CADMUS

Residential Ductless Heat Pump Study

June 21, 2019

Prepared for:

Energy Trust of Oregon
421 SW Oak Street
Suite 300
Portland, OR 97204

Prepared by:
Ari Jackson
John Walczyk

CADMUS

Table of Contents

Tables

Figures

CADMUS

Energy Trust of Oregon

MEMO

Date: October 1, 2019
To: Board of Directors
From: Dan Rubado, Evaluation Project Manager
Mark Wyman, Sr. Program Manager - Residential
Scott Leonard, Sr. Project Manager - Residential
Jackie Goss, Sr. Planning Engineer
Subject: Staff Response to the Residential Ductless Heat Pump Study

The residential Ductless Heat Pump (DHP) study completed by Cadmus provided Energy Trust with a wealth of insight into the drivers of electric savings for DHPs in both single family and multifamily applications. Overall savings were disappointing in both sectors, but they could generally be explained by known issues that Energy Trust has the ability to address. In the ideal installation scenarios, the study documented electric savings that were very similar to expected, deemed savings values. In those cases, DHP electric savings were robust and represented relatively high percentages of total energy consumption. The study also uncovered several important non-energy benefits that Energy Trust will consider in the way it values DHPs compared to their costs. These included wood fuel reductions, the addition of cooling capacity and increased thermal comfort. Participants reported that increased comfort due to increased heating and cooling capacity was one of the primary motivations for installing a DHP.

Several factors negatively impacted overall savings from DHPs, most notably:

- A high prevalence of supplemental heating fuels, particularly wood.
- Systems that were installed in previously unconditioned spaces.

Multifamily properties were much less impacted by these factors, but savings from the ideal installation scenarios were lower than in single-family homes. Homes with low baseline electricity consumption, which may already indicate supplemental fuel usage or low savings potential, also showed lower savings. In addition, larger, newer homes tended to save less electricity. Smaller systems, with a single indoor head, installed in the home's primary living space achieved the most cost-effective savings. Energy Trust will attempt to push the market toward this scenario in the future.

Although DHPs are still not cost-effective in many scenarios, Energy Trust's Residential program is pursuing strategies to improve savings and reduce costs. In addition, DHPs appear to be a good equity measure, as they benefit rural and low-income households which often use more electric resistance heating, along with smaller homes having higher occupancy levels. These are situations in which DHPs tend to save more energy and are most cost-effective. By increasing market penetration of DHPs in rural and low-income households, Energy Trust may achieve higher electric savings, decrease costs, and achieve its goals of better serving underserved populations.

Energy Trust recently received an exception to continue DHP incentives through March 2022. In that time, Energy Trust's programs will enhance measure requirements, improve screening and targeting of DHPs, and work with contractors to increase savings and reduce costs. The result will be a more cost-effective electricity-saving technology in the future. To this end, Energy Trust will adjust its measure requirements and analysis of DHP savings and costs to include the following:

- Indoor heads must be placed in the primary living space.
- Additional indoor heads will not be recommended and we'll assume that installed systems are 1-to-1 (additional indoor units are at the customer's discretion, but they are not expected to save additional energy and Energy Trust will not support them).
- Develop a new measure for DHPs displacing wood heat which is cost-effective due to the value of wood savings.
- Incorporate cooling savings for homes that would have installed a less efficient cooling system in place of a DHP.
- Quantify cooling comfort benefits for homes which add cooling.
- Incorporate avoided electricity costs for the summer cooling season.

Energy Trust programs will also undertake the following strategies and initiatives:

- Launch new fixed price offers with more stringent installation requirements and a cost ceiling.
- Target housing types and regions where DHPs are more cost-effective.
- Research improved controls for DHPs.
- Explore DHP demand response potential, especially for peak summer cooling demand. A demand response opportunity with DHPs might create an opportunity for Energy Trust to combine funds with electric utilities to improve their cost-effectiveness.

Introduction

Background

Energy Trust of Oregon has offered cash incentives for the installation of ductless heat pumps (DHPs) in single-family homes since 2008 and in multifamily residences since 2009. These systems deliver heating and cooling at greater efficiencies than many alternative systems and as a result have a comparatively high technical potential for reducing energy consumption. Table 1 provides a comparison of efficiencies of common heating and cooling systems.

Table 1. Efficiencies of Common Heating and Cooling Systems*

Operating Principal	Fuel Type	System Type	Heating Efficiency/COP	Cooling Efficiency/COP
Heat Pump/ Refrigeration Cycle	Electricity	Heat Pump	2.49+ (1)	4.39+ (1)
		Window Air Conditioner	NA	2.9–4.3 (2)
		Central Air Conditioner		4.39+ (1)
Combustion	Oil, Natural Gas, Propane	Boiler	0.80–0.98 (3)	NA
		Furnace		
	Wood	Pellet Stove	0.70–0.82 (4)	
Electric Resistance	Electricity	Baseboard	1.0 (5)	NA
		Furnace		
		Portable Heater		
		Wall Heater		

(1) ENERGY STAR, COPs converted from seasonal ratings (SEER/HSPF)
(2) ENERGY STAR, COPs converted from CEER
(3) https://www.energy.gov/energysaver/home-heating-systems/furnaces-and-boilers
(4) https://www.energy.gov/energysaver/home-heating-systems/wood-and-pellet-heating
(5) https://www.energy.gov/energysaver/home-heating-systems/electric-resistance-heating
*Values presented in this table are intended only for high-level comparisons and oversimplify many complexities encountered when considering tradeoffs between two heating or cooling systems. A detailed comparison would account for technical factors such as duct leakage, system sizing, zoning, controls, climate, etc.

The prevalence of inefficient systems and low adoption rates of DHPs in the Northwest also contributes to the large technical potential of DHPs, as shown in Table 2.

Table 2. Distribution of Primary Heating and Cooling Systems

System Type	Single-Family (1)		Multifamily (2)	
	Heating	Cooling	Heating	Cooling
Ductless Heat Pump	4%	8%	3%	14%
Air Source Heat Pump	11%	25%	2%	4%
Electric Baseboard and Wall Heater	10%	NA	56%	NA
Furnace	57%	NA	8%	NA
Window AC	NA	21%	NA	68%
Central AC	NA	43%	NA	11%

(1) NEEA RBSA II Single-Family

(2) NEEA RBSA II Multifamily

However, in calculating measure cost-effectiveness, the price of the system plays an equally important role as the potential for saving energy. Table 3 and Table 4 summarize historical costs for single-family and multifamily projects receiving incentives from Energy Trust.

Table 3. Number of Single-Family DHP Installs by Year[1, 2]

Year Installed	Number of Projects	Number of DHP Systems	Total Claimed Savings [kWh]	Average Savings Claimed per Site [kWh]	Average Install Cost
2008	38	40	88,400	2,210	$5,884
2009	158	180	392,151	2,179	$5,200
2010	477	531	1,420,019	2,674	$5,584
2011	521	572	1,946,439	3,403	$5,592
2012	815	825	2,774,910	3,364	$5,215
2013	1,231	1,236	4,192,125	3,392	$5,228
2014	1,590	1,591	5,161,477	3,244	$5,329
2015	999	999	2,719,452	2,722	$5,914
2016	989	990	2,217,934	2,240	$6,273
2017	1,842	1,848	4,167,098	2,255	$6,404

[1]Energy Trust of Oregon. Request for Proposals: Residential Ductless Heat Pump Study. 2018.

Table 4. Number of Multifamily DHP Installs by Year[1]

Year Installed	Number of Projects	Number of DHP Systems	Total Claimed Savings [kWh]	Average Savings Claimed per Site [kWh]	Average Install Cost
2009	12	13	27,677	2,129	$5,754
2010	27	54	135,063	2,499	$5,677
2011	37	154	530,532	3,273	$5,081
2012	82	208	673,159	3,124	$3,600
2013	131	173	524,932	3,108	$5,040
2014	236	525	1,458,518	2,862	$4,738
2015	254	554	1,542,922	2,846	$5,225
2016	291	746	2,089,725	2,839	$5,220
2017	375	535	1,950,905	3,769	$5,441

[1]Energy Trust of Oregon. Request for Proposals: Residential Ductless Heat Pump Study. 2018.

In 2017, Energy Trust found most DHP installation scenarios were not cost-effective. One factor in this analysis was the expiration of Oregon's Residential Energy Tax Credit for DHPs. Table 5 and Table 6 highlight where a total resource cost (TRC) test determined DHPs have a benefit cost ratio (BCR) less than 1, indicating these measures are not cost-effective.

Table 5. Oregon Cost-Effectiveness Calculator: Single-Family[1]

Measure	Measure Life (years)	Savings (kWh)	Incremental Costs ($)	Non-Energy Benefits (Annual $)	Maximum Incentive ($)	UCT BCR at Max Incentive	TRC BCR
Single-Family DHP for Zonal HZ 1	18	2,109	$5,388	$83	$2,058	1.00	0.57
Single-Family DHP for Zonal HZ 2	18	2,314	$5,388	$88	$2,258	1.00	0.62
Single-Family DHP for FAF HZ 1	18	3,836	$5,388	$134	$3,743	1.00	1.00
Single-Family DHP for FAF HZ 2	18	3,592	$5,388	$163	$3,505	1.00	1.02
Manufactured Home DHP for Zonal HZ 1	18	2,109	$4,878	$83	$2,058	1.00	0.63
Manufactured Home DHP for Zonal HZ 2	18	2,314	$4,878	$88	$2,258	1.00	0.69
Manufactured Home DHP for FAF HZ 1	18	5,736	$4,878	$39	$4,878	1.15	1.25
Manufactured Home DHP for FAF HZ 2	18	5,651	$4,878	$49	$4,878	1.13	1.25

[1]Energy Trust of Oregon. (2017). Measure Approval Document for Existing Single Family and Manufactured Housing Ductless Heat Pumps – MAD ID 70.2

Table 6. Oregon Cost-Effectiveness Calculator: Multifamily[1]

Measure	Measure Life (years)	Savings (kWh)	Incremental Costs ($)	Non-Energy Benefits (Annual $)	Maximum Incentive ($)	UCT BCR at Max Incentive	TRC BCR
Multifamily DHP Heating Zone 1	18	2,000	$3,560	$18.04	$1,952	1.00	0.61
Multifamily DHP Heating Zone 2	18	2,194	$3,560	$36.91	$2,141	1.00	0.73

[1]Energy Trust of Oregon. (2017). Measure Approval Document for Ductless Heat Pumps in Existing Multifamily – MAD ID 97

Measures that are not cost-effective are not typically supported by Energy Trust, but the Oregon Public Utility Commission (OPUC) granted an exception to allow Energy Trust to offer incentives for DHPs through the end of 2019. During this period, Energy Trust hired Cadmus to evaluate DHPs and to identify potential cost-effective installation scenarios.

Research Objectives

The goal of this evaluation is to determine the most cost-effective DHP installation scenarios and inform new residential offerings using empirical evidence. In its request for proposals, Energy Trust outlined the following research objectives:

- Quantify energy savings and costs of DHPs in single-family and multifamily buildings overall and for key installation scenarios.
- Estimate the impact of supplemental fuel usage on DHP energy savings and quantify supplemental fuel savings and benefits.
- Estimate the impact of DHPs on cooling energy usage compared to different baseline cooling scenarios.
- Determine the primary drivers of variability in DHP energy savings and costs. Identify the most cost-effective installation scenarios as well as factors that contribute to low energy savings and high costs.
- Understand how DHPs and existing heating and cooling systems are controlled for key installation scenarios.
- Understand the impact of different control strategies on savings.
- Understand the participant decision-making process and motivations for installing DHP systems, including important non-energy benefits.
- Identify improvements to Energy Trust data and data collection processes.

Research Design

The primary research objectives outlined above require estimates of annual energy savings resulting from the installation of a DHP. Cadmus used a quasi-experimental design to develop these estimates where each program participant was matched to a group of non-participants that were of the same building type, located within a limited geographic area, and had a similar energy consumption profile during the participants' pre-installation period. Cadmus divided each non-participant into pre- and post-installation periods using the installation date of the matched participant. Following this matching, Cadmus estimated Typical Meteorological Year (TMY) energy savings for each participant and non-participant as the difference between modeled pre- and post-installation consumption, and differenced each participant's results with those of matched non-participants to develop a final savings estimate.

This difference-in-difference framework is used to isolate program-specific impacts under the assumptions that pre-period electricity consumption is the correct counterfactual baseline scenario and that post-installation changes in consumption in the participant group, unrelated to DHP installations, are also present in the non-participant comparison group. This analysis was supplemented with participant and non-participant surveys, and several questions in these surveys targeted understanding how well these assumptions held for sites included in the analysis. Cadmus also used the survey responses to segment the savings analysis and to identify ideal DHP installation scenarios.

Data

Data Sources

Cadmus used the following datasets in its evaluation:

- **Utility Customer Information (UCI)**: This dataset contains monthly electric and natural gas energy consumption from program participants and non-participants, utility account numbers, and point of deliver identifiers (PODIDs) between 2011 and 2018.
- **Project Tracking**: This dataset contains attributes identifying program participants and non-participants, and it includes specifications of the installed equipment, incentives, costs, energy savings, participation in non-DHP programs, and other fields.
- **Customer Relationship Management**: This dataset contains the information necessary for contacting program participants and non-participants to conduct surveys. Attributes include names, mailing addresses, email addresses, phone numbers, rental status, and date of the most recent contact from Energy Trust.
- **Meteorological**: Meteorological variables (such as temperature and relative humidity) or derived variables (such as heating degree days [HDDs] and cooling degree days [CDDs]) are used in isolating program impacts as they allow for developing energy consumption models that account for differences in observed weather over time. Records coincident with UCI data are publicly available from NOAA (National Oceanic and Atmospheric Administration), and Typical Meteorological Year (TMY) data are publicly available from NREL (National Renewable Energy Laboratory).
- **Survey:** Cadmus conducted phone and web-based surveys with participants and non-participants in single-family and multifamily residences. These data were collected for the specific research objectives of this evaluation and used to segment the results of the billing and cost-effectiveness analysis to identify favorable DHP installation scenarios.
- **Climate Zone:** Cadmus used publicly available data from the Regional Technical Forum (RTF) to map Oregon zip codes to standardized heating and cooling zones.

