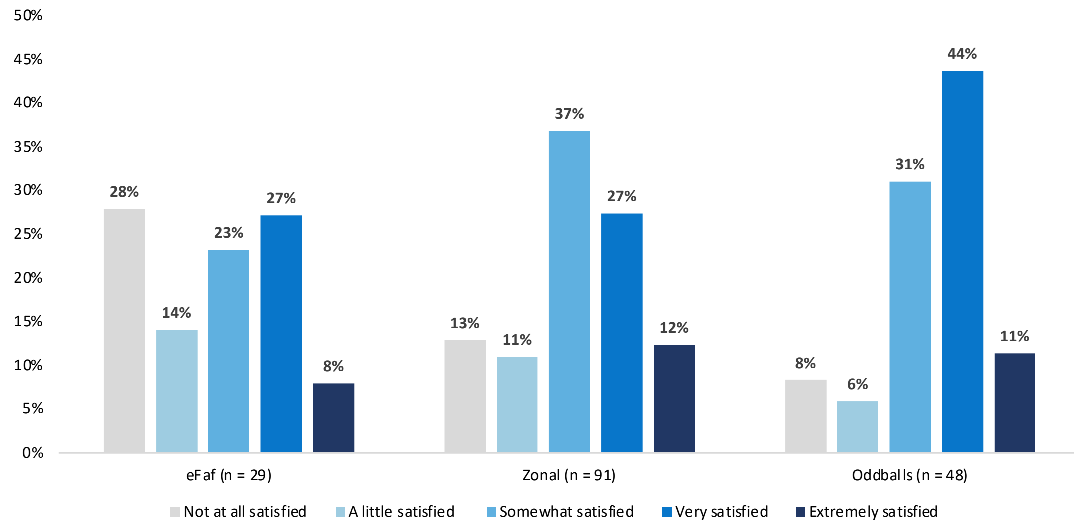
There was a strong relationship between customer satisfaction with the DHP and the smart thermostat installation. Figure 18 below shows that participants who did not install the smart thermostat device (control group and those who were assigned to the treatment group but failed to install the device) were *more* likely to report that they were very satisfied or extremely satisfied (88%) with their DHP than those who installed the smart thermostat (43%). This appears to be an unfortunate side effect, with dissatisfaction with the smart thermostat spilling over into dissatisfaction with the DHP itself.

Figure 18: Satisfaction with DHP by Installation Status



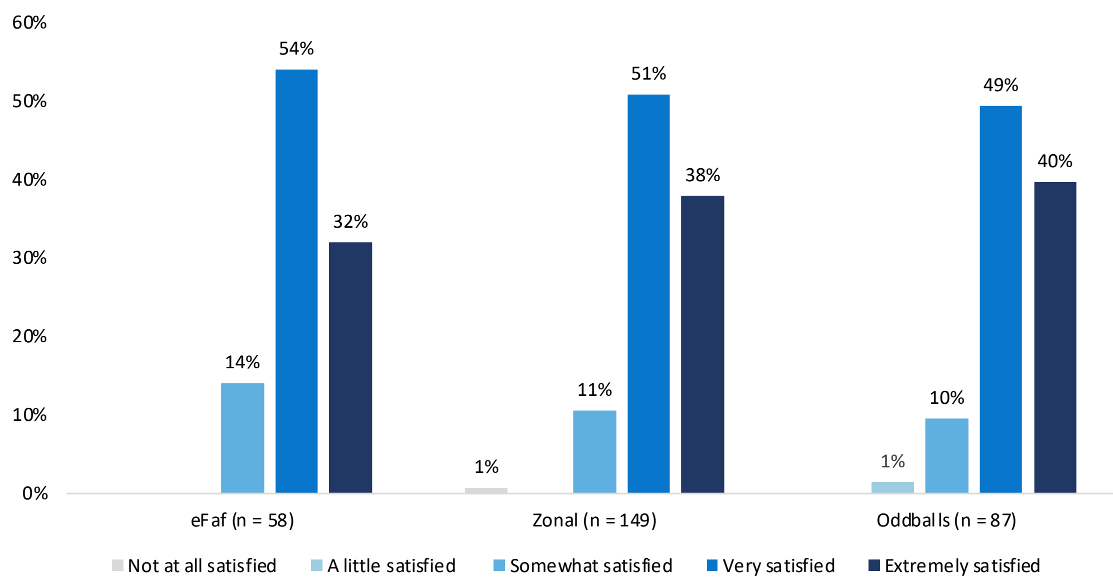
Across the study groups, satisfaction with the DHP after installing the smart thermostat was lowest for eFAF, with 42 percent not at all or only a little satisfied with the thermostat compared to 35 percent very or extremely satisfied. This is interesting, as eFAF was the only study group with positive energy savings in the billing analysis. Oddballs had the highest levels of satisfaction with the thermostats, with 55 percent very or extremely satisfied; still below Energy Trust's preferred satisfaction rate of 80+ percent. Oddballs had the greatest increases in energy usage among the three study groups after installation of the smart thermostat (Figure 19).

Figure 19: Satisfaction with DHP Since the Smart Thermostat Install (Treatment and Installed, n=168)



Among customers who did not receive the smart thermostat, or received it but did not install it, participants were much more likely to report being very or extremely satisfied across all secondary heat types. Only one respondent said they were not at all satisfied with the DHP (Figure 20).

Figure 20: Satisfaction with DHP Over the Last Year (Control or Treatment without Install, n=294)



We calculated an average satisfaction level for each group using a five-point scale, where 1 is not at all satisfied and 5 is extremely satisfied. The installation of the smart thermostat was associated with a reduction in DHP satisfaction across all three groups as shown in Table 22, with the most extreme impact for eFAF.

Table 22: Average Satisfaction with DHP Over the Last Year by Study Group

Study Group	Control or Treatment without Install (n=294)	Treatment and Installed (n=168)	Difference
eFAF	4.18	2.73	1.45
Zonal	4.28	3.14	1.14
Oddballs	4.28	3.44	0.84

Comparing DHP satisfaction by home size, we found that respondents with smaller homes were more likely to report being not at all satisfied with the DHP (Figure 21). However, when broken out by those who installed the thermostat and those who did not, the dissatisfaction with the thermostat appears to be driving the differences in satisfaction far more than home size (Figure 22 and Figure 23).

Figure 21: Satisfaction with DHP by Home Size (n=454)

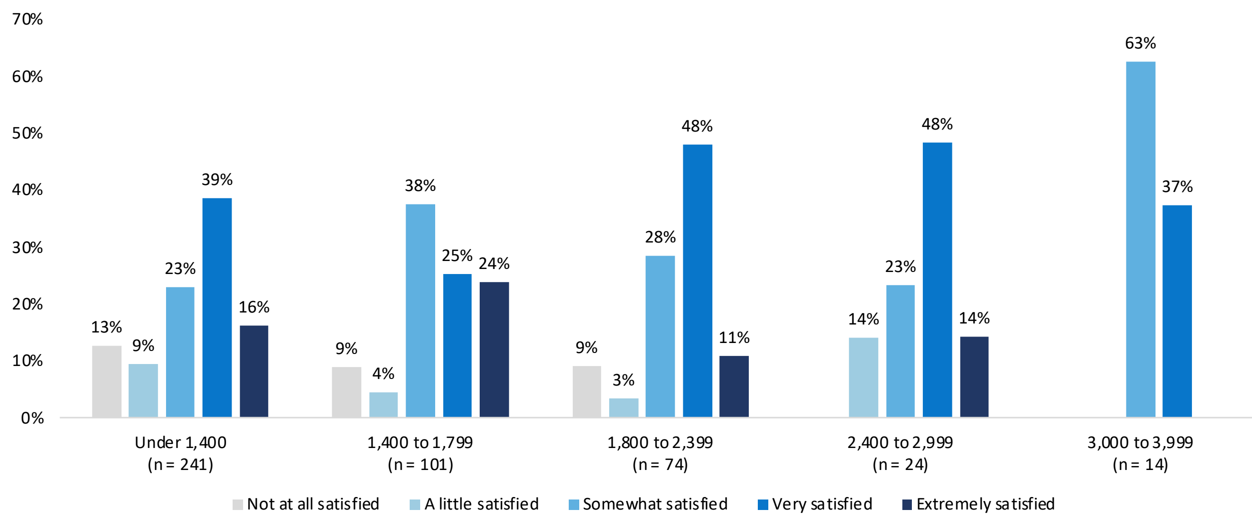


Figure 22: Satisfaction with DHP by Home Size, Without Thermostat

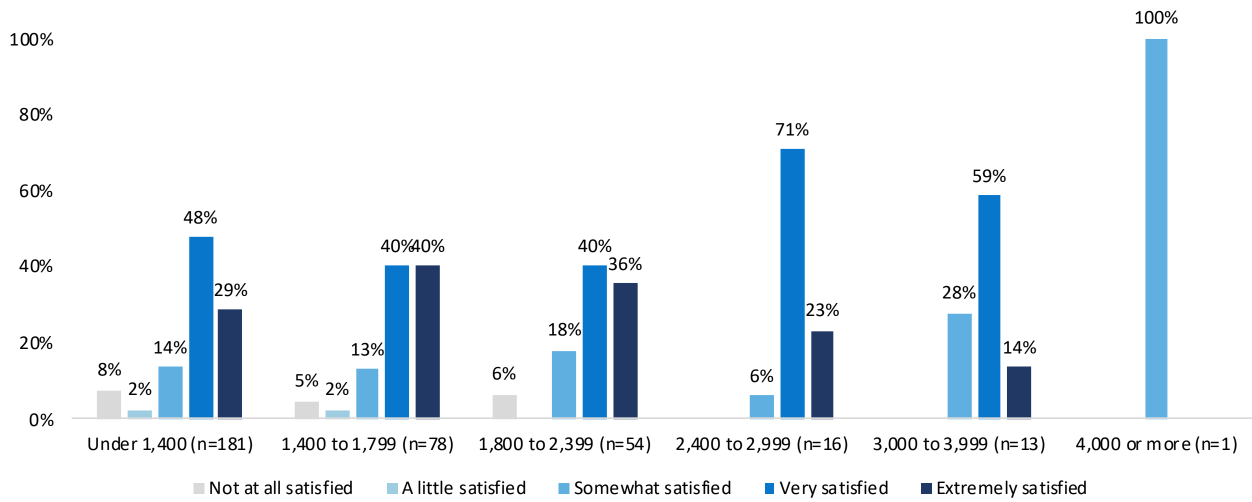
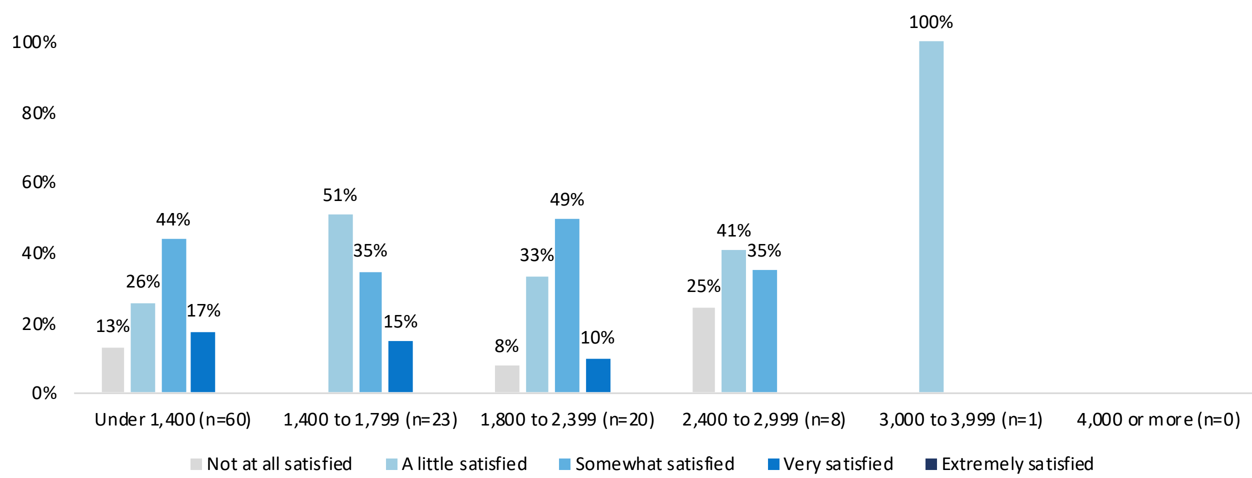


Figure 23: Satisfaction with DHP by Home Size, With Thermostat



4.2.6 Scalability

We asked Energy Trust, CLEAResult, and PGE staff as well as the smart thermostat vendor a series of questions about their perception of the future market for smart DHP controls.

Utilities want HVAC controls for load flexibility. The challenge is that controls are offering to solve a problem that consumers do not know they have. Meanwhile, vendors are competing on price and features, bringing many new devices to the market. We are seeing an increase in adoption in HVAC controls for central systems, so it is feasible that DHPs will follow. The smart thermostat vendor's CEO also mentioned this broader market push for smart home integration, expecting that DHPs will follow the trend seen in central HVAC systems.

Some program staff were apprehensive about the risks to customer data security brought by smart devices, where customer data is often accessible to the device manufacturer. The smart thermostat vendor's CEO mentioned that it was easy to pull a snapshot of a customer's device settings, and they retain a timeseries of this data; however, the smart thermostat vendor did not provide this information to the program staff.

As one person from Energy Trust put it, "I would hope [DHP controls] would be as accessible as name brand thermostat manufacturers like Nest and Ecobee, who have gotten so good at building features that people are interested in. They are making the brands as engaging as Apple…[the thermostat vendor] could offer different tiers of products with a budget version and one with all the bells and whistles." The smart thermostat vendor's CEO explained that their design priority was to keep the product lightweight so that it could be attached with an adhesive, unlike the glass and metal of a Nest thermostat. They are working on developing new features, improving the line-of-sight IR control spread pattern and battery life, supporting more brands and models of DHPs, and using the DHP remote to auto recognize and configure the thermostat to simplify device setup.

As one person from CLEAResult reported, "this type of IR product can be made by a third party, but it is suited more for a do-it-yourself (DIY) crowd that is not afraid of setup." DHP controls would have greater market penetration if they were installed with the DHP, using controls developed by the DHP manufacturer instead of an aftermarket product. Daiken has some new smart thermostat features that work across platforms with air source heat pumps and DHPs. The thermostat vendor's CEO echoed the idea that Mitsubishi, a DHP manufacturer, would likely take the biggest share of the future smart DHP controls.

The desire for smart DHP controls from the onset of this study was to improve the cost effectiveness for DHPs. If smart DHP controls are successful at saving energy, Energy Trust and implementation staff envisioned it being deployed in a variety of ways:

- As a standalone measure for existing DHPs (n=3)
- A controls requirement (n=3) or bonus incentive (n=2) for new DHPs;
- With options for direct install and self-install;
- Expanding to new construction and multifamily.

Both representatives from the smart thermostat vendor suggested offering a rebate instead of a free device. As one put it, the "rebate forces [the] customer to make [an] active decision to use the product." The smart thermostat vendor is seeing better acceptance rates on the East Coast with rebates going to installers. Many are offering bonus incentives for using the smart thermostat vendor's integrated controls for their backup systems. This way the DHP is being relied on during moderate weather, with the backup system deployed on the coldest days. From a customer support perspective, installation by a professional seems to make a big difference. When partnering with a trade ally who does the installation, the thermostat vendor would only need to train one person to perform a series of installations. This is much easier than educating consumers, and the overall adoption rate is higher. Customers do not understand as much about how the DHP and smart thermostat work, making it difficult for them to ask productive questions of the support staff.

5 Conclusions and Recommendations

The low installation rates, high uninstall rate, and low customer satisfaction suggest that it is too early for this technology to be offered to the general population of customers with DHPs. While professional installation and education may reduce the incidence of these issues, it is likely not a cost-effective solution. Specifically,

- Only 73 percent of the treatment group **successfully installed** the thermostat and 38 of these people **decided to uninstall** it within the first year; and there were
- Low rates of **customer satisfaction** with the thermostat, which led to lower rates of satisfaction with the DHP itself.

In terms of energy and demand savings, the thermostats had mixed success:

- The smart thermostat for the DHP saved an **average of 399 kWh** (3%) over one full year for customers with an electric forced air furnace (eFAF) as their secondary heat, but they *increased* energy usage for customers with non-electric (Oddballs) and zonal electric heat (260 and 663 kWh, or 2% and 5%).
- The thermostats consistently ***increased*** **peak demand** (in absence of the demand response program intervention)
- The smart thermostats successfully **reduced demand during demand response events**, though the impacts were small and highly variable across customers and events.

At a minimum, the thermostat manufacturer will need to improve the stability of the device's Wi-Fi connection, providing users with a notification when the devices have remained disconnected for an extended period. This would improve customer satisfaction while also increasing the number of thermostats that are available to receive a demand response event signal.

Findings by Research Objective

This section provides an overview of the key findings from the evaluation as they relate to each of the research objectives.

1. *Document the project design and actual implementation from the perspective of the program administrators, controls vendor, and participants.*

   Energy Trust led discussions with PGE and Pacific Power about a DHP controls study, while coordinating with the Oregon Public Utility Commission. PGE was heavily involved in the demand response portion of the study, coordinating between Energy Trust, the thermostat vendor, and the distributed energy resource management systems (DERMs) provider (Virtual Peaker). Pacific Power was also involved in a more limited role of providing data but not administering any demand response. Energy Trust led the study design and then contracted with CLEAResult to develop the implementation plan. Beyond just selling the unit, the smart thermostat vendor developed code to integrate the smart thermostat with Virtual Peaker.

CLEAResult recruited participants from a list of Energy Trust customers who had installed a DHP at least one year previously. PGE's Smart Grid Test Bed recruitment was conducted separately, going beyond Energy Trust's lists of incentivized DHPs to homes with DHPs listed in building permits that implied a DHP was present. Recruitment was identified as the most significant challenge that the study faced by all but one of the staff we interviewed (n=6 of 7), with a limited population, old contact information, high targets, and a short timeline for recruitment.

If it had not been for the COVID-19 pandemic, Energy Trust would have considered offering these devices as direct-install (the thermostat is usually installed by a professional, not self-installed). The reports from the smart thermostat vendor showed an initial installation rate of around 50 percent, much lower than program staff had expected. Both the smart thermostat vendor and CLEAResult reached out to participants, calling and emailing to offer support. Self-installation was the only option for the study at the time, leading to unfortunate consequences to the study quality in terms of the installation rates and the quality of information collected on the homes (e.g., reliance on customer self-reported home characteristics and compliance with program rules). By the end of the study, 73 percent of the treatment group had fully installed the thermostat at some point, but 38 percent of those customers had later decided to uninstall the thermostat (or 28% of everyone in the treatment group).

Of the survey respondents who said that the installation was not very easy or not at all easy (n=66 , 29%), the most-cited reason was challenges connecting to and staying connected to Wi-Fi (50%). Wi-Fi is required to set up the thermostat, but it is possible to control the DHP on the physical thermostat when the connection drops. It is not clear why the Wi-Fi connection posed such a significant challenge for customers. The participants were required to 1) install the Wi-Fi bridge device or 2) keep the thermostat plugged into an outlet while staying within line-of-sight to the IR sensor on the DHP. The smart thermostat vendor explained that Wi-Fi issues usually stem from organic disruptions in Wi-Fi connection, changes to the Wi-Fi password, or dead batteries. Customers may not realize that the device is offline because the display does not change. Energy Trust pointed out that these examples of Wi-Fi issues may explain the high rates of disconnection, but not why Wi-Fi connectivity would have *prevented* installation in the first place.

When prompted with a list of potential challenges with the device, not operating the heat pump properly (27%), not maintaining a comfortable temperature (24%), and a delay between using the app and the DHP responding (24%) were the most common challenges. Only 18 percent of respondents reported no challenges with the thermostat.

2. *Determine the timing of electricity savings by season, hour-of-day, and day-of-week.*

   Season: The changes in energy usage were more extreme in the winter than in the summer. The eFAF *savings* were higher in winter, while Oddballs and Zonal had larger *increases* in energy usage during the winter.

   Hour of day: Most of the savings for customers with electric forced air furnaces (eFAF) occurred in the middle of the day between 8 a.m. and 5 p.m. Oddballs had large and statistically significant increases in energy usage from midnight until noon, but some of these were offset by savings later at night from 8 p.m. to 9 p.m. Zonal had a smaller spike in energy usage from 6 a.m. to 10 a.m., which was exacerbated by additional small increases in energy usage in the afternoon and evening from 3 p.m. until 9 p.m.

   Day of week: For both Oddballs and Zonal, the morning impacts of the DHP controls were more extreme on weekdays than on weekends, with larger increases in energy usage.