Sample Selection

Unit of Observation

The unit of analysis in this study is energy savings per DHP installation, however, not all datasets used in the analysis are available at this granular of a level. Cadmus produced results at this level by using the combination of an Energy Trust site ID and a utility point of delivery ID (PODID) as the unit of observation in the regression modeling, totaling savings estimates over all points of delivery, and dividing by the total number of DHPs installed for the collection of sites. Cadmus determined the analysis sample using this unit of observation, and the tables and figures in this section are aggregations of data described by this combination of site ID and PODID.

The combined PODID and single-family site ID map closely to the level of an individual home, except in a small percentage of homes with more than one meter. For homes with multiple meters, each point of delivery was modeled separately, and all meters were individually included in calculating savings. The multifamily site ID approximately describes a single dwelling unit within a multifamily building. It is possible a multifamily building had a single meter for all units, although this arrangement is relatively rare, and in this case Cadmus modeled the building level consumption as long as no major energy efficiency upgrades occurred at the site. The analysis of single-family and multifamily non-participants used the same combinations of site ID and PODID.

Exclusion Criteria

Cadmus applied several exclusion criteria to determine its sample for analysis. These criteria fall into two broad categories: one focused on data sufficiency and one on the preservation of assumptions outlined in the research design.

The largest portion of PODIDs were removed because of the necessary timing of the billing data request, leaving many sites installed in 2018 without a sufficient post-installation period. The criterion leading to the second largest reductions in single-family and multifamily samples was a PODID with fewer than ten intervals of electric billing data. This is an important criterion, especially for DHPs because the systems provide heating and cooling and failing to observe energy consumption during winter or summer does not allow modeling this seasonal usage.

Another cause for reductions in single-family and multifamily samples resulted from installations of non-DHP efficiency measures during the study period. These measures are confounding to the difference-in-difference framework, but the method agreed upon with Energy Trust was to remove sites when the total *ex ante* savings from other measures during the study period was greater than 10% of *ex ante* savings for the installed DHP project. The remainder of the criteria applied excluded portions of the samples in the low single digits.

Table 7 and Table 8 summarize each criterion used to determine the final single-family and multifamily samples.

Table 7. Single-Family Participant Sample Selection

Exclusion Criteria	Count of PODIDs Before Criteria	Count of PODIDs After Criteria	Count of PODIDs Excluded	Percent of PODIDs Excluded
No Installation Date to Divide Pre- and Post-Periods	7,522	6,947	575	7.6%
No Pre-Period Data	6,947	6,317	630	8.4%
No Post-Period Data	6,317	6,275	42	0.6%
Fewer Than Ten Billing Records in Pre-Period	6,275	5,778	497	6.6%
Installation Too Close to Date of Data Request	5,778	4,662	1,116	14.8%
Fewer Than Ten Billing Records in Post-Period	4,662	3,945	717	9.5%
Pre- or Post-Period Duration Less Than 300 Days	3,945	3,942	3	0.0%
Billing Interval Duration in Pre- or Post-Period Greater Than 65 Days	3,942	3,707	235	3.1%
Multiple DHP Projects*	3,707	3,697	10	0.1%
Mis-Categorized as Single-Family	3,697	3,493	204	2.7%
Installation of Non-DHP Measures During Study Period	3,493	2,818	675	9.0%
Record of Utility Meters w/o Corresponding Billing Data	2,818	2,406	412	5.5%
Account Turnover During Study Period	2,406	1,934	472	6.3%
No Suitable Non-Participant for Matching	1,934	1,819	115	1.5%
Matched Non-Participants Did Not Meet Data Sufficiency Criteria Above	1,819	1,754	65	0.9%
Top/Bottom 1% of Pre/Post-Period Consumption	1,754	1,683	71	0.9%
Account Turnover of Matched Non-Participants	1,683	1,616	67	0.9%

*Indicates projects took place at different points in time

Table 8. Multifamily Participant Sample Selection

Exclusion Criteria	Count of PODIDs Before Criteria	Count of PODIDs After Criteria	Count of PODIDs Excluded	Percent of PODIDs Excluded
No Pre-Period Data	1,089	1,066	23	2.1%
No Post-Period Data	1,066	919	147	13.5%
Fewer Than Ten Billing Records in Pre-Period	919	841	78	7.2%
Installation Too Close to Date of Data Request	841	604	237	21.8%
Fewer Than Ten Billing Records in Post-Period	604	408	196	18.0%
Pre- or Post-Period Duration Less Than 300 Days	408	408	0	0.0%
Billing Interval Duration in Pre- or Post-Period Greater than 65 Days	408	367	41	3.8%
Installation of Non-DHP Measures During Study Period	367	229	138	12.7%
Account Turnover During Study Period	229	145	84	7.7%
No Suitable Non-Participant for Matching	145	142	3	0.3%
Matched Non-Participants Did Not Meet the Data Sufficiency Criteria Above	142	139	3	0.3%
Top/Bottom 1% of Pre/Post-Period Consumption	139	131	8	0.7%
Account Turnover of Matched Non-Participants	131	131	0	0.0%

Non-Participant Matching

This report's Research Design section discusses the use of a difference-in-difference framework with matched non-participants. After determining the final analysis samples for single-family and multifamily participants, Cadmus matched non-participants from a pool of residences that participated in non-DHP efficiency programs during Energy Trust's history (2002-2018) where the total *ex ante* savings from these programs during the assumed DHP study period were a small portion of consumption (<0.5%). The reason for using this pool of non-participants, even though they participated in other programs, was to ensure a degree of comparability (such as electric heating), similar propensity to participate in programs, and the availability of supplementary data from Energy Trust to use in the matching. Matches were restricted by building type (single-family or multifamily) and by geography, using the nearest weather station to the site as a proxy. Cadmus compared participant baseline period energy consumption with concurrent usage for every non-participant of the same building type and geography using three metrics: Euclidian distance, Mahalanobis distance, and mean bias.

Cadmus matched non-participants without replacement based on the minimum distance or bias from each participant and targeted a total of five matches. Matching occurred level of the PODID. This process was completed for each of the three metrics calculated between participants and non-participants allowing Cadmus to compare tradeoffs between bias and variance by reviewing aggregated annual usage and consumption profiles. Cadmus conducted this same review for varying numbers of matched non-participants (ranging from one to five matches).

Through this iterative process, Cadmus determined that the best available approach for matching the sample of participants was to minimize mean bias during the pre-period and to use a single non-participant. The following section includes supporting tables and figures.

Summary Statistics

There are inherent limitations in constructing a group of matched non-participants. Cadmus examined in aggregate the single-family and multifamily participant and non-participant groups to understand how similar they were and for quality control. It is important to consider that the modeling framework chosen for this study did not assume baseline period consumption of participants and non-participants are identical, but rather that differences in consumption—unrelated to a DHP installation—between the baseline and post-periods are similar.

Table 9 summarizes average baseline period consumption of participants and non-participants for the single-family and multifamily analysis samples. In this table, the unit of observation is the combination of an Energy Trust site ID and PODID; the single-family group will approximately map to a home and the multifamily group will map to a multifamily dwelling unit. There are exceptions to this mapping, but with this generalization it is intuitive why the single-family sample has on average higher annual consumption than the multifamily sample. The table also shows that the average consumption of participants and non-participants for both groups is similar. This result is in part because non-participants were matched to minimize bias.

Table 9. Average Baseline TMY Energy Consumption [kWh]

Residential Group	Sample Size	Average Participant Baseline Energy Consumption [kWh/PODID]	Average Non-Participant Baseline Energy Consumption [kWh/PODID]	Absolute Percent Difference
Single-Family	1,616	13,647	13,621	<1
Multifamily	131	9,300	9,238	<1

Cadmus also plotted average monthly baseline period energy consumption for single-family and multifamily participants and non-participants, shown in Figure 1 and Figure 2. In each figure there are approximately three years of data shown; this is because three years of DHP installations were evaluated in this study. The single-family data match well, with small deviations between participants and non-participants during the summers of 2014 and 2015. The multifamily data does not match as well, although there are some considerations that go along with this result. First, a smaller number of PODIDs were averaged to produce this figure, and in general an average of a smaller number of samples will be more variable. This smaller sample stems from the fewer number of PODIDs available for analysis and the greater number removed due to insufficient data and installations of a large number of non-DHP efficiency measures. Second, as discussed above, the analysis did not assume these average usage profiles were identical. And third, Cadmus tested alternative metrics for matching that did not greatly improve this figure without introducing large bias into the average annual baseline period consumptions summarized in Table 9. Cadmus also investigated the effects of PODIDs with the highest annual consumption causing these deviations and found that removing even a large portion of them did not have a great effect. There are limitations due to the availability of similar non-participants and tradeoffs in matching, but these are also reasons for using a difference-in-difference framework, as was done in this study.

Figure 1. Single-Family Average Baseline Period Monthly Energy Consumption Per PODID

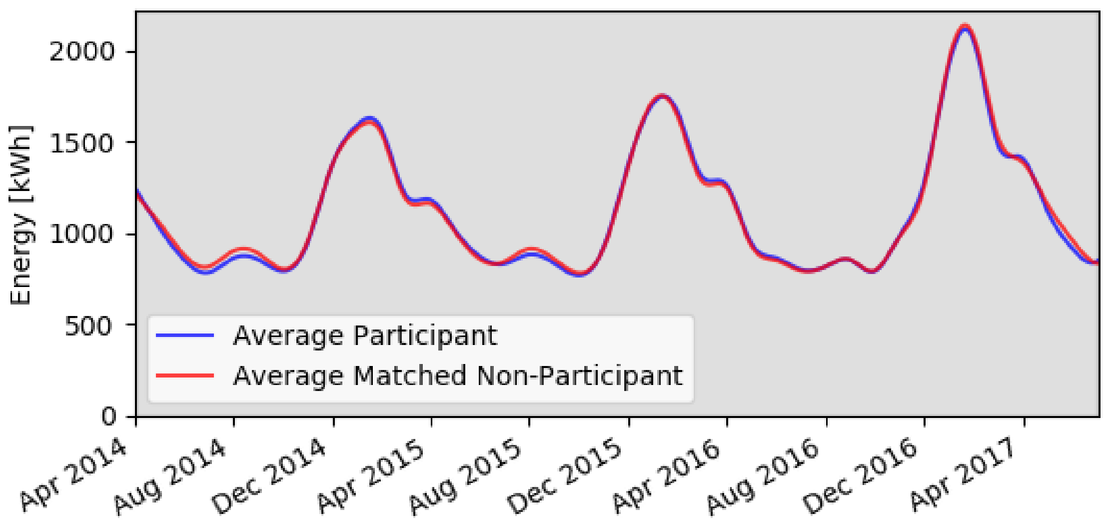


Figure 2. Multifamily Average Baseline Period Monthly Energy Consumption Per PODID

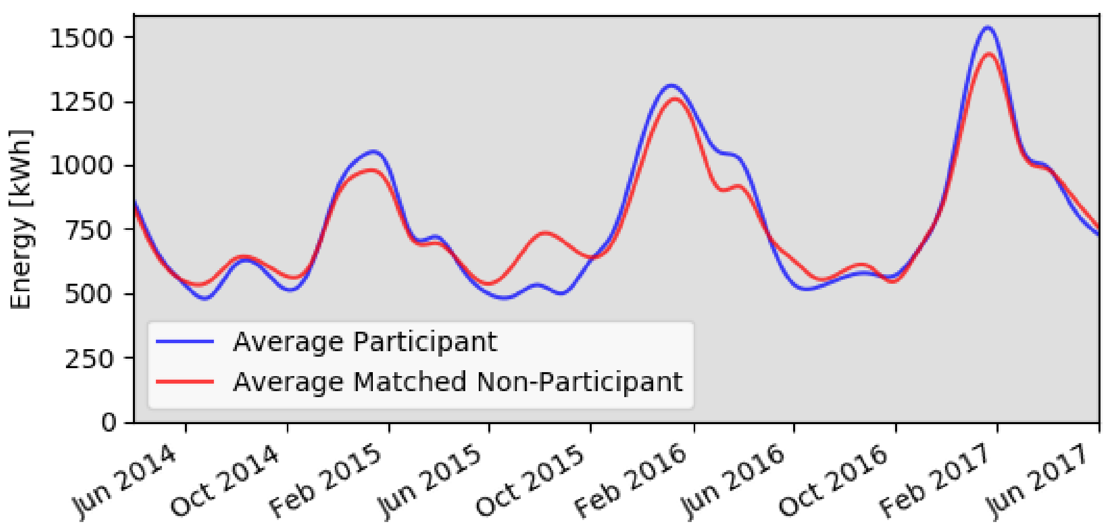


Figure 3 and Figure 4 show histograms of baseline period energy consumption. Similar to the figures above, they show approximately similar distributions between participants and non-participants.