   Savings shape: The eFAF savings were relatively stable throughout the year, fluctuating between 0.05 and 0.95 kWh savings per day, with a drop in savings during the cooling season, which was most prominent during the months of July and August. Oddballs had large *increases* in energy usage, with the largest *increases* around 2.8 kWh in December and January and small positive savings of 0.14 to 0.22 kWh on select days between June and September. Zonal followed a similar, though less prominent pattern, with a maximum daily *increase* in energy usage of 1.7 kWh in December and January and small positive savings of 0.02 and 0.04 kWh on select days between May and July.

3. *Assess the overall success and future potential of DHP controls in terms of energy efficiency, demand reduction, demand response, and customer satisfaction.*

   Energy efficiency: Customers who installed DHP controls with an eFAF exhibited statistically significant annual energy savings of 399 kWh (3.4%) or around 1.1 kWh per day, whereas Oddballs and Zonal exhibited a statistically significant *increase* in energy usage of 260 and 663 kWh (2.1% and 5.0%) attributed to the DHP controls; savings are measured as the incremental impact above and beyond any changes exhibited by the control group during the same period. Oddballs self-reported having slightly lower non-electric bills after installing the smart DHP controls, but the difference was not statistically significant.

Energy savings during system peak hours: Customers with eFAF had significant energy savings during the first two hours of PGE's summer peak hours from 3 p.m. to 5 p.m., but no significant changes in energy usage during Pacific Power's summer peak hours of 5 p.m. to 9 p.m. Oddballs had significant savings during the last two hours of Pacific Power's peak, 8 p.m. and 9 p.m. Customers with Zonal had small, yet statistically significant, *increases* in energy usage during the summer peak for both PGE and Pacific Power.

Unfortunately, Oddballs and Zonal both exhibited significant *increases* in energy usage during the morning and evening utility peaks on weekdays in winter (December-February). Customers with eFAF had significant *savings* during this morning peak, but just one hour of significant savings during the evening peak at 5 p.m.

Demand reduction: It appears that DHP controls are unlikely to deliver demand savings, leading to an *increase* in peak demand. On the coldest day of the weather normalized year, participants with eFAF have slightly lower (though insignificant) demand during the morning peak, while Oddballs and Zonal significantly *increased* their demand after installing the smart DHP controls. All three study groups *increased* their energy usage during the summer peak hours on the hottest day of the year, except for Oddballs from 6 p.m. to 8 p.m. (and only one of those hours was statistically significant).

Demand response: We found evidence of load shifting during demand response events in both seasons, with an average hourly net impact of 0.23 kW in summer and 0.16 kW in winter among Smart Grid Test Bed participants. The net impacts include a penalty for the peak load *increases* of 0.10 and 0.11 caused by the installation of the smart thermostat, which offset some of the event savings of 0.33 kW in summer and 0.27 kW in winter (measured relative to similar non-event days with the thermostat). When we looked at individual participants and events, the event savings varied greatly, from -1.18 to 2.32 kW in summer and from -3.63 to 1.47 kW in winter. These estimated savings values are based on a very small number of devices that were connected and responded to events (n=5 to 7 devices per event).[14] There were some consistently high and low performers within each season. We did not identify any consistent customer characteristics in the survey that explain why some homes save more than others. That said, our findings do suggest that the smart DHP controls are capable of load shifting.

Customer satisfaction: Customer satisfaction with the device was lower than expected, with only 25 percent of eFAF, 27 percent of Zonal, and 24 percent of Oddballs very or extremely satisfied with the device. Many respondents said they were not at all satisfied

[14] PGE requested that the evaluation focus on devices that responded to events and did not opt out to provide an optimistic view of what this technology could achieve if all issues with device connectivity and willingness to participate were resolved.

with the smart thermostat, ranging from 23 percent of Oddball participants and up to 43 percent of eFAF participants being not at all satisfied.

Participants who did not install the smart thermostat (the control group and those who were assigned to the treatment group but failed to install the device) were *more* likely to report that they were very satisfied or extremely satisfied (89%) with their DHP than those who installed the device (43%). This is an unfortunate side effect, with dissatisfaction with the smart thermostat spilling over into dissatisfaction with the DHP itself.

Across the three study groups, there was a consistent relationship between energy savings and satisfaction with the DHP after installing the smart thermostat. Satisfaction with the DHP was lowest for eFAF, with 42 percent not at all or only a little satisfied with the DHP after the thermostat install compared to 35 percent very or extremely satisfied. Oddballs had the highest levels of satisfaction, with 55 percent very or extremely satisfied with their DHP after the thermostat install; still below Energy Trust's preferred satisfaction rate of 80+ percent. Oddballs also had the greatest *increases* in energy usage among the three study groups after installation of the smart thermostat.

Appendix A: Staff and Vendor Interviews

A.1 Energy Trust, CLEAResult, and PGE Staff Interview Guide

1. First, can you briefly summarize your role in planning or implementing the DHP Controls Coordinated Research Project and how long you have been in this role? Which implementation staff and vendor contacts you primarily worked with?

Implementation

2. How were participants identified and recruited for this study? Were there any significant successes or challenges attributed to this process?
3. Did you face any challenges with customer support? *(If needed: support offered by program staff, we will ask about the vendor next) [Note any significant issues, time burden.]*
4. What challenges did you face during the installation phase? What were the solutions to those challenges?
5. Did you hear any unexpected customer complaints or feedback?
6. Is there anything program staff should do differently next time?

Device and Vendor

7. How satisfied are you with the DHP controls device? Not at all satisfied, a little satisfied, somewhat satisfied, or very satisfied?
8. What concerns do you have about the DHP controls device? *[Probe: its capabilities, installation/setup challenges, the vendor, and integrity of the research project]*
9. Overall, how satisfied were you with the controls vendor [vendor name]?
10. *[If not "very satisfied":]* What could the controls vendor have done differently?
11. How responsive was the controls vendor to program staff? (If needed: requests for data, installation issues)
12. If the device is successful, how do you envision it being used in programs? What are the likely use cases?
13. Do you have any concerns about offering this device to more customers and continuing to work with this vendor long-term?
14. Are there other devices that have come along that fill the same niche that may be better?
15. What do you think the future of DHP controls market will look like?

PGE DR Testbed

16. Were you involved in the coordination between with PGE and Energy Trust for the DR portion of the study? *[If "no", skip to next section.]*

17. Can you give a quick overview of how the DR testbed status and issues were communicated between PGE and Energy Trust?
18. Are there any aspects of this coordination that should have been done differently?
19. How confident are you in the success of PGE's DR events? Why is that?
20. Do you have any concerns about the DR capabilities of the device?

Successes, Challenges, and Lessons Learned

21. What aspects of the study are going particularly well?
22. What are the most significant challenges that the study faced in the last year? *[Probe: recruiting, data tracking, device issues].*
    a. How are these challenges being addressed?
23. Did you learn anything valuable that will help improve the process for future studies like this?

Closing

24. Are there any other topics or issues we did not cover that you think would help inform our evaluation work?

Thank you for your time!

A.2 Vendor Interview Guide

Intro*:* "This study was developed in response to research that Energy Trust conducted on new DHPs that showed lower than expected energy savings. There were a variety of reasons for the poor performance, including a lack of proper controls. DHP Controls are projected to save energy by reducing the reliance on secondary heating systems."

1. First, can you briefly summarize your role in Energy Trust's DHP Controls Research Project and how long you have been in this role? *[If needed: product development, order fulfillment, customer support, data sharing, and integrating with PGE's DR vendor to enable DR events]*
2. Which staff at CLEAResult, Energy Trust and PGE did you work with primarily?

Device

3. What do you see as the key selling points of the [model] thermostat? *[If needed: replace the DHP remote with a wall-thermostat, smarter HVAC controls, connecting the DHP to other smart home devices]*
4. How do you expect the [model]thermostat to achieve energy savings?
5. How confident are you that the [model]thermostat will achieve energy savings? Very confident, somewhat confident, or not confident? Why is that?

6. What are the demand response capabilities of the device? How does this work?
    a. It sounds like PGE experienced an issue with [the thermostat vendor's] DR functionality during the recent heat wave (late June), which was the first attempt at using the [model] devices in a DR event. Evidently, when the event was called and the signal was sent, the [model] devices didn't respond. PGE is investigating what went wrong and where the weak links were in the chain.
    b. What happened?
    c. How can we avoid similar issues in the future?
    d. Did you learn anything else during the process of investigating the issue and coordinating with PGE?
7. How confident are you that the [model] thermostat will achieve demand savings? Very confident, somewhat confident, or not confident? Why is that?
8. What are your long-term plans for the [model] thermostat? *[Probe: new features, compatibility with more equipment and controls devices, aesthetics]* Do you have any related devices in development?
9. Are you aware of other manufacturers with devices that have come along that fill the same niche? If yes: What do you think differentiates your [model] thermostat from other devices on the market?
10. What do you think the future of DHP controls market will look like?
11. What do you estimate is your current share of the smart DHP controls market, not including any controllers that ship with the DHP?
12. Do you expect your market share to increase, decrease, or stay the same over the next few years? Why is that?

Program Implementation

13. Did you face any challenges during the <u>project planning</u> stage? *[if needed: contracting,* supporting the design of the study, *questions from program staff, order fulfillment]*
14. How about the <u>installation</u> phase? What were the solutions to those challenges? *[if needed: customer installation support, tracking device registrations, data requests]*
15. Did you face any challenges during the <u>setup and operation of PGE DR</u> events?
16. Have there been any other challenges with devices that are already installed and registered?
17. Did you hear any unexpected customer complaints or feedback?
18. Did you face any challenges with <u>study support and data requests</u>?
19. Are there any other aspects of your coordination with program staff that should have been done differently? *[if needed: between [the thermostat vendor], the program staff at CLEAResult, Energy Trust, and PGE?]*
20. If Energy Trust provides incentives for these devices, it could be in the form of: an independent rebate, an installation requirement or bonus incentive for new DHPs, or possibly a direct install by program staff.

a. What concerns do you have about the [model] thermostat being offered by a utility-sponsored program, as opposed to independent customer purchases? *[Probe: device capabilities, installation/setup challenges, distribution of devices by program staff, communication with program staff, data requests, and integrity of the research project]*
b. Are any of your concerns specific to the program scenario? *[If needed: Do you have the same concerns if the controls are a requirement for all new DHPs vs. purchase incentives, which may include existing DHPs?]*

Takeaways

21. What aspects of the study are going particularly well?
22. What were the most significant challenges that you faced with the Energy Trust study in the last year? *[Probe: planning, tracking, device issues].*
    b. How are these challenges being addressed?
23. Did you learn anything valuable that will help improve the process for working with utility programs in the future?
24. Are there any other topics or issues we did not cover that you think would help inform our evaluation work?