Figure 3. Single-Family Baseline Period TMY Energy Consumption Per PODID

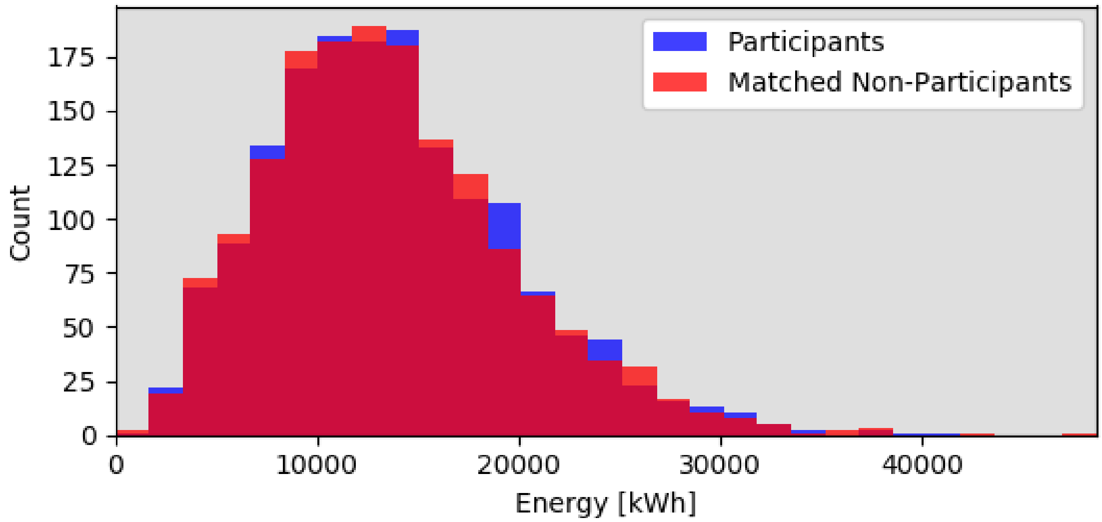


Figure 4. Multifamily Baseline Period TMY Energy Consumption Per PODID

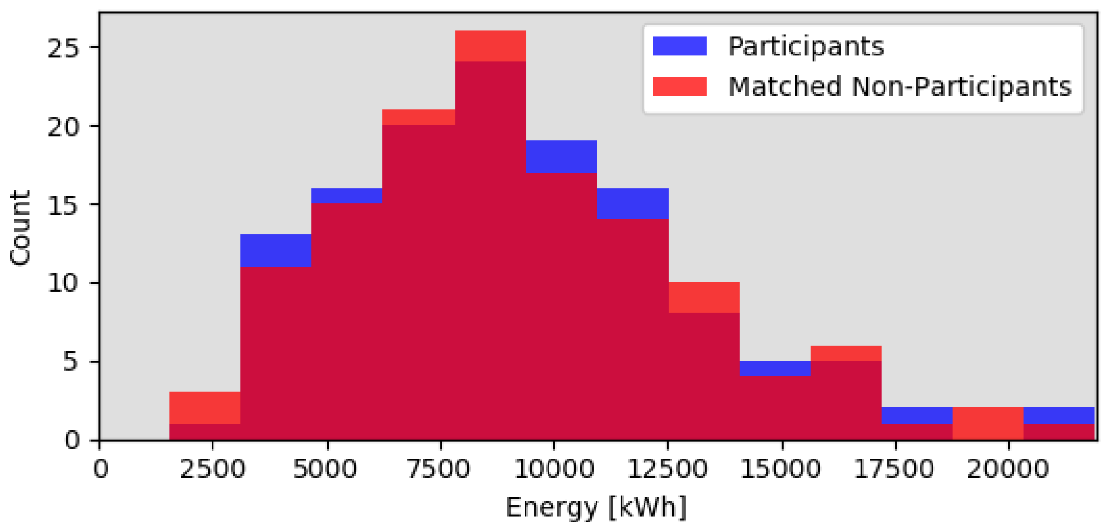


Figure 5 and Figure 6 show the locations of single-family and multifamily samples. The red and blue dots representing participants and matched non-participants are semi-transparent for individual PODIDs and appear solid where multiple PODIDs overlap.

Figure 5. Single-Family Participants and Matched Non-Participants

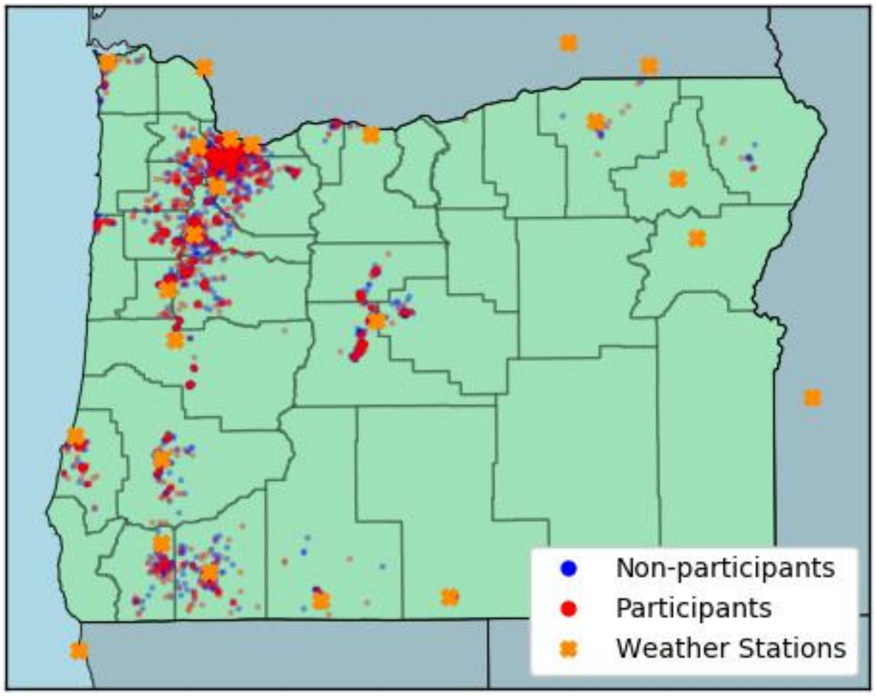


Figure 6. Multifamily Participants and Matched Non-Participants

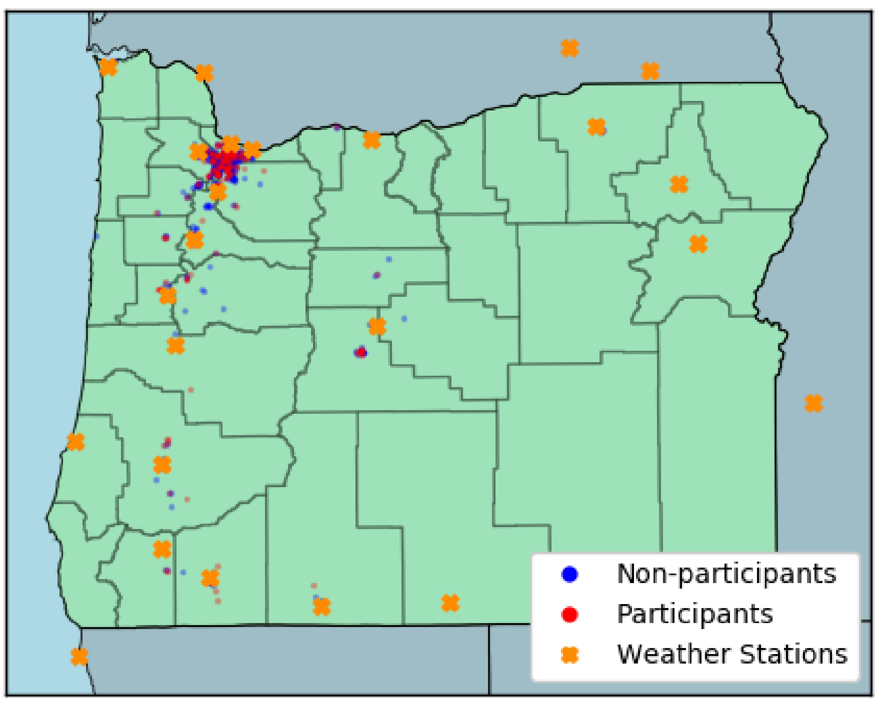


Table 10 summarizes site attributes for single and multifamily participants and non-participants, and Table 11 summarizes attributes of single and multifamily DHP installations. The sample sizes shown are the number of sites, whereas non-participants were matched by PODID, this explains the differences in Ns for participants and non-participants. There are differences in baseline heating systems for single-family participants and non-participants, however each of the primary systems operate on electric resistance and are suitable for matching in a PRISM analysis. Less than 10% of non-participant multifamily systems were document so we don't have this same level of insight.

Table 10. Site Attribute Summary Statistics

Site Attribute	Single-Family						Multifamily					
	Participants: N=1,589			Non-Participants: N=1,592			Participants: N=124			Non-Participants: N=122		
	Ct.	Pct.	Avg.	Ct.	Pct.	Avg.	Ct.	Pct.	Avg.	Ct.	Pct.	Avg.
Vintage	1,308	82	1967	1,537	97	1968	71	57	1976	110	90	1985
Utility	1,589	100	NA	1,592	100	NA	124	100	NA	122	100	NA
PAC	862	52	NA	800	50	NA	30	24	NA	33	27	NA
PGE	763	48	NA	792	50	NA	93	75	NA	88	72	NA
CGN	0	0	NA	0	0	NA	1	1	NA	1	1	NA
Baseline Heating System	1,589	100	NA	1,592	100	NA	124	100	NA	122	100	NA
Zonal ER	1,276	80	NA	162	10	NA	84	68	NA	10	8	NA
eFAF	313	20	NA	1430	90	NA	7	6	NA	1	1	NA
Unspecified	0	0	NA	0	0	NA	33	26	NA	111	91	NA
Market Type	1,050	66	NA	1,592	100	NA	124	100	NA	122	100	NA
Single-Family Home	1,050	100	NA	1,592	100	NA	0	0	NA	0	0	NA
Multifamily Property	0	0	NA	0	0	NA	124	100	NA	122	100	NA
Heating Zone	1,589	100	NA	1,558	98	NA	124	100	NA	122	100	NA
Zone 1	1,399	88	NA	1417	91	NA	117	94	NA	116	95	NA
Zone 2	190	12	NA	141	9	NA	7	6	NA	6	5	NA
Region	1,589	100	NA	1,592	100	NA	124	100	NA	122	100	NA
Central Oregon	142	9	NA	140	9	NA	7	6	NA	6	5	NA
Eastern Oregon	18	1	NA	17	1	NA	0	0	NA	0	0	NA
North Coast	52	3	NA	42	3	NA	0	0	NA	0	0	NA
Portland Metro & Hood River	609	38	NA	627	39	NA	96	77	NA	89	73	NA
Southern Oregon	295	19	NA	295	18	NA	4	3	NA	4	3	NA
Willamette Valley	473	30	NA	471	30	NA	17	14	NA	23	19	NA

Table 11. Participant DHP Attribute Summary Statistics

DHP Attribute	Single-Family: N=1,589			Multifamily: N=124		
	Ct.	Pct.	Avg.	Ct.	Pct.	Avg.
Total Outdoor Units [Count/Site]	1,589	100	1.06	124	100	1.23
Total Capacity [Btu/Site]	1,549	97	22,595	34	27	17,424
Average HSPF	1,047	68	11.34	124	100	11.28
Total Indoor Units [Count/Site]	1,588	100	NA	124	100	NA
1	938	59	NA	75	61	NA
2	410	26	NA	36	29	NA
3	158	10	NA	8	7	NA
4	57	4	NA	4	3	NA
5	13	<1	NA	0	0	NA
6	11	<1	NA	0	0	NA
9	0	0	NA	1	<1	NA
12	1	<1	NA	0	0	NA

Methodology

Regression Analysis

Modeling Limitations

Discussed in the Research Design section of this report are some of the assumptions used in estimating energy savings from monthly billing data, and it is worth providing here some concrete examples to illustrate the limits of the analysis and give context to the results. One assumption of the difference-in-difference framework is that baseline period electric energy consumption is an appropriate baseline for calculating savings, however there are several scenarios in which this assumption fails. Some of these scenarios resulted from true counterfactual heating or cooling systems either not consuming electricity or never having been purchased. For example, we observed in the survey data that many homes burn wood for heat but looking strictly at electric usage will not account for a reduction in the consumption of wood. Also, there are cases where during summer a previously unconditioned space is now cooled by a DHP, but we can see in the survey data homes where the correct counterfactual assumption is a window AC. Further instances in the survey data show where spaces now receive more heating than before and where cooling would not have occurred without the installation of a DHP. In these cases, it is important to consider that incentivizing a DHP is increasing the utility of the home and that a simple cost-effectiveness test may not fully capture all benefits of an installation.

The report first presents the regression analysis results without the added context of the survey data. Although there are limitations, the datasets are largest prior to merging the survey data, and keeping sample sizes as large as possible is important in making strong recommendations. The results are then segmented using the survey data to identify scenarios where model assumptions are best preserved and where savings show the greatest potential.

PRISM

Cadmus estimated meter level energy savings using the industry-standard PRInceton Score-keeping Method (PRISM)[1]. This approach fits separate statistical models to billing and weather data measured during pre- and post-installation periods for all program participants and matched non-participants. In each model, the dependent variable is monthly energy consumption and the candidate independent variables are HDDs and CDDs. Cadmus optimized degree day base temperatures for groupings of sites associated with individual weather stations. The optimization conducted a grid search over ranges of base temperatures to maximize the fit of weather dependent energy consumption. The form of this model including a baseload, heating, and cooling profile is shown below:

---

1 Fels, M. (1986). PRISM: An Introduction. Energy and Buildings, 9, 5-18. Retrieved from http://www.marean.mycpanel.princeton.edu/~marean/images/prism_intro.pdf

$$Energy\ Consumption = \beta_1 + \beta_2 HDD + \beta_3 CDD$$

With quantities and dimensions of:

$Energy\ Consumption$: PODID level energy consumption in kWh estimated during the period during which billing data were measured (about monthly for this study)

HDD: Heating degree days calculated between billing intervals, base temperatures were optimized for each weather station

CDD: Cooling degree days calculated between billing intervals, base temperatures were optimized for each weather station

Figure 7 shows the monthly energy consumption for a single site included in the single-family sample and Figure 8 shows that site's HDDs during the same time period. These two time series have similar trends, taking on higher values during winter and lower values during summer. It is this type of seasonal variability that regression modeling is intended to capture.

Figure 7. Sample Site Pre/Post-Period Energy Consumption

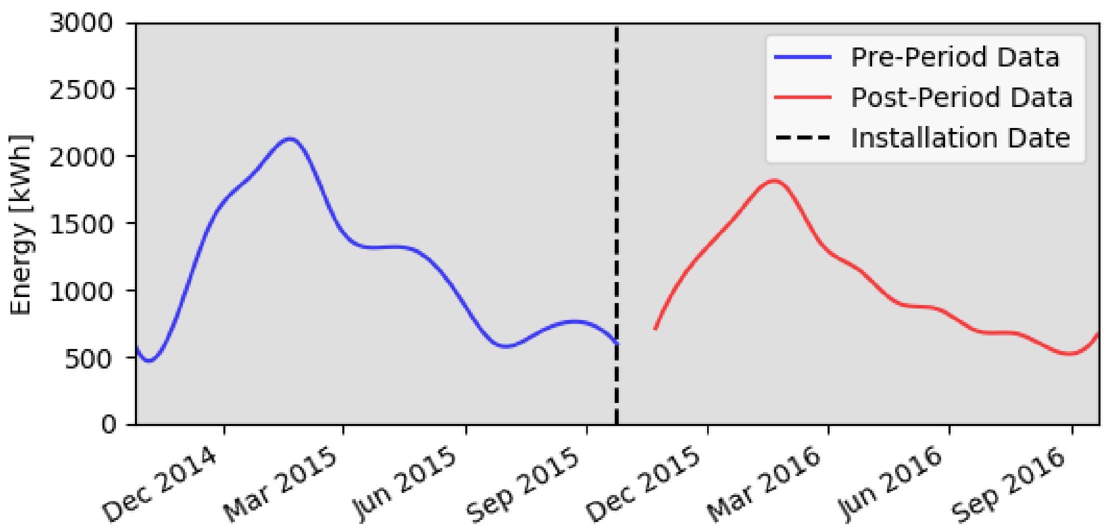


Figure 8. Sample Site Pre/Post-Period Heating Degree Days

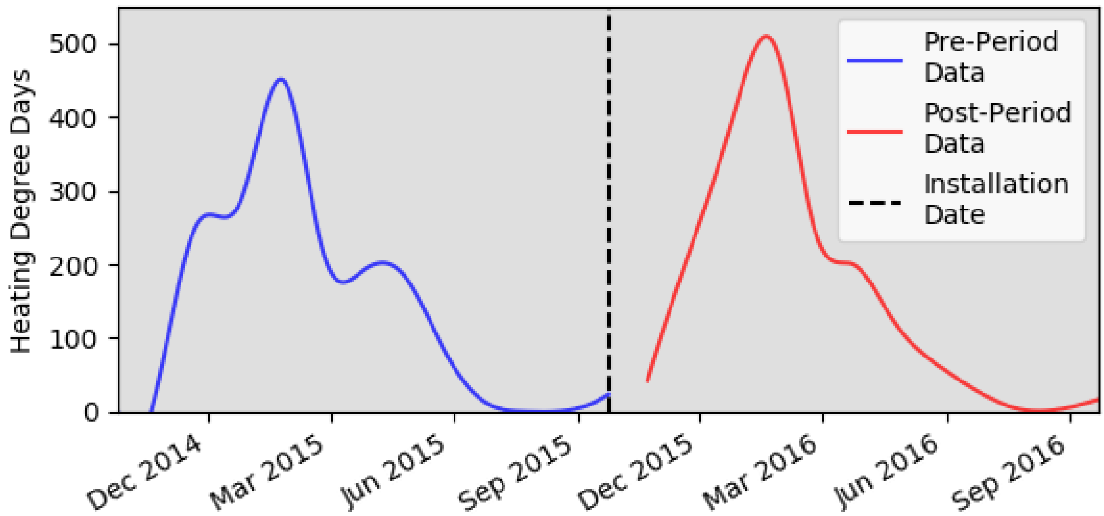
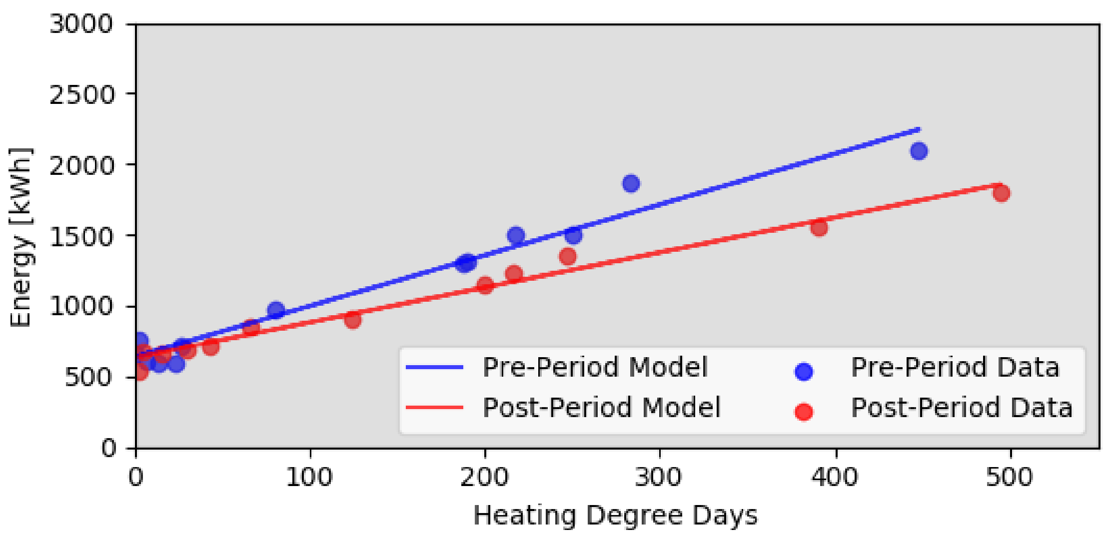


Figure 9 is a scatter plot created from the paired data from Figure 7 and Figure 8, shown with best fit regression lines to demonstrate the linear relationship between energy consumption (the dependent variable) and HDDs (the independent variable) during the pre- and post-periods. It is clear from the figure that energy consumption unrelated to HDDs are similar during the two periods, each with a y-intercept around 700 kWh, but the slope of the post-period model is lower. This reduction in slope is interpreted as a reduction in energy consumption per increase in HDD.

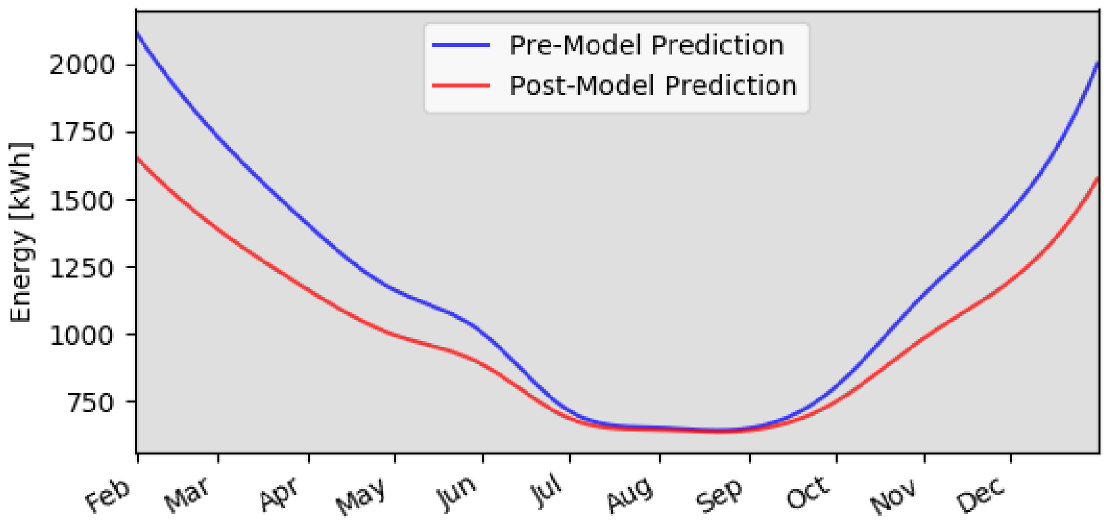
Figure 9. Sample Site Pre/Post-Period PRISM Modeling



Cadmus fit these types of linear models to the pre- and post-periods for each PODID. The model fitting process was constrained in two ways. First, parameters for HDDs and CDDs were only included if p-values for these estimates were less than 0.1, and second, the model intercepts were required to be positive. In the case that a model was fit with a negative intercept, the data were re-fit to a model with an intercept fixed at zero.

Cadmus used the resulting models to predict energy consumption during a typical meteorological year using standardized industry datasets meant to represent “normal” annual weather conditions at a geographic location. Figure 10 illustrates these pre- and post-model predictions during a typical year for a single PODID.

Figure 10. Sample Site Pre/Post-Period PRISM Model Application



The savings for this PODID are the difference between pre- and post-model predictions. In this example, savings are not observed during the summer because the PODID’s energy consumption did not correlate with CDDs. The final step in estimating savings is to subtract from each participant any savings from matched non-participants. Cadmus divided total savings by the total number of DHP installations to calculate savings per DHP, as shown below.

$$AVG(Savings_{TMY}) = \Sigma_{i=1}^{n} Savings_{TMY_i} / \Sigma_{i=1}^{n} DHP_i$$

With quantities:

$AVG(Savings_{TMY})$: Average TMY energy savings in kWh per DHP installation

$Savings_{TMY_i}$: Energy savings in kWh for all PODIDs at site i

DHP_i: Number of DHPs installed at site i

Panel Regression

In its RFP for this study, Energy Trust specified a second modeling technique be applied to the single-family and multifamily datasets to understand how energy savings varied with the method used in estimation. Energy Trust specifically asked that this second technique be a panel regression model.

Cadmus used the following regression equation with the same samples of single-family and multifamily PODIDs to calculate energy savings in addition to the estimates developed through PRISM modeling.

$$Energy\ [kWh] = \beta_1 * HDD + \beta_2 * CDD + \beta_3 * HDD * Part + \beta_4 * CDD * Part + \beta_5 * Post + \beta_6 * HDD * Post + \beta_7 * CDD * Post + \beta_8 * Part * Post + \beta_9 * HDD * Part * Post + \beta_{10} * CDD * Part * Post + TimeEffects + EntityEffects$$

With the following quantities:

HDD : Heating degree days calculated base 60 F calculated from hourly temperature data measured at nearest weather station

CDD : Cooling degree days calculated base 70 F calculated from hourly temperature data measured at nearest weather station

$Part$: Indicator variable, 1 for program participants and 0 for matched non-participants

$Post$: Indicator variable, 1 for post-installation period and 0 for pre-installation period

$TimeEffects$: A constant for each time period controlling for differences in consumption that vary over time but are constant across sites

$EntityEffects$: A constant for each entity controlling for differences in consumption that vary across sites but are constant over time

Average typical year energy savings per PODID were calculated as:

$$Energy\ Savings\ [kWh] = \beta_8 + \beta_9 * HDD_{TMY} + \beta_{10} * CDD_{TMY}$$

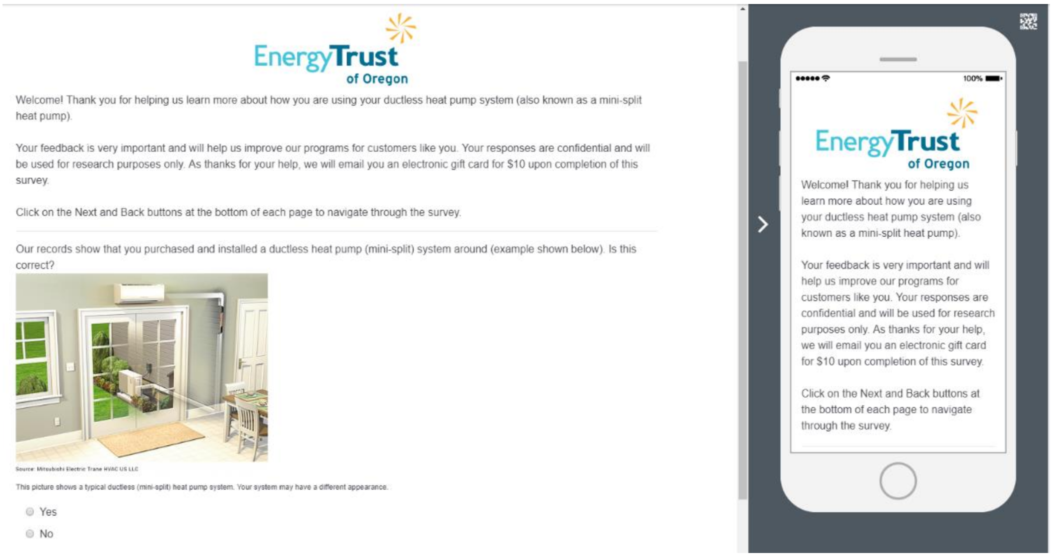
The results of this modeling and comparisons with PRISM results are discussed in the next section.

Survey

Cadmus conducted program participant and non-participant surveys between July 2018 and January 2019. This effort utilized the program tracking data to gather information including site characteristics, heating and cooling system data, and changes in energy consumption; and for program participants asked detailed question about how they use their DHP and why they installed it. Cadmus tested all survey questions prior to contacting the public on a sample of approximately thirty volunteers recruited from professional connections of the individuals involved in this study. Survey respondents had the option to answer questions in Spanish.

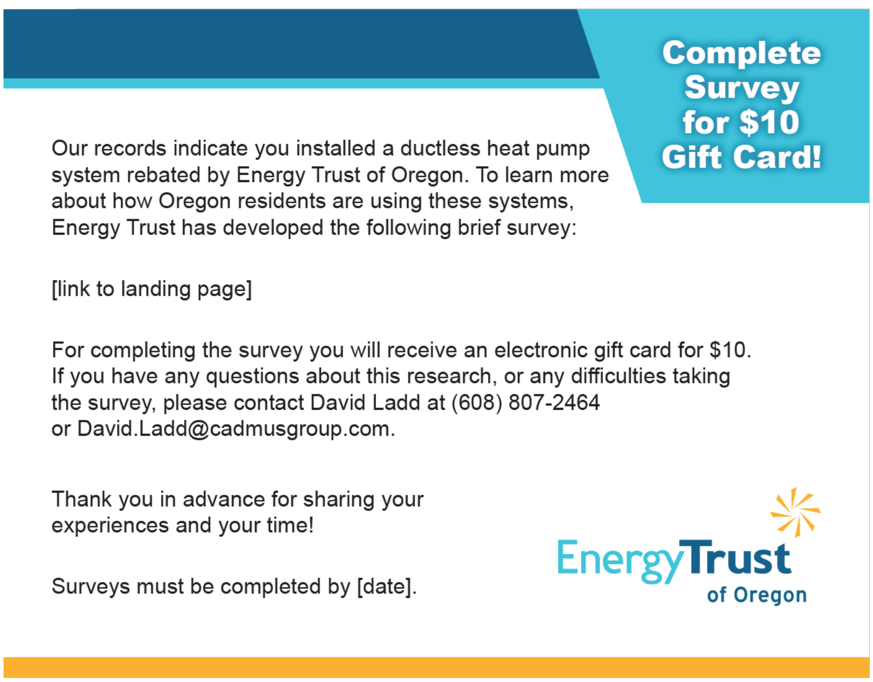
All program participants and non-participants included in the analysis sample received surveys from Cadmus. Email was the initial mode of contact and was facilitated using the online Qualtrics platform. In these emails, Cadmus described purpose of contacting these individuals, offered a $10 electronic gift card, and provided a link to the web implementation of the survey. A sample of the survey landing page is shown in Figure 11.