Thank you for your time!

Appendix B: Participant Survey

B.1 Survey Instrument

Authentication

Thank you for participating in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study. Energy Trust has hired Evergreen Economics to conduct a survey, and other research tasks, on their behalf. Your help with this research will help homes across Oregon save money and energy.

To thank you for answering our questions, we **will send you a $10 check** for helping us with this important phase of the research.

To begin, please enter the 4-digit participant ID provided in the letter you received from Energy Trust of Oregon.

Introduction

Would you like a description of **Energy Trust of Oregon's ductless (mini-split) heat pump Wi-Fi thermostat study?** [If "Yes"….]

PACIFIC POWER | PGE | EnergyTrust of Oregon

In late 2021 you received a gift card for completing an application for Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study.

[TREAT] As a member of the treatment group, you were shipped a free Wi-Fi thermostat. After installing your new [make model], you could take advantage of the free [make] mobile app to control your ductless heat pump from anywhere, whether you are home or away. Energy Trust will continue to follow up with you throughout the study period to make sure you're getting the most out of your [make model].

[TREAT and TESTBED] You also had an opportunity to earn rebates on your PGE bill through their Ductless Heat Pump Rewards program, available exclusively for residents of the PGE Smart Grid Test Bed. PGE adjusts your thermostat by a couple of degrees during occasional Peak Time Events, and you don't need to do anything but collect the rewards as you help shape Oregon's clean energy future.

[CONTROL] As a participant in our control group, you will receive your free [make model] Wi-Fi thermostat after our study has concluded. Your energy usage data and survey data are an important as a point of comparison for us to understand the performance of Wi-Fi thermostats for ductless systems.

Q1. Think back to when you first agreed to participate in our ductless heat hump Wi-Fi Thermostat study. What was the MOST important factor in your decision to participate? Would you say…
   a. Mostly an interest in a wall-mounted thermostat (to replace the remote control)
   b. Mostly an interest in in the new technology and/or smart controls features (e.g., scheduling, geofencing, mobile app)
   c. Mostly the gift card offered for participating
   d. All three factors were equally important to me.

[If CONTROL, skip to next section.]

Q2. [Display photo of the white device] Is the [make model] thermostat currently installed and in use?
   a. Yes
   b. No

Q3. [If Q2=No] Did you attempt to get the thermostat installed in your home?
   a. Yes

b. No

Q4. [If Q3=Yes] Initially, were you able to successfully complete the installation?

a. Yes
b. No

Q5. [If Q2= No] Why did you [if Q4=Yes: "choose to uninstall", if Q4="No": "not complete the installation of", if Q3=No "not attempt to install"] the thermostat? (select all that apply)

a. Thermostat was not compatible with my ductless heat pump
b. Wi-fi bridge issues
c. Disagreement within the household
d. Thermostat broke/was not working correctly
e. [If Q3 = A] Thermostat did not control ductless heat pump properly
f. [If Q3 = B] Installation was too complicated
g. [If Q3 = B] No longer wished to install thermostat or participate in study
h. [If Q3 = B] Other installation challenges: ______ [open end]
i. Other concerns about the thermostat: ______ [open end]
j. Something else (please tell use): ______ [open end]

[If Q2=A or Q4=A, flag as "TREAT DEVICE"; otherwise flag as "TREAT NO DEVICE"]

Q6. [If TREAT DEVICE] Were you able to get the [make] Wi-Fi bridge installed in your home? [Display photo of the white Wi-fi bridge device]

a. Yes
b. No, I was unable to install it
c. No, I did not try to install it

Device [TREAT & (Q2=Yes, installed or Q3=Yes, attempted)]

Q7. How easy was installing the [make model] thermostat?

a. Not at all easy
b. Not very easy
c. Somewhat easy
d. Very easy
e. Extremely easy

Q8. [If Q7 != D | E] What went wrong during the installation?

a. _______ [open end]

Q9. During the installation process, did you turn to any of the following for help? (Check all that apply)

a. Use the installation guide

b. Request help from [vendor], the thermostat manufacturer
c. Contact Energy Trust residential team
d. Watch videos online (like YouTube)
e. Other: ______ [open end]
f. I did not use anything for help

Q10. [If Q9 = A] Was the installation guide helpful?
a. Yes
b. Somewhat
c. No

Q11. [If Q9 = B | C] Overall how satisfied were you with the [b.[make model]/c. "Energy Trust"] customer support?
a. Not at all satisfied
b. A little satisfied
c. Somewhat satisfied
d. Very satisfied
e. Extremely satisfied

[If TREAT NO DEVICE, skip to next section.]

Q12. The [make model] has many settings available to customize the heating and cooling of your ductless (mini-split) heat pump that you may or may not be aware of. How frequently do you use these features, if at all?
i. Option to adjust settings using **the mobile app** on a phone or tablet
ii. **Scheduling** temperatures by time and day-of-week
iii. **Geofencing** – automatically detects when you are away
iv. **Away Mode** – sets temperature for occupied times
v. **Temperature Sensing** – measures room temperature on the thermostat instead of the ductless heat pump
vi. **Room Hold** – set temperatures for a specific room (defaults to a temporary hold)
vii. **Integrate** with another device (e.g. Amazon Alexa, Google Assistant)
viii. Other: _____ [open end]

a. I was not aware of this feature before this survey
b. Never
c. I tried it a few times
d. I use it regularly

Q13. [If Q12 vii. (Integrate with other device) > b. Never] Which device(s) have you integrated with your [make model]? (select all that apply)
a. Amazon Alexa

b. Google Assistant
c. A central thermostat
d. Remote occupancy sensor
e. Other: _____ [open end]

Q14. Since installing the [make model] thermostat, what challenges have you had with it, if any? (select all that apply)

a. Batteries running out
b. Not maintaining a comfortable temperature
c. Not operating the ductless heat pump properly
d. Delay between using the app and the ductless heat pump responding
e. Delay between using the thermostat and the ductless heat pump responding
f. Difficulty with the thermostat's user interface (the physical device)
g. Difficulty using the mobile app
h. Other: _____ [open end]
i. None

TB1. [If TREAT DEVICE & utility = "PGE" & testbed != TRUE] Would you be interested in an opportunity to earn rebates ($1/kWh) on your PGE bill through their Ductless Heat Pump Rewards program? PGE would adjust your thermostat by a couple of degrees during occasional Peak Time Events, and you don't need to do anything but collect the rewards as you help shape Oregon's clean energy future.

a. Not at all interested
b. A little interested
c. Somewhat interested
d. Very interested
e. Extremely interested

Other HVAC System(s)

Q15. [IF TREAT & INSTALLED] What rooms are served by the ductless (mini-split) heat pump controlled by your [make model] thermostat? (Select all that apply)

a. Great room/open area
b. Living room, den, or family room
c. Recreation room
d. Dining room
e. Kitchen
f. Hallway
g. Bedroom(s)
h. Loft
i. Office, study
j. Attic or basement

k. ADU or addition, separate from main home
l. Other: ________ [open end]

Q16. [IF TREAT & INSTALLED] Approximately what percentage of your home does this ductless heat pump (with the [make model]) serve?
a. 0-19% of the square footage
b. 20-39%
c. 40-59%
d. 60-79%
e. 80-100%

SET HEAT LOOP BLOCK HERE (repeating Q18-Q26 for each heating system)

Q17. Which of the following heating systems, if any, do you have [Treatment: "in the [list rooms selected in Q15] with the ductless heat pump", Control: **"in the same room(s**) as the ductless heat pump(s)"]? We are only interested in systems or equipment that were used **at least one day in the past year** for heating (select all that apply):
a. Forced air furnace
b. Underfloor radiant heat or radiant panels
c. Boiler/hot water system
d. Central heat pump system
e. Fireplace or stove
f. Baseboard or wall heaters
g. Radiant ceiling heat
h. Portable space heater
i. Other: _________ [open end]
j. None, the ductless heat pump is the only heating system

[If Q17= None, skip to next section.]

HEAT LOOP START

Q18. [Repeat for each heating system mentioned in Q17] What type of fuel does the [heating system] use?
a. Electricity
b. Natural gas
c. Oil/kerosene
d. Propane
e. Wood/pellets

Q19. [Repeat for each heating system mentioned in Q17] How often do you use the [heating system] to heat your home during the winter?
a. Every day

b. 3 to 6 days per week
c. 1 to 2 days per week
d. Less than 1 day per week
e. Not sure/don't know

Q20. [Repeat for each unit mentioned in in Q17 a-k] How do you typically control your [heating system]? The photos provided below are examples of control systems and yours may look different. Please choose the closest option available.

a. Wall mounted controls
b. A remote control
c. On-unit controls
d. [IF heating system = fireplace or stove & fuel = wood/pellets] Manually, by adding wood/pellets and tending to the fireplace or stove
e. Other: _______

Examples of heating controls:

a. Wall-mounted

b. Remote control

c. On-unit controls

Q21. [IF Q20 != D] Does the [heating system] control **allow** you to:

a. Only turn the unit on/off
b. Choose the output level (low to high, but not a specific temperature)
c. Choose a single temperature (e.g., heat to 68 degrees)
d. Program a schedule with multiple temperatures (by time and day-of-week, not just a timer)

Examples of heating controls:

a. Only on/off

b. Choose output level

c. Choose temperature

d. Schedule multiple temperatures

Q22. [If Q21= ”program a schedule” & Q20 != D] How often do you put your [heating system] on a schedule, with different temperatures depending on the time and day-of-week?

a. It is **always** on a schedule
b. It is **sometimes** on a schedule
c. It is **rarely** on a schedule
d. It is **never** on a schedule

Q23. [If Q22=always or sometimes] How much do your setpoint temperatures vary throughout the week?

a. 1-5°F
b. 6-10°F
c. 11-20°F
d. More than 20°F

Q24. [If Q21!=”program a schedule”& Q20 != D] How often do you [If Q21= On/Off: “turn on/off”, else “adjust the settings of”] the [Q17 heating unit] during the winter?

a. [If Q21= On/Off] Never, it is always on
b. [If Q21!= On/Off] Never, I don’t adjust the settings
c. Weekly
d. Daily
e. Multiple times per day

Q25. [Repeat for each heating system mentioned in Q17] Which statement best describes your [heating system]?

a. It heats fewer rooms than the ductless heat pump system
b. It heats the same rooms as the ductless heat pump system
c. It heats more rooms than the ductless heat pump system