Figure 11. Mockup Web and Mobile Survey



Cadmus follow up with individuals who did not respond to email requests or who did not provide an email addresses with a physical post card containing a link to the web survey. An example postcard is shown in Figure 12.

Figure 12. Mockup Recruiting Postcard



Cadmus staff conducted phone surveys with the remaining individuals and entered verbal responses into the web version of the survey in Qualtrics. Some individuals were simply provided a link to the online survey over the phone to provide responses at a more convenient time.

Results

Regression Modeling

Cadmus first calculated annual energy savings at the meter level, based on PODID, using the PRISM methodology, and the results are summarized in Table 12. Average model R-squared values for each combination of analysis group and study period ranged from 0.83 to 0.87. Non-participants for both single-family and multifamily residences saw small but negative annual savings, contributing to slightly higher final savings values.

Table 12. PRISM Modeling Results – Average Energy Savings per PODID

Residential Group	Site [Count]	PODID [Count]	TMY Pre-Usage [kWh/PODID]	Participant Savings [kWh/PODID]	Non-Participant Energy [kWh/PODID]	Savings [kWh/PODID]	Confidence Interval at 90%	Savings [%]
Single-Family	1,589	1,616	13,647	764	-23	787	(594, 980)	5.8
Multifamily	124	131	9,300	1,236	-207	1,443	(1,025, 1,861)	15.5

Table 13. PRISM R-Squared Values

Residential Group	Average Pre-Model R-Squared	Average Post-Model R-Squared
Single-Family	0.83	0.85
Multi-family	0.86	0.87

Cadmus also conducted panel regression modeling at the PODID level to compare with these PRISM results.

The annual TMY energy savings calculated using these panel regression models are included in Table 14 along with equivalent estimates developed using the PRISM method. Single-family results between the two methods are within 3% and multifamily results are within 11%, showing good agreement between the two modeling approaches, and the mean panel regression results are not statistically significantly different from the PRISM results. One difference in the datasets used in by each modeling approach is the calculation of HDDs and CDDs. Cadmus optimized the heating and cooling base temperatures for similar groupings of PODIDs in the PRISM analysis, but these temperatures were fixed in the panel regression model. Still, testing the effect of holding base temperatures constant for both methods produced similar results.

Table 14. Estimated Program Savings [kWh/PODID] by Modeling Technique

Residential Group	Site [Count]	PODID [Count]	DHP [Count]	TMY Pre-Usage [kWh/PODID]	PRISM Savings [kWh/PODID]	PRISM Savings [%]	Panel Regression Savings [kWh/PODID]
Single-Family	1,589	1,616	1,682	13,647	787	5.8	807
Multifamily	124	131	152	9,300	1,443	15.5	1,289

The unit of analysis for this study is not annual energy savings per PODID, but rather annual savings per DHP. To calculate this value Cadmus totaled savings across all PODIDs and divided by the total number of DHPs installed at those sites. These results are shown in Table 15.

Table 15. PRISM Modeling Results—Average Energy Savings per DHP

Residential Group	Site [Count]	PODID [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Confidence Interval at 90%	Savings [%]
Single-Family	1,589	1,616	1,682	13,879	756	(571, 942)	5.8
Multifamily	124	131	152	9,825	1,244	(862, 1626)	15.5

Survey

Single-Family Participants

Cadmus conducted two surveys of single-family participants and in each case offered a $10 incentive. The first survey asked detailed questions about motivations for installing DHPs, site characteristics, and room-level heating and cooling systems. There were 704 responses to this survey and Cadmus fielded a second condensed survey to anyone still not having responded. This supplemental survey yielded 93 additional responses that were merged with the data from the original survey. The response rate for the original survey was 31% (38% for those contacted using email) and the supplemental survey was 11%. Because these two surveys did not contain the same set of questions, and the questions asked within each survey in many cases depended on how previous questions were answered, the number of responses to each question is variable. In this section, results are discussed in relation to the study's research objectives, and the Sub-Group Analysis section combines these tables and others with billing analysis results.

One research objective for this study was to better understand non-energy benefits associated with DHPs and the decision-making process of program participants. Cadmus asked participants an initial question about the way they primarily used their DHP, whether for heating, cooling, or both equally. As shown in Table 16, only a small fraction of participants reported cooling as the most common application for their systems, although more than 70% claimed that cooling was a primary function in addition to heating.

Table 16. Single-Family Participant Primary DHP Use Case

Use Case	Site [Count]	Site [%]
Heating/Cooling	512	73
Heating	143	20.4
Cooling	46	6.6
Total	701	100

Table 17 summarizes survey respondents' motivations for installing DHPs in greater detail. Importantly, each respondent could select as many reasons as they wanted for purchasing a DHP and because of this the columns in Table 17 cannot be totaled.

Table 17. Single-Family Participant DHP Purchase Motivations

Motivation	Site [Count]	Site [%]
Save Energy	581	73
Save Money	563	70.7
Thermal Comfort	495	62.2
Cool Previously Un-Cooled Area	493	61.9
Interest in Sustainability	279	35.1
Replace Functional System	251	31.5
Interest in Technology	162	20.4
Heat Previously Un-Heated area	150	18.8
Replace Broken System	148	18.6
Safety	141	17.7
Improve Air Quality	117	14.7
Free Window Previously Occupied by an AC	100	12.6
Other	96	12.1
Quieter Operation	30	3.8
Don't Need to Move with Season	19	2.4
New addition	8	1
Don't know	2	0.3

*796 total respondents

The primary motivations for single-family participants had for purchasing DHPs were saving money and saving energy, however several non-energy benefits were also important considerations in a large proportion of sites. At greater than 60%, thermal comfort was the third most selected motivation, implying that, in most cases, respondents were interested in adding some level of heating or cooling to their homes; a total of 120 respondents indicated they were adding both heating and cooling. This added comfort increases the utility of a residence but is not captured by an energy savings analysis when the pre-installation period is the assumed baseline.

On this topic, Cadmus asked for each room conditioned by a DHP if the space was better heated during winter and better cooled during summer. Table 18 contains aggregated responses for rooms heated with a DHP. If a room was heated to a higher temperature post-installation, this was indicated as 'Warmer'; if a room was not as well heated as with the previous system, the response was labeled as 'Cooler'. Table 19 displays analogous responses for the cooling season. Based on these self-reported changes in the temperatures it is clear a large portion of participants increased the amount of conditioning in spaces served by DHPs. The number of rooms indicated in these tables also indicates the number of indoor units. To collect this data, Cadmus asked respondents were asked to describe the room type of space conditioned by each indoor unit, and then asked further conditions about that space.

Table 18. Single-Family Participant Change in Room Temperature—Heating

Temperature Change—Heating	Room [Count]	Room [%]
Warmer	531	68.2
Same	192	24.6
Cooler	56	7.2
Total	779	100

Note: 688 total respondents

Table 19. Single-Family Participant Change in Room Temperature—Cooling

Temperature Change - Cooling	Room [Count]	Room [%]
Cooler	627	88.2
Same	66	9.3
Warmer	18	2.5
Total	711	100

Note: 680 total respondents

From Table 17, an interest in sustainability and an interest in technology each were selected for more than 20% of respondents, however these are not great candidates for quantifying non-energy benefits. Improved air quality was a motivation for more than 14% of participants and could potentially be weighed against the counterfactual purchase of an air filter.

The use of supplemental fuels is an important consideration also not captured in an analysis of monthly electric bills and one of the study's key research objectives was to quantify their prevalence. Cadmus collected in-depth heating system information for each space conditioned by a DHP, including systems used prior to installing a DHP that are no longer used, systems currently used in conjunction with the DHP, and actions homeowners would have taken had they not installed a DHP.

Table 20 summarizes counts and percentages of all systems used during the baseline period to heat the same spaces where DHPs used for heating were installed (this question was not asked of spaces where DHPs that were used exclusively for cooling), and shows electricity was used for this purpose more than any other fuel. However, close to 20% of systems were stoves or fireplaces burning wood and a large portion of furnaces were reported as non-electric. These data were collected from 787 sites.

Table 20. Single-Family Participant Baseline Heating Systems

Baseline Heating System	Heating System [Count]	Heating System [%]
None	60	5.1
Baseboard/Space Heater: Electric	542	46.3
Baseboard: Natural Gas	1	0.1
Boiler: Natural Gas	1	0.1
Fireplace: Natural Gas	24	2
Fireplace: Propane	4	0.3
Fireplace: Unknown	12	1
Fireplace: Wood	54	4.6
Furnace: Electric	36	3.1
Furnace: Natural Gas	17	1.4
Furnace: Oil	8	0.7
Furnace: Propane	2	0.2
Furnace: Unknown	41	3.5
Other: Electric	55	4.7
Other: Natural Gas	28	2.4
Other: Oil	1	0.1
Other: Propane	10	0.9
Other: Unknown	42	3.6
Other: Wood	3	0.3
Radiant Floor: Electric	9	0.8
Radiant Floor: Unknown	4	0.3
Stove: Electric	1	0.1
Stove: Other	4	0.3
Stove: Unknown	45	3.8
Stove: Wood	169	14.4
Total	1,173	100

Note: 787 total respondents

In cases where past supplemental fuel usage was apparent from survey responses, Cadmus gathered additional data to help quantify a reduction in usage that could be considered in designing DHP programs. There are tradeoffs in collecting these type of data; asking higher-level questions produces more reliable responses but are more difficult for use in quantifying savings, whereas responses to more granular questions are easier to quantify but less dependable. Cadmus began with asking if participants having previously consumed natural gas, oil, propane, or wood if their usage increased, decreased, or stayed the same after installing a DHP ("don't know" was also an option). Table 21 tallies the responses. Greater than 78% of sites reported a reduction in fuel consumption, 14% said their usage stayed the same, and the remaining portion were unsure or thought they used more fuel. The highest number of sites reporting a reduction in supplemental fuels burned wood or wood pellets.

Table 21. Single-Family Participant Change in Supplemental Fuel Usage

Supplemental Fuel	Site [Count]	Site [%]
Natural Gas		
Less	57	77
Same	15	20
More	2	3
Total	74	100
Oil		
Less	16	100
Propane		
Less	11	79
Same	2	14
More	1	7
Total	14	1
Wood		
Don’t know	19	8
Less	192	78
Same	32	13
More	3	1
Total	246	100

It is important to understand when changes in fuel consumption result from the installation of a DHP because it indicates the assumed baseline in an analysis of electric bills does not quantify the complete benefit of the system. Cadmus attempted to determine this benefit by further asking participants who changed their fuel usage to estimate their savings following their DHP purchase. Responses could be entered in dollar values for all fuels as well as in therms for natural gas, gallons for oil and propane, and cords or bags of pellets for wood. Cadmus also considered that homeowners may think of these figures in the context of varying lengths of time (e.g., annual versus monthly), and provided space for this type of explanation. However, in reviewing the responses to these questions, several limitations become apparent. In addition to entering nonsensical values, many participants clearly misunderstood the question to ask about their total consumption and not their reduction in consumption. Reductions reported per month also proved less reliable as it remained unknown if this value was an average and what months it applied to. A third issue is the unlikelihood that reported values are representative of a “typical year” that is needed to accurately adjust a savings baseline. After reviewing all responses, Cadmus removed values that appeared unreliable and reported average savings for fuels with large enough counts of sites in Table 22. Despite the uncertainty around these averages, a significant amount of reduction in fuel usage clearly followed the installation of a DHP.

Table 22. Single-Family Participant Estimated Annual Decrease in Supplemental Fuels Usage

Fuel	Site [Count]	Average Annual Reduction [$]	Standard Error
Natural Gas	22	469	116
Wood	117	365	28

Another question not directly posed in the primary research objectives of this study but worth considering is to what extent are DHPs used to condition the spaces in which they are installed? Cadmus asked participants to list heating and cooling systems currently used in addition to their DHP and specified that systems occupying the same space but not actively used should not be included. Table 23 and Table 24 show responses to this question, indicating DHPs are the sole heat source in 45% of rooms and the sole cooling source in 64% of rooms. Use of multiple systems to condition a single space detracts from the savings potential of DHPs when additional systems are less efficient. From these responses, it appears this occurs in a large percentage of installations.

Table 23. Single-Family Participant Current Heating Systems in Addition to a DHP

Additional Heating System	Room [Count]	Room [%]
None	477	45
Baseboard/Space Heater: Electric	221	20.9
Boiler: Natural Gas	1	0.1
Fireplace: Natural Gas	19	1.8
Fireplace: Propane	4	0.4
Fireplace: Wood	49	4.6
Furnace: Electricity	17	1.6
Furnace: Natural Gas	10	0.9
Furnace: Oil	7	0.7
Furnace: Propane	1	0.1
Furnace: Unknown	4	0.4
Other: Electricity	32	3
Other: Natural Gas	23	2.2
Other: Oil	1	0.1
Other: Propane	10	0.9
Other: Unknown	2	0.2
Other: Wood	3	0.3
Radiant Floor: Electricity	8	0.8
Stove: Unknown	17	1.6
Stove: Wood	153	14.4
Total	1059	100

Note: 787 total respondents

Table 24. Single-Family Participant Current Cooling Systems in Addition to a DHP

Additional Cooling System	Room [Count]	Room [%]
None	582	64.4
Fan	212	23.5
Room AC	91	10.1
Other	12	1.3
Central AC	7	0.8
Total	904	100

Note: 777 total respondents

Cadmus further asked homeowners to rank their current heating and cooling systems in order of their contribution to conditioning each space where a DHP is installed and tabulated counts of when incentivized DHPs were ranked first, second, and third. This question was asked only when multiple systems were selected as currently being used for heating or cooling. Table 25 and Table 26 show most of the time a DHP was used in conjunction with other systems it was the primary unit, but close to 40% of the time for heating and 30% of the time for cooling another system was used more often. These sets of tables describing the use of additional systems indicate potential for increasing energy savings above current levels by persuading homeowners to use their DHPs more often.