Q26. Why do you use the [heating system]?

a. The ductless heat pump doesn’t heat the space well enough
b. The [heating system] is cheaper to run than the ductless heat pump

c. The [heating system] is more convenient than the ductless heat pump
d. [If Q25 = C] I need to heat rooms in my home that the ductless heat pump does not reach
e. [If Q17= fire/stove] I enjoy the look/feel of the fireplace or stove
f. Some other reason: ______ [open end]

SET COOL LOOP BLOCK HERE

Q27. Which of the following cooling systems, if any, do you have [Treatment: "in the [list rooms selected in Q12] with the ductless heat pump", Control: **"in the same room(s)** as the ductless heat pump(s)"]? We are only interested in systems or equipment that were used **at least one day in the past year** for cooling (select all that apply):

a. Central AC
b. Window, wall, or portable AC
c. Whole house fan
d. Portable fans or ceiling fans
e. Other: _________ [open end]
f. None, the ductless heat pump is the only cooling system

COOL LOOP START

Q28. [Repeat for each cooling system mentioned in Q27] How often do you use the [cooling system] to cool your home during the summer?

a. Every day
b. 3 to 6 days per week
c. 1 to 2 days per week
d. Less than 1 day per week
e. Not sure/don't know

Q29. [Repeat for each cooling system mentioned in Q27] How do you typically control your [cooling system]? The photos provided below are examples of control systems and yours may look different. Please choose the closest option available.

a. Wall mounted controls
b. A remote control
c. On-unit controls
d. Other: _______

Examples of cooling controls:

a. Wall-mounted b. Remote control c. On-unit controls

Q30. Does the [cooling system] control **allow** you to:

a. Only turn the unit on/off
b. Choose the output level (low to high, but not a specific temperature)
c. Choose a single temperature (e.g., cool to 75 degrees)
d. Program a schedule with multiple temperatures (by time and day-of-week, not just a timer)

Examples of cooling controls:

a. Only on/off b. Choose output level c. Choose temperature d. Schedule multiple temperatures

Q31. [If Q21 Q30 = "program a schedule"] How often do you put your [cooling system] on a schedule, with different temperatures depending on the time and day-of-week?

a. It is **always** on a schedule
b. It is **sometimes** on a schedule
c. It is **rarely** on a schedule
d. It is **never** on a schedule

Q32. [If Q30Q21!="program a schedule"] How often do you [If Q30 = On/Off: "turn on/off", else "adjust the settings of"] the [cooling system] during the summer?

a. [Q30 = On/Off] Never, it is always on
b. [Q30 != On/Off] Never, I don't adjust the settings
c. Weekly
d. Daily

e. Multiple times per day

Q33. [Repeat for each cooling system mentioned in Q27]Which statement best describes your [cooling system]?

a. It cools **fewer** rooms than the ductless heat pump system
b. It cools the **same** rooms as the ductless heat pump system
c. It cools **more** rooms than the ductless heat pump system

Q34. Why do you use the [cooling system]?

a. The ductless heat pump doesn't cool the space well enough
b. The [cooling system] is cheaper to run than the ductless heat pump
c. The [cooling system] is more convenient than the ductless heat pump
d. [If Q33 = C] I need to cool rooms in my home that the ductless heat pump does not reach
e. Some other reason: ______ [open end]

COOL LOOP END

Q35. [If 1+ heating system in Q17] If it is too **cold** in your home, which system turns on first? [carry forward all heating systems selected in Q17]

a. The ductless heat pump
b. The [heating systems]
c. They turn on at the same time
d. Don't know

Q36. [If 1+ cooling system in Q27] If it is too **hot** in your home, which system turns on first? [carry forward all cooling systems selected in Q27]

a. The ductless heat pump
b. The [cooling system]
c. They turn on at the same time
d. Don't know

Demand Response (only TREAT DEVICE and TESTBED)

As a resident in the PGE Smart Grid Test Bed, you were also enrolled in PGE's Ductless Heat Pump Rewards program. [If click "More Info"….]

As participant in this program, you earn rebates on your PGE bill through their Ductless Heat Pump Rewards program. These are available exclusively for residents of the PGE Smart Grid Test Bed.

PGE adjusts your thermostat by a couple of degrees during occasional Peak Time Events and you don't need to do anything but collect the rewards as you help shape Oregon's clean energy future.

[Display photo of the white Wi-fi bridge device and PGE SGTB logo]

TB2. How many Peak Time events do you recall occurring this summer?
[require integer response]

TB3. How do you feel about the number of Peak Time events that occurred this summer?
- a. There were too many Peak Time events
- b. There were about the right number of Peak Time events
- c. There were too few Peak Time events
- d. Not sure

TB4. How did you learn about Peak Time events? Select all that apply.
- a. Email notification
- b. Display on the [make model] thermostat
- c. Notification in the [make model] app
- d. I noticed a change in temperature
- e. Something else: [open ended]
- f. Don't know

TB5. [IF TB4 != F] Would you change anything about the event notifications you received? [open-end]

TB6. How often did you adjust/override your thermostat settings during the Peak Time events, either manually or via the app?
- a. I adjusted/overrode thermostat settings during **all** Peak Time events
- b. I adjusted/overrode thermostat settings during **most** Peak Time events
- c. I adjusted/overrode thermostat settings during **about half** of the Peak Time events
- d. I adjusted/overrode thermostat settings during **a few** of the Peak Time events
- e. I **never** adjusted/overrode thermostat settings during any of the Peak Time events
- f. Don't know

TB7. During the occasional Peak Time events, when PGE adjusted your thermostat by a couple degrees, how was the comfort of your home impacted?
- a. My home was more comfortable

b. I did not notice any change in comfort in my home
c. My home was slightly less comfortable
d. My home was much less comfortable
e. Don't know/I wasn't home during events

TB8. How satisfied are you with the PGE Ductless Heat Pump Rewards program overall?
a. Not at all satisfied
b. A little satisfied
c. Somewhat satisfied
d. Very satisfied
e. Extremely satisfied

TB9. Would you change anything about the PGE Ductless Heat Pump Rewards program?

Changes in the Home

Q37. Did you purchase any ductless heat pump thermostats for your home [If TREAT: "in addition to the free [make model] thermostat sent by Energy Trust"] since December 2020?
a. Yes
b. No

Q38. [If Q37=A] What type of thermostat(s) did you purchase?
a. Flair Puck
b. Ecobee
c. Google Nest
d. Honeywell D6
e. Sensibo Sky
f. Mistubishi, Fujitsu, Daiken, or other OEM
g. Something else: ________ [open end]

Q39. Did you make any significant changes to your home since December 2020, such as an addition, remodel, new heating system, or other major home upgrades (e.g., solar, electric vehicle charger)?
a. Yes
b. No

Q40. [If Q39=A] Please describe the change(s) you made to your home:
a. ________ [open end]

Q41. [If **any** Q18!= electric] After using the new controls for a few months, did you notice any changes in your natural gas, fuel oil, or other **non-electric energy bills**?
a. Much lower non-electric bills

b. Slightly lower non-electric bills
c. No change
d. Slightly higher non-electric bills
e. Much higher non-electric bills

Q42. Do you use the ductless heat pump system more this year than in 2020?
a. Use it **more now** than in 2020
b. Use it the **same** as in 2020
c. Use it **less now** than in 2020
d. Do not use it **at all** anymore

Q43. [Q17 != None] Do you use your other heating system(s) more this year than in 2020? You selected [list all heating systems].
a. Use the other system(s) **more now** than in 2020
b. Use the other system(s) the **same** as in 2020
c. Use the other system(s) **less now** than in 2020
d. Do not use the other system(s) **at all** anymore

Q44. [Q27 != None] Do you use the other cooling system(s) more this year than in 2020?
a. Use the other system(s) **more now** than in 2020
b. Use the other system(s) the **same** as in 2020
c. Use the other system(s) **less now** than in 2020
d. Do not use the other system(s) **at all** anymore

Q45. [If TREAT DEVICE & Q12 = "heard of scheduling"] How often do you use your [make model] thermostat to put your ductless heat pump on a schedule, with different temperatures depending on the time and day-of-week?
a. It is **always** on a schedule
b. It is **sometimes** on a schedule
c. It is **rarely** on a schedule
d. It is **never** on a schedule

Q46. [If Q45=always or sometimes] How much do your ductless heat pump setpoint temperatures vary throughout the week? (lowest to highest °F)
a. 1-5°F
b. 6-10°F
c. 11-20°F
d. More than 20°F

Q47. How often do members of your household change the ductless heat pump's temperature settings or turn it on/off? [If TREAT DEVICE: "Please consider all changes to settings on the physical [make model] thermostat, in the mobile app, or with the old remote."]
a. Multiple times a day

b. Once a day
c. Weekly
d. Less than once a week

Q48. Did you adjust the temperature on the ductless heat pump more often, less often or about the same [If ever installed [make model]: “since installing the [make model]thermostat”, If control: “this year compared to 2020”]?
a. I/we adjust the temperature **more** often
b. I/we adjust the temperature **less** often
c. I/we adjust the temperature **about the same** as before

Q49. Was your home more or less comfortable during this past **winter** [If ever installed [make model]: “after installing the [make model]thermostat”], than in the winter of 2020 or was it the same?
a. My home was **more** comfortable after installing the [make model] thermostat
b. My home was **less** comfortable after installing the [make model] thermostat
c. My home was **about the same** level of comfort after installing the [make model] thermostat

Q50. Was your home more or less comfortable during this past **summer** [If ever installed [make model]: “after installing the [make model] thermostat”], than in the summer of 2020 or was it the same?
a. My home was **more** comfortable after installing the [make model] thermostat
b. My home was **less** comfortable after installing the [make model] thermostat
c. My home was **about the same** level of comfort after installing the [make model] thermostat

Satisfaction

Q51. Overall, how satisfied are you with your ductless heat pump [If ever installed [make model] : “since installing the [make model] thermostat”, If control: “Thinking about the past summer and winter, how satisfied are you with your ductless heat pump?”]
a. Not at all satisfied
b. A little satisfied
c. Somewhat satisfied
d. Very satisfied
e. Extremely satisfied

[IF CONTROL or TREAT NO DEVICE skip ahead to next section.]