Table 25. Single-Family Participant Current Heating System Ranking

DHP Heating Rank	Room [Count]	Room [%]
First	126	60.3
Second	80	38.3
Third	3	1.4
Total	209	100

Note: 179 total respondents

Table 26. Single-Family Participant Current Cooling System Ranking

DHP Cooling Rank	Room [Count]	Room [%]
First	80	71.4
Second	32	28.6
Third	0	0
Total	112	100

Note: 97 total respondents

One option for expanding DHP usage is to control operation programmatically, helping to increase the proportion of spaces served primarily by these systems while alternative systems are present. This could be accomplished by turning down setpoints of other systems or having a single set of controls for all systems (although many homes would not currently have that ability). Cadmus surveyed homeowners' DHP control strategies during the heating and cooling seasons and found 10% to 12% of systems were configured with programmable, wall-mounted controls. The remainder of systems were used as needed and controlled manually, operating with a remote or an on-unit thermostat, as summarized in Table 27 and Table 28. In these tables the phrase 'Manual' implies the system was controlled manually and turned on and off as needed; this is in contrast to programmable controls, where the system will automatically turn on and off to achieve scheduled set points. In the Sub-Group Analysis section of the report we look at savings by control strategy, but it is intuitive that a DHP that with programmable controls, similar to most primary heating systems or central ACs, would contribute to greater displacement of heating and cooling from less efficient systems if configured correctly.

Table 27. Single-Family Participant DHP Controls—Heating

Heating Controls	Room [Count]	Room [%]
Manual Remote Thermostat	579	79.2
Programmable Wall-Mounted Thermostat	88	12
Manual Wall-Mounted Thermostat	42	5.7
Manual On-Unit Thermostat	22	3
Total	731	100

Note: 695 total respondents

Table 28. Single-Family Participant DHP Controls—Cooling

Cooling Controls	Room [Count]	Room [%]
Manual Remote Thermostat	577	81.3
Programmable Wall-Mounted Thermostat	72	10.1
Manual Wall-Mounted Thermostat	39	5.5
Manual On-Unit Thermostat	22	3.1
Total	710	100

Note: 684 total respondents

Understanding the impacts of DHPs on the usage of energy for cooling was a research objective outlined for this study. As previously discussed, this topic is especially important in relation to the assumed baseline used in a billing analysis. Specifically, when a DHP adds cooling to a previously uncooled space, but a homeowner would have cooled that space by a different means had they not installed a DHP, the assumed baseline of a PRISM analysis does not correctly estimate savings. In many cases this counterfactual system is unknown, but Cadmus collected this information from participants who use their DHPs for cooling. In more than 70% of cases, homeowners would have used their existing equipment or left the space uncooled; for these sites, a billing analysis should reliably estimate savings. However, close to one-fifth of respondents indicated that they would have installed a room AC in the spaces where a DHP was installed had they not purchased a DHP. In this scenario, savings should be calculated based on post-period cooling energy consumption and the difference in efficiencies of the DHP and AC systems. This analysis is discussed in depth in the Sub-Group Analysis section report. Table 29 summarizes the responses to the question of how individuals would have provided cooling to the spaces where DHPs were installed had they not installed a DHP.

Table 29. Single-Family Participant Counterfactual Cooling Systems

Counterfactual Cooling System	Room [Count]	Room [%]
Use Existing Cooling Equipment	320	38.6
Leave Room Uncooled	288	34.8
Install Room AC	152	18.4
Install Central HP	38	4.6
Install Central AC	22	2.7
Install Other Cooling Equipment	5	0.6
Don't know	3	0.4
Total	828	100

Note: 718 total respondents

Multifamily Participants

Cadmus also surveyed multifamily participants and offered a $10 incentive for responses. The survey questions similarly focused on the research objectives outlined for this study but were more limited in scope because some information was specific to either residents or property owners. With the contact information provided, Cadmus could not assume all individuals taking the survey occupied the spaces served by the DHP, and instead asked a more general set of questions that project contacts could answer reliably. A second limitation was the low sample size, resulting from a smaller number of program participants and a greater number of potential sites removed due to insufficient billing data. These challenges make it more difficult to find trends in the multifamily data, but even this smaller set of responses can help show where similar trends were observed in the single-family data and strengthen conclusion drawn from those data. The response rate for the multifamily survey was 27%.

Cadmus found a similar distribution of responses between single-family and multifamily participants for primary DHP use cases, with 75% of multifamily sites interested in heating and cooling, about 20% in heating only, and 1.5% in cooling only.

Table 30. Multifamily Participant DHP Primary Use Case

Primary DHP Use	Site [Count]	Site [%]
Heating/Cooling	51	75
Heating	16	23.5
Cooling	1	1.5
Total	68	100

The Table 31 results further break down motivations for installing DHPs. Similar to results with the equivalent single-family table, multifamily participants could select multiple motivations for installing DHPs and so the columns in Table 31 cannot be totaled. Saving energy and money were also the top two motivations, although each at a higher percentage than for single-family homeowners. Thermal comfort and cooling previously un-cooled areas were selected for most multifamily sites. As discussed in the previous section, using DHPs for these reasons can reduce savings calculated from a pre/post billing analysis, but still add utility to homes that should be considered. Respondents could select as many motivations as they wanted for the question summarized in Table 31 and so the columns cannot be totaled.

Table 31. Multifamily Participant DHP Motivation

Motivation	Site [Count]	Site [%]
Save Energy	57	83.8
Save Money	55	80.9
Cool Previously Un-Cooled Area	42	61.8
Interest in Sustainability	42	61.8
Thermal Comfort	36	52.9
Replace Functional System	29	42.6
Interest in technology	22	32.4
Safety	17	25
Other	9	13.2
Improve Air Quality	8	11.8
New Addition	7	10.3
Replace Broken System	6	8.8
Heat Previously Un-Heated Area	5	7.4
Free Window Previously Occupied by an AC	4	5.9

Note: 68 total respondents

Table 32 displays counts and percentages of all heating systems used during the baseline period to condition spaces now conditioned by a DHP. Relative to single-family homes, a higher proportion of baseline systems consume electricity in multifamily residences, with electric baseboard and space heaters comprising 69% of systems. A smaller portion of systems consume supplemental fuels, such as fireplaces, and are not accounted for in the assumptions of a billing analysis. However, as fewer sites reported using these types of systems, it was more difficult to determine how non-electricity fuel consumption changed on average after installing a DHP. The numbers in Table 32 indicate natural gas consumption decreased for most respondents—also the case for single-family homes—but too few sites were available to extrapolate to a larger population.

Table 32. Multifamily Participant Baseline Heating Systems

Baseline Heating System	Heating System [Count]	Heating System [%]
None	3	3.2
Baseboard/Space Heater: Electric	64	68.8
Fireplace: Natural Gas	6	6.5
Fireplace: Unknown	1	1.1
Fireplace: Wood	2	2.2
Furnace: Electric	2	2.2
Furnace: Natural Gas	2	2.2
Other: Electric	7	7.5
Other: Natural Gas	1	1.1
PTHP: Electric	2	2.2
Radiant Floor: Electric	2	2.2
Stove: Unknown	1	1.1
Total	93	100

Note: 68 total respondents. No electric fireplaces were reported.

Table 33. Multifamily Participant Change in Supplemental Fuel Usage

Supplemental Fuel	Site [Count]	Site [%]
Natural Gas: Don't know	2	22.2
Natural Gas: Less	6	66.7
Natural Gas: Same	1	11.1
Total	9	100

Table 34 and Table 35 summarize heating and cooling systems actively used to condition the same spaces where DHPs have been installed. Close to 35% of these spaces still report being at least partially heated by electric baseboard and space heaters, indicating potential for increasing DHP energy savings by further displacing these systems. Potential also exists for displacing the 10% of rooms using an AC for cooling in conjunction with a DHP.

Table 34. Multifamily Participant Current Heating Systems in Addition to a DHP

Additional Heating System	Room [Count]	Room [%]
None	35	46.7
Baseboard/Space Heater: Electricity	26	34.6
Fireplace: Natural Gas	5	6.7
Fireplace: Unknown	1	1.3
Fireplace: Wood	1	1.3
Furnace: Natural Gas	1	1.3
Other: Electricity	2	2.7
Other: Natural Gas	1	1.3
PTHP: Unknown	1	1.3
Radiant Floor: Electricity	2	2.7
Total	75	100

Note: 67 total respondents

Table 35. Multifamily Participant Current Cooling Systems in Addition to a DHP

Additional Cooling System	Room [Count]	Room [%]
None	36	52.2
Fan	23	33.3
Room AC	7	10.1
Other	3	4.3
Total	69	100

Note: 68 total respondents

In multifamily residences, controlling DHPs with programmable thermostats presents an opportunity to reduce use of inefficient heating and cooling systems. Table 36 shows the current state of survey respondents' DHP controls, suggesting high potential to shift more residents from manual to automatic operation. In the phrasing of this survey question 'Manual' indicated a homeowner manually turns their DHP on and off as needed, in contrast to programmable thermostats where the system will automatically turn on and off to achieve scheduled set points.

Table 36. Multifamily Participant DHP Controls

Controls	Room [Count]	Room [%]
Manual Remote Thermostat	108	93.1
Programmable Wall-Mounted Thermostat	4	3.4
Manual Wall-Mounted Thermostat	4	3.4
Total	116	100

Note: 38 total respondents

In asking about counterfactual cooling systems, Cadmus found multifamily residences have a smaller percentage of room AC than single-family homes in the absence of a DHP. This may also be the result of a much smaller sample of multifamily respondents. As noted in the single-family section, sites where rooms ACs would have been installed had a DHP not been installed present an issue for PRISM analysis. Table 37 shows a large proportion of rooms that would have remained uncooled in the absence of a DHP. This scenario aligns with assumptions used in a billing analysis but will contribute to lower savings by adding cooling load during the summer. This does, however, increase a home's thermal comfort. The responses in Table 37 were obtained by asking homeowners how they would have cooled the spaces new conditioned by a DHP had that DHP not been installed. The term 'Existing' in this table indicates a homeowner would have continued using the system currently in place when the DHP was installed, as opposed to purchasing a new system.

Table 37. Multifamily Participant Counterfactual Cooling Systems

Counterfactual Cooling System	Cooling System [Count]	Cooling System [%]
Leave Room Un-cooled	30	44.1
Use Existing Cooling Equipment	25	36.8
Install Room AC	7	10.3
Don't know	4	5.9
Install Central AC	2	2.9
Total	68	100

Note: 68 total respondents

Sub-Group Analysis

Cadmus merged the results of the regression analysis with the Project Tracking and survey data to produce the tables in this section. These tables summarize average TMY energy savings per DHP and installation costs per DHP when grouped by one or more variables from the Project Tracking and survey data. The purpose of this analysis is to identify the most cost-effective DHP installation scenarios. In many cases the total sample sizes between tables changes because of the availability of data, and in cases where variables were not recorded or sites were removed as part of the QC process, the sample sizes will be smaller. The subheadings in this section reflect the research objectives of this study. For reference, the table showing the savings values of all participants from the regression analysis is repeated below in Table 38.

For each table in this section a duplicate table is provided where sites are restricted to a set of ideal conditions. The purpose of these tables is to eliminate confounding variables, specifically any use of supplemental fuels or the installation of multiple outdoor units (Energy Trust only incentivizes the first outdoor unit installed). These duplicate tables summarize groups of sites where either heating systems were documented and no systems consumed supplemental fuels or where on documentation of fuel usage was available. This selection is distinct from including all sites where heating systems were known and none consumed supplemental fuels (this information would have required a survey response) and the choice was made to maintain a larger sample. These tables all include a note stating, "Sites with multiple DHPs or documented supplemental fuel usage excluded". A separate set of tables presents results for sites with complete heating system information. All other tables present data for all sites available for analysis.

Table 38. PRISM Modeling Results—Average Energy Savings per DHP

Residential Group	Site [Count]	PODID [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Confidence Interval at 90%	Savings [%]
Single-Family	1,589	1,616	1,682	13,879	756	(571, 942)	5.8
Multifamily	124	131	152	9,825	1,244	(862, 1,626)	15.5

Table 39. PRISM Modeling Results—Average Energy Savings per DHP*

Residential Group	Site [Count]	PODID [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Confidence Interval at 90%	Savings [%]
Single-Family	1,025	1,048	1,025	14,468	1,067	(818, 1,317)	7.4
Multifamily	97	97	97	9,410	1,416	(977, 1,855)	15

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Key Installation Scenarios

Energy Trust's residential DHP Measure Approval Documents (MADs) stratify cost-effectiveness along building type (single-family vs. multifamily), heating zone (zones 1 and 2), and baseline heating system (electric zonal and forced air furnace). Cadmus first grouped savings and cost values by building type and heating zone because these attributes were available from the Project Tracking data and provided larger samples for analysis. These values are shown in Table 40 and Table 41.