Q52. Overall, how satisfied are you with your [make model] thermostat?
a. Not at all satisfied

b. A little satisfied
c. Somewhat satisfied
d. Very satisfied
e. Extremely satisfied

Q53. [IF AWARE OF SCHEDULING in Q12] How satisfied are you with the scheduling features of the [make model] thermostat? [Display photo of scheduling window in the mobile app.]
a. Not at all satisfied
b. A little satisfied
c. Somewhat satisfied
d. Very satisfied
e. Extremely satisfied
f. Don't know, I never tried to set up a schedule

Q54. [IF AWARE OF OTHER FEATURES in Q12] How satisfied are you with the other features of the [make model] thermostat? (E.g., mobile app and geofencing.)
a. Not at all satisfied
b. A little satisfied
c. Somewhat satisfied
d. Very satisfied
e. Extremely satisfied
f. Don't know, I never used the other features

Q55. If you could change one thing about the [make model] thermostat, what would it be?
a. _________ [open end]

Household Characteristics

Q56. When making changes to your home's temperature, how important are each of the following? [shown as a grid]
i. Comfort
ii. Energy cost
iii. Energy conservation

a. Not at all important
b. A little important
c. Somewhat important
d. Very important
e. Extremely important

Q57. Are there any other important factors you consider when making changes to your home's temperature?

a. No
b. Yes (please tell us): _______ [open end]

The next few questions are about you and your household. Energy Trust strives to serve all races, ethnicities, income levels, and communities in its service territory. These questions are optional but will provide context for us to better understand the results of this study. Anything you share will remain confidential.

Q58. How many people live in your home? Please count yourself and any other adults and children who live there at least half of the time.
a. _____ [require integer]

Q59. [IF Q58 < 1] You have indicated that no one lives in the home. Why is this home unoccupied most of the year?
a. It is a second home
b. It is a vacation rental or investment property
c. It is undergoing renovations
d. Other: _________ [open end]

Q60. In general, since the beginning of the COVID-19 pandemic (March 2020), how has your household's overall time spent at home changed?
a. I/we have spent **a great deal more time** at home because of COVID-19
b. I/we have spent **somewhat more time** at home because of COVID-19
c. I/we have spent **a little less more** at home because of COVID-19
d. The amount of time I/we spend at home **did not change** because of COVID-19
e. I/we have spent **a little less time** at home because of COVID-19
f. I/we have spent **somewhat less time** at home because of COVID-19
g. I/we have spent **a great deal less time** at home because of COVID-19

Q61. [If Q44 > 0] We are asking about household income to help us understand how this technology affects families in different circumstances. Would you estimate your 2020 household income was above or below [$ amount as 200% FPL based on occupancy from Q6] before taxes? (no response required)
a. Above [$ amount]
b. Below [$ amount]

Q62. [If Q61=Above] Would you estimate your 2020 household income was above or below [$ amount as 400% FPL based on occupancy from Q6] before taxes? (no response required)
c. Above [$ amount]
d. Below [$ amount]

Closing

Thank you for participating in this study!

Q63. Is there anything else you would like to tell us about your responses to these questions [If TREAT ", the [model] thermostat", If TESTBED ", the PGE rewards program"] or this study?

a. No.
b. Yes: ________ [open end]

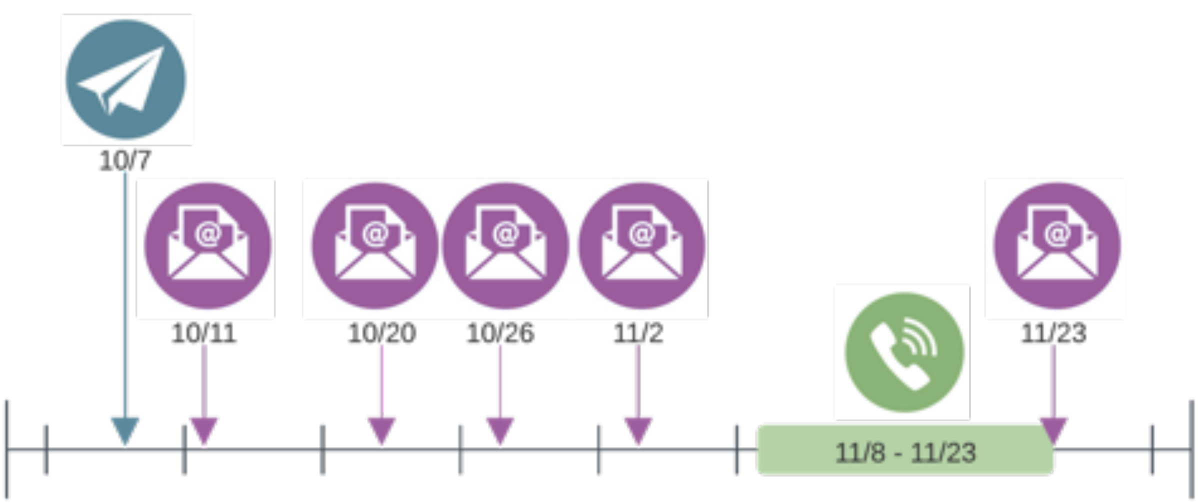
Q64. Where should we send your $15 survey completion incentive check?

a. Name: ________________________
b. Street Address: ________________________
c. City, State: ________________________
d. Zip: _____________________

B.2 Recruitment Materials

Evergreen used three modes for the survey recruitment: mail, email, and phone. Evergreen mailed a survey invitation letter, followed by an email survey invitation and up to four email reminders as shown in Figure 24. We also called non-respondents to remind them about the survey, offer to conduct the survey over the phone, referring them to the web survey if preferred, or leaving a voicemail offering both of those options if no one answers. We called each non-respondent twice, varying the time of day.

Figure 24: Survey Recruitment Timeline



B.2.1 Letters

The thermostat manufacturer, model, and photo have been redacted from these letters.

Treatment Group

1500 SW First Ave, Suite 1000
Portland, OR 97201

(503) 894-8676
evergreenecon.com

421 SW Oak St., Suite 300
Portland, OR 97204

(866) 368-7878
energytrust.org

October 8, 2021

«Name»
«Addr_Street_cap»
«Addr_City», «Addr_State» «Addr_Zip»

Dear «Name»:

Thank you for participating in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study. As we enter the final phase of this study, we are asking for a little bit more of your time to tell us about your experience. Energy Trust has hired Evergreen Economics to conduct some of this research on their behalf. Your help with this research will help homes across Oregon save money and energy.

To thank you for answering our questions, we will send you **a $10 check** for helping us with this important phase of the research.

As a participant in this study, you were sent a free <Make Model> Wi-Fi thermostat ($120 value) and asked to install it in your home and leave it in place for one year. Your feedback and energy usage data will be important to helping us understand the performance of Wi-Fi thermostats for ductless systems.

<Thermostat Image>

We appreciate your participation and adherence to the study guidelines! The data you've provided so far has been extremely helpful in our research to better understand how ductless heat pumps in Oregon are used and how they perform.

We want to ask you a few questions about your experience installing and using the Flair Puck thermostat, as well as changes to your home that may impact your energy use over time. The questions will only take a few minutes of your time to complete and will be invaluable to our research on Wi-Fi thermostats for ductless systems in Oregon.

The link to participate is: http://energytrust.org/dhp-survey

When prompted, **please enter «site_id» as your participant ID.**

Please contact me (Sarah) if you encounter any technical issues. If you have questions about the study, please visit Energy Trust's website or call Energy Trust at (866) 368-7878.

Thank you,

Sarah Monohon
Evaluation Staff
dhp-survey@evergreenecon.com
(971) 888-7478
Evergreen Economics

Dan Rubado
Sr. Project Manager – Evaluation
Dan.Rubado@energytrust.org
Energy Trust of Oregon

Control Group

EVERGREEN ECONOMICS
1500 SW First Ave, Suite 1000
Portland, OR 97201
(503) 894-8676
evergreenecon.com

Energy Trust of Oregon
421 SW Oak St., Suite 300
Portland, OR 97204
(866) 368-7878
energytrust.org

October 8, 2021

«Name»
«Addr_Street_cap»
«Addr_City», «Addr_State» «Addr_Zip»

Dear «Name»:

You may recall your household has been participating in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study. As we enter the final phase of this study, we are asking for a little bit more of your time to tell us about your experience. Energy Trust has hired Evergreen Economics to conduct some research tasks, on their behalf. Your help with this research will help homes across Oregon save money and energy.

To thank you for answering our questions, we will send you **a $10 check** for helping us with this important phase of the research.

As a participant in the study, to thank you for your help, you will receive your free <Make Model> Wi-Fi thermostat ($120 value) after this study concludes. This is in addition to the $10 thank you check that we will send you after you complete this questionnaire. Your feedback and energy usage data will be an important point of comparison for us to understand the performance of Wi-Fi thermostats for ductless systems.

<Thermostat Image>

We appreciate your participation and adherence to the study guidelines! The data you've provided so far has been extremely helpful in our research to better understand how ductless heat pumps in Oregon are used and how they perform.

We want to ask you a few questions about changes to your home that may impact your energy use over time. The questions will only take a few minutes of your time to complete and will be invaluable to our research on Wi-Fi thermostats for ductless systems in Oregon.

The link to participate is: http://energytrust.org/dhp-survey

When prompted, **please enter «site_id» as your participant ID.**

Please contact me (Sarah) if you encounter any technical issues. If you have questions about the study, please visit Energy Trust's website or call Energy Trust at (866) 368-7878.

Thank you,

Sarah Monohon
Evaluation Staff
monohon@evergreenecon.com
(971) 888-7478
Evergreen Economics

Dan Rubado
Sr. Project Manager – Evaluation
Dan.Rubado@energytrust.org
Energy Trust of Oregon

B.2.2 Emails

This section provides copy from the survey recruitment emails.

First Email

Ductless Heat Pump Wi-Fi Thermostat Study

Dear <<name>>,

[Treat: Thank you for participating in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study.] [Control: You may recall your household has been participating in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study.] As we enter the final phase of this study, we are asking for a little bit more of your time to tell us about your experiences. Energy Trust has hired Evergreen Economics to conduct a survey, and other research tasks, on their behalf. Your help with this research will help homes across Oregon save money and energy.

To thank you for answering our questions, we will send you **a $10 check** for helping us with this important phase of the research.

[Treat: As a participant in this study, you were sent a free <<Vendor Model>> Wi-Fi thermostat ($120 value) and asked to install it in your home and leave it in place for one year.] [Control: As a participant in this study, you will receive your free <<Vendor Model>> Wi-Fi thermostat ($120 value) after our current study concludes. This is in addition to the thank you $10 check that we will send you after you complete this questionnaire.]

[Treat: **This time is much easier —]** We want to ask you a few questions about [Treat: your experience installing and using the <<Vendor Model>> thermostat as well as] changes to your home that may impact your energy use over time. The questions will only take a few minutes to complete and will be invaluable to our research on Wi-Fi thermostats for ductless systems in Oregon.