Table 40. Average TMY Energy Savings and Installation Costs by Heating Zone

Sub-Group	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Single Family – Zone 1	1,406	1,487	13,914	895	(693, 1,097)	6.8	5,846	(5,724, 5,968)
Single Family – Zone 2	150	158	13,495	-337	(-930, 257)	-2.6	5,610	(5,342, 5,879)
Multifamily – Zone 1	112	140	9,586	1,202	(779, 1,626)	15.7	5,059	(4,549, 5,569)
Multifamily – Zone 2	6	6	12,620	2,035	(196, 3,874)	16.1	6,009	(4,390, 7,627)

Table 41. Average TMY Energy Savings and Installation Costs by Heating Zone*

Sub-Group	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Single Family – Zone 1	880	880	14,556	1,253	(979, 1,526)	8.6	5,878	(5,745, 6,012)
Single Family – Zone 2	120	120	13,667	-33	(-713, 648)	-0.2	5,867	(5,549, 6,184)
Multifamily – Zone 1	86	86	9,052	1,363	(899, 1,826)	15.1	5,283	(4,975, 5,590)
Multifamily – Zone 2	5	5	13,063	2,321	(590, 4,051)	17.8	6,411	(4,601, 8,220)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

It is surprising that single family homes in zone 2 show negative savings, although there are fewer sites than in zone 1. Removing homes in zone 2 from single family homes has the effect of increasing average savings for homes in heating zone 1, which are about 150 kWh higher than the average of all homes. Savings from multifamily dwellings in heating zone 1 do not deviate far from the average value for the group, this is because very few dwellings are in heating zone 2.

Cadmus used the baseline heating system information collected through surveys to further stratify savings and costs. It is important to note that in collecting baseline system information, Cadmus asked respondents to indicate heating systems they used during the baseline period that served the same spaces where the indoor unit of a DHP was installed. In many instances homes had multiple types of systems. Each row in Table 42 and Table 43 indicates that a site had either zonal electric resistance or a forced air furnace in one of the rooms where a DHP was installed. However, other system types may also have been used to heat that space. Also, because the survey response rates were in the range of 30%, there are far fewer sites shown in this table.

Table 42. Average TMY Energy Savings and Installation Costs by Heating Zone and Heating System

Sub-Group	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Single Family – Zone 1 – Zonal ER	266	287	13,642	1,331	(914, 1,748)	10.5	6,021	(5,734, 6,308)
Single Family – Zone 2 – Zonal ER	25	29	12,317	356	(-804, 1,516)	3.4	5,116	(4,615, 5,618)
Single Family – Zone 1 – FAF	24	24	14,514	3,485	(1,732, 5,238)	24	4,976	(4,527, 5,424)
Multifamily – Zone 1 – Zonal ER	18	22	6,928	579	(-340, 1,498)	10.2	4,616	(3,586, 5,646)

Table 43. Average TMY Energy Savings and Installation Costs by Heating Zone and Heating System*

Sub-Group	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Single Family – Zone 1 – Zonal ER	124	124	13,736	2,185	(1,531, 2,839)	15.9	5,933	(5,582, 6,284)
Single Family – Zone 1 – FAF	10	10	14,524	5,884	(3,197, 8,570)	40.5	5,015	(4,326, 5,705)
Single Family – Zone 2 – Zonal ER	10	10	14,501	2,729	(836, 4,622)	18.8	5,646	(4,652, 6,640)
Multifamily – Zone 1 – Zonal ER	13	13	7,397	954	(-24, 1,931)	12.9	4,709	(3,997, 5,421)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

The savings for single-family homes in zone 2 present a similar issue as before, although to a lesser degree. But the savings are much higher in heating zone 1 were either electric baseboard or a forced air furnace was known to be present. The sample sizes for multifamily dwelling are too small to draw any strong conclusions.

The same attributes used to stratify costs and savings in the above tables were also available in the Project Tracking data for the complete sample of participants. These data are used to reproduce the previous tables.

Table 44. Average TMY Energy Savings and Installation Costs by Heating Zone and Heating System – Project Tracking Data

Sub-Group	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Single Family – Zone 1 – Zonal ER	1,126	1,191	13,748	769	(549, 990)	5.9	5,874	(5,738, 6,009)
Single Family – Zone 2 – Zonal ER	124	131	13,519	-349	(-991, 293)	-2.7	5,606	(5,312, 5,900)
Single Family – Zone 1 – FAF	280	296	14,581	1,401	(907, 1,895)	10.2	5,734	(5,456, 6,011)
Single Family – Zone 2 – FAF	26	27	13,377	-279	(-1,837, 1,279)	-2.2	5,631	(4,961, 6,302)
Multifamily – Zone 1 – Zonal ER	58	71	8,664	985	(460, 1,510)	13.9	5,137	(4,474, 5,800)
Multifamily – Zone 1 – FAF	3	3	10,721	2,669	(632, 4,706)	24.9	7,115	(5,119, 9,112)

Table 45. Average TMY Energy Savings and Installation Costs by Heating Zone and Heating System – Project Tracking Data*

Sub-Group	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Single Family – Zone 1 – Zonal ER	714	714	14,223	964	(667, 1,261)	6.8	5,956	(5,805, 6,106)
Single Family – Zone 2 – Zonal ER	101	101	13,774	-136	(-882, 611)	-1	5,854	(5,508, 6,199)
Single Family – Zone 1 – FAF	166	166	15,992	2,494	(1,833, 3,156)	15.6	5,546	(5,261, 5,832)
Single Family – Zone 2 – FAF	19	19	13,096	514	(-1,159, 2,186)	3.9	5,936	(5,100, 6,772)
Multifamily – Zone 1 – Zonal ER	45	45	8,821	1,163	(502, 1,824)	13.2	5,547	(5,109, 5,985)
Multifamily – Zone 1 – FAF	2	2	12,230	3,330	(579, 6,082)	27.2	8,306	(7,638, 8,974)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 46 and Table 47 compare the average savings and cost values calculated as part of this evaluation with those presented in Energy Trust's MADs for DHPs. For context, there are several factors driving up the evaluated costs that make direct comparison with the MAD values difficult, including the installation of multiple indoor and outdoor units. MAD values are also calculated on a per site basis, whereas the evaluated savings are per DHP. It is clear the evaluated savings are lower in Table 46, but this result must be understood in the context of the methodological limitations outlined in the Regression Analysis section of the report. Most importantly, we know from surveys and gas consumption data that there is a large presence of supplemental fuel usage that cannot be accounted for when only analyzing electric billing records. There is also the issue of assuming the correct cooling baseline in cases when a homeowner would have purchased a less efficient system had they not installed a DHP. Both limitations are discussed in the following sections.

Table 46. Average TMY Energy Savings and Installation Costs by Heating Zone and Heating System and Measure Approval Document (MAD) Values[1, 2]

Measure	MAD Savings [kWh/Site]	Evaluated Savings [kWh/DHP]	MAD Incremental Costs [$/Site]	Evaluated Installation Cost [$/DHP]	MAD TRC BCR
Single-Family DHP for Zonal HZ 1	2,109	1,321	5,388	6,035	0.57
Single-Family DHP for Zonal HZ 2	2,314	356	5,388	5,116	0.62
Single-Family DHP for FAF HZ 1	3,836	3,852	5,388	5,212	1.00
Single-Family DHP for FAF HZ 2	3,592	NA	5,388	NA	1.02
Multifamily DHP Heating Zone 1	2,000	1,202	3,560	5,059	0.61
Multifamily DHP Heating Zone 2	2,194	2,035	3,560	6,009	0.73

[1]Energy Trust of Oregon. (2017). Measure Approval Document for Existing Single Family and Manufactured Housing Ductless Heat Pumps – MAD ID 70.2

[2]Energy Trust of Oregon. (2017). Measure Approval Document for Ductless Heat Pumps in Existing Multifamily – MAD ID 97

Table 47. Average TMY Energy Savings and Installation Costs by Heating Zone and Heating System and Measure Approval Document (MAD) Values*[1, 2]

Measure	MAD Savings [kWh/Site]	Evaluated Savings [kWh/DHP]	MAD Incremental Costs [$/Site]	Evaluated Installation Cost [$/DHP]	MAD TRC BCR
Single-Family DHP for Zonal HZ 1	2,109	2,185	5,388	5,933	0.57
Single-Family DHP for Zonal HZ 2	2,314	2,729	5,388	5,646	0.62
Single-Family DHP for FAF HZ 1	3,836	5,884	5,388	5,015	1.00
Single-Family DHP for FAF HZ 2	3,592	NA	5,388	NA	1.02
Multifamily DHP Heating Zone 1	2,000	1,363	3,560	5,283	0.61
Multifamily DHP Heating Zone 2	2,194	2,321	3,560	6,411	0.73

[1]Energy Trust of Oregon. (2017). Measure Approval Document for Existing Single Family and Manufactured Housing Ductless Heat Pumps – MAD ID 70.2

[2]Energy Trust of Oregon. (2017). Measure Approval Document for Ductless Heat Pumps in Existing Multifamily – MAD ID 97

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Supplemental Fuels

Fuel switching is a limitation in analyzing electric billing records to evaluate energy savings of DHPs. Cadmus surveyed heating systems and fuels used in spaces conditioned by DHPs and used this data to segment the savings analysis. The results are shown in Table 48 and Table 49. Many of the homes surveyed had more than one heating system and for this reason the savings values from one of these sites would be represented in more than one row. For example, a home with electric baseboard and a wood stove would be aggregated into each of those rows; every site included in a row reported at least the system listed in the first column as a baseline.

Table 48. Single Family Average TMY Energy Savings and Installation Costs by Baseline Heating System

Baseline Heating System	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Baseboard/Space Heater: Electric	342	372	13,484	1,160	(802, 1,519)	9.4	5,911	(5,670, 6,152)
Fireplace: Natural Gas	10	11	12,406	257	(-1,706, 2,219)	2.3	7,705	(5,711, 9,699)
Fireplace: Propane	3	3	14,220	3,588	(-2,883, 10,059)	25.2	4,671	(4,436, 4,905)
Fireplace: Unknown	8	9	12,673	552	(-819, 1,922)	4.9	6,279	(4,458, 8,100)
Fireplace: Wood	32	34	13,703	989	(58, 1,919)	7.7	6,576	(5,565, 7,587)
Furnace: Electric	25	25	14,524	3,486	(1,801, 5,171)	24	4,984	(4,554, 5,415)
Furnace: Natural Gas	8	8	8,785	-636	(-1,531, 259)	-7.2	7,322	(5,094, 9,550)
Furnace: Oil	6	6	14,206	-2,186	(-4,478, 105)	-15.4	6,604	(5,011, 8,198)
Furnace: Propane	2	3	13,664	1,560	(-2,369, 5,488)	17.1	4,907	(-950, 10,764)
Furnace: Unknown	29	31	13,428	187	(-1,232, 1,605)	1.5	6,137	(5,401, 6,874)
None	40	42	11,849	259	(-824, 1,343)	2.3	5,070	(4,308, 5,832)
Other: Electric	45	46	15,036	2,297	(1,500, 3,093)	15.6	5,805	(5,165, 6,445)
Other: Natural Gas	15	16	10,582	-815	(-2,400, 769)	-8.2	5,541	(4,663, 6,419)
Other: Propane	9	11	14,208	21	(-1,777, 1,820)	0.2	6,316	(4,187, 8,446)
Other: Unknown	24	33	14,688	1,311	(-233, 2,856)	12.3	5,803	(4,497, 7,109)
Radiant Floor: Electric	6	7	17,812	-1,115	(-4,563, 2,333)	-7.3	5,067	(4,299, 5,836)
Radiant Floor: Unknown	4	5	17,063	2,123	(-2,719, 6,964)	15.5	5,822	(3,091, 8,553)
Stove: Other	3	3	10,550	635	(-2,024, 3,295)	6	4,579	(4,414, 4,744)
Stove: Unknown	31	34	14,136	-467	(-1,613, 680)	-3.6	5,416	(4,923, 5,908)
Stove: Wood	132	145	13,258	-174	(-751, 402)	-1.4	5,617	(5,323, 5,910)

*Respondents were presented with a list of systems and allowed to select 'Other' if their system wasn't listed, this was followed with an option to manually enter the type of system they had, but this text entry wasn't mandatory or in all cases reliable

Table 49. Single Family Average TMY Energy Savings and Installation Costs by Baseline Heating System*

Baseline Heating System	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Baseboard/Space Heater: Electric	149	149	13,891	2,162	(1,570, 2,754)	15.6	5,885	(5,572, 6,197)
Furnace: Electric	11	11	14,547	5,668	(3,199, 8,137)	39	5,032	(4,407, 5,656)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

It is clear from this table that the targeted baseline systems for the program, zonal electric resistance and electric furnaces, are on average saving much more than the group of unsegmented participants. As we saw in the Survey section of the report, there is a large portion of homes with wood and pellet stoves and the average savings of these individuals are -174 kWh/DHP. There is a similar trend for homes with natural gas and oil furnaces. This finding is intuitive because DHPs in these homes are displacing non-electric heating and may increase electricity usage while reducing wood or gas consumption. Combined, these two groups of sites have a significant negative impact on overall program savings.

It was also possible for survey participants to report there was no heating system present during the baseline period and this is indicated in Table 48 with the label 'None'. In this scenario, a DHP is being installed in a previously unconditioned space, however this is not what is assumed in conducting a billing analysis and has the effect of lowering program savings. For single family homes this group saw an average of 259 kWh/DHP in savings.

The smaller sample of multifamily participants makes it difficult to make inferences when stratifying the data using survey responses but, for reference, savings are shown in Table 50 and Table 51.

Table 50. Multifamily Average TMY Energy Savings and Installation Costs by Baseline Heating System

Baseline Heating System	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Baseboard/Space Heater: Electric	20	24	7,030	531	(-311, 1,374)	9.1	4,692	(3,750, 5,634)
Fireplace: Natural Gas	3	3	5,924	452	(-4,464, 5,367)	7.6	5,759	(3,790, 7,728)
Other: Electric	2	2	6,063	348	(-1,477, 2,174)	5.7	4,517	(4,160, 4,874)

Table 51. Multifamily Average TMY Energy Savings and Installation Costs by Baseline Heating System*

Baseline Heating System	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Baseboard/Space Heater: Electric	14	14	7,687	933	(22, 1,843)	12.1	4,855	(4,153, 5,556)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Cadmus further refined Table 48 to include single-family sites with only baseline heating systems that consumed electricity; this varies from the previous tables in that it excludes sites where supplemental fuels may have been present in addition to an electric system. The first step in developing this sample was to remove all sites with recorded gas consumption from the UCI data (14% of single-family homes, ~2% of multifamily buildings), then Cadmus used the survey responses to exclude any homes with heating systems that didn't consume electricity or where the fuel type was unknown. These results are shown in Table 52.