To start, please click: http://energytrust.org/dhp-survey

When prompted, **please enter <<site_id>> as your participant ID.**

[Treat: Your feedback is important for Energy Trust to better understand how Wi-Fi thermostats impact home comfort and energy usage.] [Control: Your feedback and energy usage will be an important as a point of comparison for us to understand the performance of Wi-Fi thermostats for ductless systems.]

Please reply to this email for help with any technical issues. You can also visit Energy Trust's website or call 1.866.368.7878 for more information about this study.

Best,
Sarah

Sarah Monohon
Energy Trust Evaluation Staff

Reminder Email

EnergyTrust of Oregon

Ductless Heat Pump Wi-Fi Thermostat Study

Dear <<name>>,

We are just reaching out because we have not heard back from you. You may recall your household has been participating in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study.

We will **send you a $10 incentive check** as a thank you for your time if you take part in the next important phase of this study. If you take just a few minutes to share your experiences, you can help us learn how Wi-Fi thermostats impact home comfort and energy usage. This research will help homes across Oregon save money and energy.

[Treat: As a participant in this study, you were sent a free <<Vendor Model>> Wi-Fi thermostat ($120 value) and asked to install it in your home and leave it in place for one year. Your feedback is important for Energy Trust to better understand how Wi-Fi thermostats impact home comfort and energy usage.] [Control: As a participant in this study, in addition to the $10 for answering our questions, you will also receive your free Wi-Fi thermostat ($120 value) after our current study concludes. Your feedback and energy usage will be an important as a point of comparison for us to understand the performance of Wi-Fi thermostats for ductless systems.]

Please take a few minutes to help us:

To start, please click: http://energytrust.org/dhp-survey

When prompted, **please enter <<site id>> as your participant ID.**

The study will just be asking you questions about [Treat: your experience installing and using the <<Vendor Model>> thermostat as well as] any changes to your home that may affect your energy use over time.

Please reply to this email for help with technical issues during the survey. If you have questions about the study, you can visit Energy Trust's website or call Energy Trust at 1.866.368.7878

Best,
Sarah

Sarah Monohon
Energy Trust Evaluation Staff

Second Reminder Email

Text highlighted in blue was only displayed for the treatment group, while text highlighted in green was displayed for the control group, and purple was for the Test Bed.

EnergyTrust of Oregon

Ductless Heat Pump Wi-Fi Thermostat Study

Dear <<name>>,

We are reaching out again because we have not heard back from you. [Treat: As a participant in this study [[SGTB: and the Ductless Heat Pump Rewards Program]], you were sent a free Wi-Fi thermostat ($120 value) and asked to install it in your home and leave it in place for one year. [[SGTB: You are one of only 18 homes that had an opportunity to earn rewards from PGE during Peak Time Events by using your <<Vendor Model>>.]] **Even if you were unable to install or set up the device,** your feedback is important for Energy Trust to better understand how Wi-Fi thermostats impact home comfort and energy usage.] [Control: You may recall your household enrolled in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study. As a participant in this study, in addition to $10 for answering our questions, **you will also receive a free <<Vendor Model>> Wi-Fi thermostat** ($120 value) once this study concludes. Your feedback and energy usage will be an important as a point of comparison for us to understand the performance of existing Wi-Fi thermostats for ductless systems.]

To thank you for answering our questions, we will send you **a $10 check** for helping us with this important phase of the research.

Please take a few minutes to help us:

To start, please click: http://energytrust.org/dhp-survey

When prompted, **please enter <<site id>> as your participant ID.**

As we enter the final phase of this study, we are asking for a little bit more of your time to tell us about your experiences [Control: with your ductless heat pump] [Treat: trying to install and using the thermostat [[SGTB: to curb your energy usage during Peak Time Events]]] as well as any changes to your home that may affect your energy use over time. [Treat: You can help us learn how Wi-Fi thermostats impact home comfort and energy usage (even if you never used it).] Energy Trust has hired Evergreen Economics to conduct a survey, and other research tasks, on their behalf. This study will help homes across Oregon save money and energy.

Please feel free to call or email me for help. You can also visit Energy Trust's website or call Energy Trust at 1.866.368.7878.

Best,
Sarah

Sarah Monohon
Energy Trust Evaluation Staff

Final Reminder Email: Treatment Group

Subject line: "Last chance: $10 for your thoughts on the smart thermostat"

Ductless Heat Pump Wi-Fi Thermostat Study

Dear <<NAME>>,

If you are not using the <<Vendor Model>> , **that's OK!** In fact, it's *particularly* important for us to hear from you so we understand what your experience has been. As a thank you for answering our questions, we will send you **a $10 check** for helping us with this important phase of the research.

To start, please click: https://energytrust.org/dhp-survey

When prompted, **please enter <<site ID>> as your participant ID.**

As a participant in this study you were sent a free <<Vendor Model>> Wi-Fi thermostat ($120 value) and asked to install it in your home and leave it in place for one year. **Even if you changed your mind and decided not to or were unable to install or set up**

the <<Vendor Model>> device, your feedback is still very helpful and important! Your input will help Energy Trust create offerings that will best serve homes like yours in Oregon.

As we enter the final phase of this study, we are asking for a little bit more of your time to tell us about your impressions of the <<Vendor Model>> thermostat (even if you never used it) as well as any changes to your home that may affect your energy use over time. Energy Trust has hired Evergreen Economics to conduct this survey, and other research tasks, on their behalf.

Please reply to this email for help or if you'd prefer to do the survey over the phone. If you have questions about the study, you can visit Energy Trust's website or call Energy Trust on 1.866.368.7878.

Best,
Sarah

Final Reminder Email: Control Group

Subject line: "Last chance: $10 for your thoughts on heat pumps"

EnergyTrust of Oregon

Ductless Heat Pump Wi-Fi Thermostat Study

Dear <<NAME>>,

How do you control your ductless (mini-split) heat pump? Did you use any other heating or cooling equipment this year? To thank you for answering these questions (and a few others), we will send you **a $10 check** for helping us with this important phase of the research.

To start, please click: https://energytrust.org/dhp-survey

When prompted, please enter <<site ID>> as your participant ID.

You may recall your household enrolled in Energy Trust of Oregon's ductless heat pump Wi-Fi thermostat study. As a participant in this study, in addition to $10 for answering our questions, **you will also receive a free <<Vendor Model>> Wi-Fi thermostat** ($120 value) once this study concludes. Your feedback and energy usage will be important as a point of comparison for us to understand the performance of Wi-Fi thermostats for ductless systems.

As we enter the final phase of this study, we are asking for a little bit more of your time to tell us about your heating equipment and any major changes to your home that may have affected your energy use over time. Your input will help Energy Trust create offerings that will best serve homes like yours in Oregon. Energy Trust has hired Evergreen Economics to conduct this survey and other research tasks, on their behalf.

Please reply to this email for help or if you'd prefer to do the survey over the phone. If you have questions about the study, you can visit Energy Trust's website or call Energy Trust on 1.866.368.7878.

Best,
Sarah

Appendix C: Regression Outputs

Table 23 provides the coefficient estimates for the daily model by supplemental heating type. Statistically significant *increases* in energy usage are shown in red text. The $Treat * Post$ coefficient provides the average daily impact of the smart DHP controls on the home's baseline. The $HDD * Treat * Post$ coefficients provide the incremental impact of the smart DHP controls for each additional heating degree day (HDD) (i.e., any change in the heating slope) from the relevant base temperature (under 45°F or between 45-60°F) in the heating season of a normalized weather year (TMY3). Similarly, the $CDD * Treat * Post$ coefficients provide the incremental impact of the smart DHP controls for each additional cooling degree day (CDD) (i.e., any change in the cooling slope) from the relevant base temperature (over 80°F or between 65-80°F) in the cooling season of a normalized weather year (TMY3).

Table 23: Daily Model Coefficient Estimates

Supplemental Heating	Model Coefficients					LATE Adjustment	Normalized Energy Savings
	$\widehat{\beta}_{Treat*Post}$	$\widehat{\beta}_{CDD_{80}*Treat*Post}$	$\widehat{\beta}_{CDD_{80-65}*Treat*Post}$	$\widehat{\beta}_{HDD_{45}*Treat*Post}$	$\widehat{\beta}_{HDD_{60-45}*Treat*Post}$	# T-stat / # Treat	(kWh, after adjustment)
Zonal	-0.017	-0.287**	-0.031	-0.258**	0.010	0.771	-260 ± 59
eFAF	1.548**	-0.646**	-0.065	0.008	-0.078*	0.667	399 ± 100
Oddballs	-0.944**	-0.569**	0.254**	-0.165**	-0.019	0.685	-663 ± 93

NOTE: p-value * <0.10, ** <0.05

We estimated normalized electricity savings by combining the regression coefficients with normalized weather conditions from TMY3 for each hour of each day (Table 24). The coefficient on each $TOW * Treat * Post$ coefficient provides the average hourly impact of the smart DHP controls on baseline energy consumption, while the coefficient on each $HDH * Treat * Post$ coefficient provides the incremental impact of the smart DHP controls for each additional degree of heating load (i.e., estimated change in the kWh required for heating one hour when outdoor air temperature drops by one additional degree Fahrenheit). There are also 48 distinct coefficients for $TOW * Treat * Post$ (one for each hour on weekdays and one for each hour on weekends) and one coefficient for the average hourly impact of $Treat * Post$ that contribute to the savings estimate; these are not shown in the table in the interest of space. The local average treatment effect (LATE) adjustment was applied to the estimated impact of the treatment to account for the proportion of sites assigned to the treatment group that never completed the device installation and setup.

Table 24: Hourly Coefficient Estimates and LATE Adjustment

Supplemental Heating	$\widehat{\beta}_{\substack{HDH_{45}*\\Treat*Post}}$ (0,45)	$\widehat{\beta}_{\substack{HDH_{60-45}*\\Treat*Post}}$ [45,60)	$\widehat{\beta}_{\substack{CDH_{80-65}*\\Treat*Post}}$ [65,80)	$\widehat{\beta}_{\substack{CDH_{80}*\\Treat*Post}}$ (80,100)	LATE Adjustment # T-stat / # Treat
Zonal	0.007**	<0.001	0.001*	0.003**	0.771
eFAF	0.001**	-0.001	0.001	0.012**	0.667
Oddballs	0.007**	0.003**	-0.001	0.005**	0.685

NOTE: p-value: * <0.1, ** <0.05.

We assessed that there may be a sufficient sample size to make a meaningful comparison of savings across the following customer segments: single versus multi-head systems, home size, heating zone, daily use of the DHP, homes that have children, homes with an adult working from home (WFH), income level, occupancy, floor plan, and amount of time spent at home during the COVID-19 pandemic. Table 25 provides the coefficients and normalized energy savings by supplemental heating type and customer segment. We have omitted customer segments with fewer than 30 customers, as the sample is likely too small to draw meaningful conclusions from.

Table 25: Normalized Annual Energy Savings and Model Coefficients of Smart DHP Controls by Subgroup

Supple-mental Heating	Category	Sub-Group	$\widehat{\beta}_{Treat*Post}$	$\widehat{\beta}_{CDD_{80}*Treat*Post}$	$\widehat{\beta}_{CDD_{80-65}*Treat*Post}$	$\widehat{\beta}_{HDD_{45}*Treat*Post}$	$\widehat{\beta}_{HDD_{60-45}*Treat*Post}$	Norm Energy Savings (kWh, after LATE adj)
Zonal	Overall		-0.017	-0.287**	-0.031	-0.258**	0.010	-260 ± 59
	Multi-Head	Yes	0.782**	-0.460**	-0.051	-0.350**	-0.052	-306 ± 86
		No	-1.022**	-0.088	-0.047	-0.226**	0.105**	-378 ± 82
	Square Footage	<1,400	-0.131	-0.384**	0.079	-0.242**	0.032	-202 ± 67
		1,400-1,799	-1.526**	-0.377	0.042	-0.639**	0.148**	-896 ± 126
		1,800+	2.116**	-0.038	-0.529**	0.159	-0.123	368 ± 181
	Heat Zone	1	0.025	-0.146	0.001	-0.288**	0.026	-232 ± 62
	DHP Use	Everyday	-0.039	-0.362**	-0.037	-0.263**	0.001	-372 ± 61
	Has Children	Yes	0.518	-0.719**	-0.026	-0.162**	0.024	72 ± 116
		No	-0.132	-0.120	-0.050	-0.233**	-0.009	-409 ± 69
	Adult WFH	Yes	-1.367**	-0.163	0.055	-0.242**	0.055	-695 ± 86
		No	1.414**	-0.321*	-0.134	-0.277**	-0.069*	-29 ± 82
	Income	< 200% FPL	0.101	0.637	0.024	-0.454**	0.184**	305 ± 165
		200-400% FPL	-0.946*	-0.357	0.301**	-0.058	-0.015	-409 ± 119
		> 400% FPL	-1.222**	-0.405*	-0.144	-0.365**	0.102**	-735 ± 98
	Occupancy	1	-0.255	-0.116	-0.159	-0.566**	0.223**	-27 ± 98
		2	0.101	-0.473**	-0.003	-0.046	-0.182**	-748 ± 90
		3+	0.559	-0.081	-0.084	-0.088	0.087*	436 ± 112

Supple-mental Heating	Category	Sub-Group	$\widehat{\beta}_{Treat*Post}$	$\widehat{\beta}_{CDD_{80}*Treat*Post}$	$\widehat{\beta}_{CDD_{80-65}*Treat*Post}$	$\widehat{\beta}_{HDD_{45}*Treat*Post}$	$\widehat{\beta}_{HDD_{60-45}*Treat*Post}$	Norm Energy Savings (kWh, after LATE adj)
	Floor Plan	Open	-0.393	-0.138	-0.084	-0.137**	-0.014	-464 ± 81
		Not-Open	1.242**	-0.276	-0.083	-0.437**	0.018	78 ± 103
	Home During COVID	Great deal more	-0.917**	-0.124	0.005	-0.284**	0.104**	-368 ± 96
		Little more	-1.026**	-0.402	0.177	-0.224**	0.030	-552 ± 106
		Same or less						
eFAF	Overall		1.548**	-0.646**	-0.065	0.008*	-0.078	399 ± 100
	Multi-Head	Yes	-0.737	-1.192*	0.627**	-0.424**	-0.118	-1,149 ± 198
		No	2.167**	-0.270	-0.377**	0.074	0.028	1,103 ± 112
	Square Footage	<1,400	1.784**	-0.857**	-0.070	0.044	-0.019	813 ± 115
		1,400-1,799						
		1,800+						
	Heat Zone	1	1.312**	-0.842**	0.088	-0.181**	-0.029	326 ± 112
	DHP Use	Everyday	2.399**	-0.435*	-0.268**	0.025	-0.150**	440 ± 108
	Has Children	Yes						
		No	0.511	-0.889**	0.112	-0.007	-0.019	178 ± 105
	Adult WFH	Yes	-0.058	-0.526	0.082	0.379**	0.047	687 ± 169
		No	1.986**	-0.762**	-0.074	-0.189**	-0.104*	240 ± 123
	Income***	< 200% FPL						

Supple-mental Heating	Category	Sub-Group	$\widehat{\beta}_{Treat*Post}$	$\widehat{\beta}\ CDD_{80*}$ $Treat*Post$	$\widehat{\beta}\ CDD_{80-65*}$ $Treat*Post$	$\widehat{\beta}\ HDD_{45*}$ $Treat*Post$	$\widehat{\beta}\ HDD_{60-45*}$ $Treat*Post$	Norm Energy Savings (kWh, after LATE adj)
		200-400% FPL						
		> 400% FPL						
	Occupancy	1	3.973**	-1.004**	-0.271	0.359**	-0.523**	25 ± 170
		2	-0.863	-0.533*	0.071	0.005	0.175**	308 ± 133
		3+						
	Floor Plan	Open	1.940**	-0.555*	-0.304**	0.256**	-0.036	960 ± 132
		Not-Open						
	Home During COVID	Great deal mor	0.499	-0.716**	0.083	-0.167**	0.007	70 ± 152
		Little more						
		Same or less						
Oddballs	Overall		-0.944**	-0.569**	0.254**	-0.165**	-0.019	-663 ± 93
	Multi-Head	Yes	1.760**	-0.126	-0.060	-0.086	-0.052	547 ± 124
		No	-4.670**	-1.000**	0.635**	-0.336**	0.049	-2,354 ± 138
	Square Footage	<1,400	-3.885**	-0.223	0.143	0.146**	-0.051	-2,023 ± 143
		1,400-1,799	0.446	-0.615	0.329*	-0.237**	-0.168**	-619 ± 172
		1,800+	-0.075	-1.456**	0.723**	-0.191**	0.060	350 ± 176
	Heat Zone	1	-0.997**	-0.984**	0.348**	-0.197**	-0.016	-704 ± 99
	DHP Use	Everyday	-1.642**	-0.921**	0.477**	-0.131**	0.068	-497 ± 113

Supple-mental Heating	Category	Sub-Group	$\widehat{\beta}_{Treat*Post}$	$\widehat{\beta}_{CDD_{80}*Treat*Post}$	$\widehat{\beta}_{CDD_{80-65}*Treat*Post}$	$\widehat{\beta}_{HDD_{45}*Treat*Post}$	$\widehat{\beta}_{HDD_{60-45}*Treat*Post}$	Norm Energy Savings (kWh, after LATE adj)
	Has Children	Yes	0.730	-0.499	-0.184	0.035	-0.112	-231 ± 219
		No	-1.444**	-0.613**	0.359**	-0.210**	0.009	-802 ± 102
	Adult WFH	Yes	1.203*	-0.018	0.073	0.147	-0.040	711 ± 157
		No	-2.298**	-0.825**	0.389**	-0.226**	-0.035	-1,470 ± 120
	Income	< 200% FPL	0.942	-1.639**	0.679**	0.224*	-0.206**	230 ± 190
		200-400% FPL	-1.454	-0.264	0.597**	-0.207*	0.059	-383 ± 222
		> 400% FPL						
	Occupancy	1						
		2	-2.830**	-1.000**	0.569**	-0.348**	0.088	-1,266 ± 126
		3+	0.228	-0.736*	-0.277	0.035	-0.177**	-872 ± 181
	Floor Plan	Open	-3.867**	-0.995	0.568	-0.234**	0.174**	-1,301 ± 161
		Not-Open	-0.930**	-1.390**	0.565**	-0.444**	0.154**	-133 ± 159
	Home During COVID	Great deal more	-1.344	-1.028**	0.774**	0.446**	-0.447**	-1,613 ± 222
		Little more						
		Same or less						

NOTE: p-value: * <0.10, ** <0.05

*** There were fewer than 30 customers in all three income brackets for eFAF. All of these coefficients have been intentionally omitted.

Table 26 provides the model coefficients and normalized energy savings by supplemental heating type collected on the intake survey compared to the supplemental heating type collected in the follow-up survey. The intake survey grouped customers into supplemental heating type bins based on the secondary heating type ***in the home***, whereas the follow-up survey asked about the supplemental heating type for ***the room(s) served*** by the DHP. The follow-up survey found that a large group of these homes did not have any supplemental heating for the room served by the DHP (46%, or 185 out of 398).

Table 26: Normalized Energy Savings and Model Coefficients of DHP Controls by Supplemental Heat Type

Supple-mental Heating	Survey	$\hat{\beta}_{Treat*Post}$	$\hat{\beta}\ _{Treat*Post}^{CDD_{80}*}$	$\hat{\beta}_{Treat*Post}^{CDD_{65-80}*}$	$\hat{\beta}\ _{Treat*Post}^{HDD_{45}*}$	$\hat{\beta}_{Treat*Post}^{HDD_{60-45}*}$	Norm Energy Savings (kWh, after LATE adj)	n
Zonal	Intake	-0.017	-0.287**	-0.031	-0.258**	0.010	-260 ± 59	320
	Evergreen	0.052	-0.297	-0.175	-0.389**	-0.099*	-940 ± 124	62
eFAF	Intake	1.548**	-0.646**	-0.065	0.008*	-0.078	399 ± 100	108
	Evergreen	-2.094**	-1.403**	0.699**	0.254**	0.351**	1,121 ± 223	19***
Oddball	Intake	-0.944**	-0.569**	0.254**	-0.165**	-0.019	-663 ± 93	166
	Evergreen	-0.685	-1.233**	0.463**	-0.039	-0.156**	-877 ± 126	95
Mixed	Evergreen	0.165	-0.523	0.029	0.170*	-0.108	-190 ± 186	37
No Other	Evergreen	-0.505*	-0.271	0.098	-0.269**	0.123**	-40 ± 75	185

NOTE: p-value: * <0.10, ** <0.05

*** This savings estimate may not be reliable because it is based on only 19 sites.