Table 52. Single Family Average TMY Energy Savings and Installation Costs without Supplemental Fuel Usage

Baseline Heating System	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Baseboard: Electric	165	175	14,060	1,946	(1,419, 2,474)	14.7	5,675	(5,368, 5,981)
Other: Electric	19	19	15,956	3,190	(1,896, 4,485)	20	5,789	(4,732, 6,846)
Furnace: Electric	13	13	14,033	5,448	(3,328, 7,569)	38.8	4,934	(4,399, 5,470)

The savings shown in Table 52 are all much higher than the program average and more in line with the values presented in the single family DHP MAD.

Cooling Baseline

The Regression Analysis section of this report discussed how a billing analysis can assume the wrong cooling baseline and have the effect of diminishing savings. This occurs when a program participant would have purchased a less efficient cooling system, such as a window AC, if they had not installed a DHP. The Survey section of this report showed that approximately 18% of single-family homes and 10% of multifamily dwellings indicated they would have installed a window AC if it wasn't for their DHP. One way to calculate savings in this scenario, assuming these individuals wouldn't have otherwise purchased a DHP, is to develop an estimate of cooling-related energy consumption and multiply this value by the difference of the inverse ratios of assumed baseline and efficient cooling systems. One limitation specific to calculating savings between a DHP and a window AC is that the cooling efficiency ratings of the systems are not identical. A DHP's efficiency is rated with a SEER value that is measured over a range of outdoor temperatures, but a window AC is rated with an EER, which represents the system's efficiency at a single outdoor temperature (usually 95 degrees F). Directly comparing these two measures has the effect of increasing savings. With this limitation in mind, the equation for calculating savings is shown below:

$$Savings = \left(\frac{1}{EER_{BL}} - \frac{1}{SEER_{EE}}\right)\left(\frac{3412.14}{1000}\right)(kWh_{cool})$$

With quantities and dimensions:

$Savings$: TMY cooling energy savings measured in kWh

EER_{BL}: Energy efficiency ratio measured in Btu/Wh

$SEER_{EE}$: Seasonal energy efficiency ratio measured in Btu/Wh

kWh_{cool}: TMY cooling energy consumption measured in kWh

Conversion factor: 3412.14 [Btu/h]/kW and 1 W/1000 kW

Cadmus developed an estimate of cooling related consumption from the same regression models used to estimate annual energy savings by using only the term coefficient for cooling degree days. The consumption values shown in Table 53 are calculated from the post-period models of single and multifamily participants who demonstrated some level of cooling. Cadmus calculated the savings values from these estimates using baseline equipment EERs and energy efficient DHP SEERs. Cadmus assumed baseline EERs using the federal minimum AC efficiency and DHP SEERs from commonly observed values in the study. It is clear from the surveys that a billing analysis misrepresents the baseline cooling system for a portion of individuals and that correcting this would increase the estimated DHP savings.

Table 53. Average TMY Cooling Savings – Assumed AC Baseline

Residential Group	Site [Count]	DHP [Count]	Cooling Consumption [kWh/DHP]	Consumption Confidence Interval at 90%	High Efficiency SEER*	Baseline Efficiency EER**	Cooling Savings [kWh/DHP]
Single-Family	545	585	677	(636, 718)	18	11.3	204
Multifamily	40	49	422	(293, 550)	18	11.3	127

The challenge in incorporating cooling savings calculated as in Table 53 with the savings developed using a billing analysis is the availability of survey responses indicating the actions participants would have taken if they hadn't purchased a DHP. Cadmus re-analyzed the sub-group where this survey and billing data were present to estimate the impact of using a billing analysis to calculate heating savings and a TRM analysis to calculate cooling savings. There were 69 single-family and 2 multifamily participants available for this analysis that indicated their counterfactual cooling system was an AC; the multifamily analysis is not presented because of the small sample size.

A review of survey responses for the sub-group of single-family participants that indicated they would have installed an AC unit if not for the DHP shows the following breakdown of baseline cooling systems.

Table 54. Single-Family Reported Baseline Cooling Systems Where AC Was the Counterfactual Cooling System

Baseline Cooling System	Site [Count]	Site [%]
Fan	13	19%
Fan, Room AC	6	9%
None	36	52%
Other, Fan	4	6%
Room AC	10	14%
Total	69	100%

Note: 69 total respondents

Table 54 illustrates two limitations in this analysis. The first is that although these individuals indicated they would have purchased an AC had they not purchased a DHP, greater than 20% already had an AC as a baseline (the survey also allowed respondents to select 'Existing System' as their counterfactual cooling system). We don't know precisely the thought process of these individuals; they may have purchased a new AC to replace the current system or not differentiated between the options 'Existing System' and 'Room AC'. Either way, these homeowners do not fit the profile intended for this analysis because their baseline and counterfactual systems are the same. However, in these cases, a TRM analysis would not be any less valid but we're specifically looking to analyze individuals that do not fit the assumptions of a billing analysis. The second limitation is that the billing data is only available at the site level and where DHPs are installed with multiple indoor units it's possible for one space to have the same baseline and counterfactual system while another space doesn't. Cadmus removed sites with Room ACs or multiple systems in the baseline to address these issues. The remaining sample size was 49 and all baseline systems were either 'Fan' or 'None'.

Cadmus estimated the TMY cooling consumption for the 49 single-family participants from their billing data. The average of these estimates was 439 kWh and their distribution is provided in Table 55.

Table 55. Single-Family Estimated TMY Cooling Usage – AC Counterfactual Cooling System

TMY Cooling Usage [kWh]	Site [Count]	Site [%]
[0, 200]	17	35%
(200, 400]	13	27%
(400, 600]	6	12%
(600, 800]	3	6%
(800, 1,000]	3	6%
(1,000, 1,200]	3	6%
(1,200, 1,400]	2	4%
(1,400, 1,600]	2	4%
Total	49	100%

Not all participants in this sub-group demonstrated a positive relationship between CDDs and monthly energy consumption despite indicating they used their DHP for cooling. Of the 49 accounts, 10 had zero modeled TMY cooling consumption. This result is in a part a limitation of using monthly data whereas sub-metering may have captured the cooling reported in the surveys, although this may not have been a substantial amount of cooling.

Cadmus applied the same methodology and assumptions used in Table 53 to estimate TMY cooling savings from annual cooling consumption. The average cooling savings per DHP was 130 kWh and is summarized in Table 56. This value is lower than the 204 kWh estimated for all sites with demonstrated cooling usage and is the result of the lower average TMY cooling usage.

Table 56. Single-Family Estimated TMY Cooling Savings – AC Counterfactual Cooling System

Residential Group	Site [Count]	DHP [Count]	Cooling Consumption [kWh/DHP]	High Efficiency SEER*	Baseline Efficiency EER**	Cooling Savings [kWh/DHP]
Single-Family	49	50	439	18	11.3	130

*Assumed DHP with 18 SEER

**Assumed AC with 11.3 EER, no federal minimum SEER of ACs, using EER will produce a higher savings estimate

The reason for conducting this analysis on this sub-group of participants was to identify through survey responses individuals where the assumptions of a billing analysis were not supported. Specifically, Cadmus corrected for the assumption that the pre-installation period was the correct cooling baseline for calculating savings. The 49 participants included in the analysis reported using their DHPs for cooling and having either no cooling or only using a fan prior to installing their DHP, and for these reasons it would be reasonable to assume that a billing analysis would indicate added electric consumption (negative savings) during times when cooling was required. This result would be despite their reported intention to purchase air conditioning in the absence of purchasing a DHP. These negative savings associated with cooling would reduce annual TMY savings, but by substituting savings calculated using a

TRM approach and survey responses Cadmus would better estimate annual savings based on intentions of participants. It was then surprising that the billing analysis did not calculate negative savings for most of the 49 participants and the average cooling savings were higher than the 130 kWh calculated in Table 56. The equivalent cooling savings value calculated by the billing analysis was 184 kWh. There is no clear explanation for the discrepancy between the logical expectation and the empirical reality of this result, however it is important to consider the limitations of the data collected for this analysis. Monthly billing data allows us to model cooling consumption but not with the granularity AMI or sub-metering would provide; this process is made more challenging by a short cooling season. Also, participant responses, even from well-designed surveys, are still subject to many difficulties in soliciting reliable information from individuals. Despite this counterintuitive result, the effect of the correction on the overall sample of single-family participants would be small because survey responses were only available for 49 participants that fit the intended profile and this sample is a fraction of the nearly 1,600 sites included in total.

Controls

Cadmus surveyed how program participants control their DHPs by asking if it was operated manually (turned on and off as needed) or using a programmable thermostat with scheduled set points. Homeowners were also asked if these controls were set on the unit, with a remote, or with a wall-mounted thermostat. The Survey section of this report discussed the potential for increasing energy savings with the adoption of programmable controls. This was in the context of homeowners reporting using less efficient heating and cooling systems more than the installed DHP system. The concept is that if controls are configured to automatically use a DHP before using less efficient systems then energy savings will increase, but it is unlikely this is occurring in practice. The savings values in Table 57 indicate DHPs that were controlled with programmable thermostats saved much less than those controlled manually, but this analysis does not capture how those programmable controls were configured. If done correctly, controls do still present an opportunity for increasing energy savings by reducing the use of less efficient systems. Savings values calculated for sites without multiple outdoor units or documented supplemental fuel usage are shown in Table 58.

Table 57. Single Family Average TMY Energy Savings and Installation Costs by DHP Controls

DHP Controls	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Manual Remote Thermostat	405	439	13,455	1,074	(731, 1,416)	8.6	5,699	(5,496, 5,901)
Programmable Wall-Mounted Thermostat	63	69	13,187	95	(-848, 1,037)	0.8	6,185	(5,480, 6,891)
Manual Wall-Mounted Thermostat	35	41	16,204	1,300	(38, 2,563)	9.4	6,141	(5,051, 7,231)
Manual On-Unit Thermostat	20	24	12,709	285	(-781, 1,351)	2.7	5,011	(4,294, 5,729)

Table 58. Single Family Average TMY Energy Savings and Installation Costs by DHP Controls*

DHP Controls	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Manual Remote Thermostat	130	130	13,542	2,257	(1,613, 2,902)	16.7	5,950	(5,610, 6,290)
Programmable Wall-Mounted Thermostat	11	11	14,527	2,879	(1,383, 4,375)	19.8	6,101	(4,871, 7,330)
Manual Wall-Mounted Thermostat	8	8	18,609	3,513	(697, 6,328)	18.9	4,681	(4,228, 5,135)
Manual On-Unit Thermostat	5	5	9,889	821	(-1,490, 3,133)	8.3	5,462	(4,571, 6,353)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Site Attribute Analysis

Many variables describing single and multifamily sites were available in the Project Tracking and survey data. This section of the report explores many of these attributes to identify variability in DHP energy savings and installation costs.

Table 59 and Table 60 present average DHP energy savings and installation costs by room type for single family homes. For each row, the sites aggregated all had a DHP indoor unit installed in the room type listed in the first column; any site with multiple rooms where indoor units were installed will be included in multiple rows of the table. Most indoor units were installed in living rooms and these systems also have the highest savings of any room type with reasonable sample size. The average savings of 1,118 kWh/DHP for sites where a DHP indoor unit was installed in a living room is higher than the 756 kWh/DHP for all sites, and the 2,528 kWh/DHP calculated with supplemental fuels removed is more than three times higher. Also notable is the higher cost of installations in homes where an indoor unit conditioned a bedroom. It appears this was the case because indoor units installed in bedrooms were often secondary and multiple indoor units increases the cost of installation. The room-level information collected from surveys for multifamily dwellings was insufficient for this analysis.

Table 59. Single Family Average TMY Energy Savings and Installation Costs by Room Type

Room Type	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Living Room	415	449	13,218	1,118	(770, 1,465)	9.1	5,796	(5,580, 6,013)
Bedroom	203	233	14,187	621	(147, 1,096)	5	7,037	(6,694, 7,380)
Other	31	36	14,643	826	(-294, 1,945)	6.5	6,309	(5,497, 7,121)
Kitchen	29	33	13,805	206	(-930, 1,342)	1.7	6,151	(5,143, 7,158)
Dining Room	26	32	14,562	201	(-992, 1,393)	1.7	6,310	(5,246, 7,374)
Office	16	18	14,987	-509	(-2,346, 1,327)	-3.8	8,245	(6,839, 9,652)
Basement	16	19	17,568	-191	(-1,955, 1,573)	-1.3	8,343	(6,123, 10,562)
Sunroom	6	11	16,538	-952	(-4,883, 2,980)	-10.5	3,330	(1,696, 4,964)
Hallway	4	4	14,290	384	(-1,801, 2,569)	2.7	7,870	(6,479, 9,261)
Loft	3	4	12,405	333	(-1,141, 1,807)	3.6	5,399	(3,075, 7,723)
Bathroom	2	3	9,937	2,181	(-919, 5,281)	32.9	2,969	(1,120, 4,818)
Garage	2	2	20,580	3,668	(1,224, 6,112)	17.8	3,500	(1,198, 5,803)

Table 60. Single Family Average TMY Energy Savings and Installation Costs by Room Type*

Room Type	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Living Room	128	128	13,464	2,528	(1,875, 3,180)	18.8	6,009	(5,653, 6,364)
Bedroom	62	62	15,171	2,114	(1,120, 3,107)	13.9	7,578	(7,036, 8,120)
Kitchen	8	8	13,380	2,322	(43, 4,600)	17.4	6,409	(5,541, 7,277)
Dining Room	6	6	8,665	-118	(-2,312, 2,077)	-1.4	7,377	(5,725, 9,029)
Office	3	3	19,083	-12	(-4,338, 4,314)	-0.1	10,262	(7,792, 12,732)
Other	3	3	17,890	2,248	(-3,252, 7,748)	12.6	7,615	(5,233, 9,997)
Basement	2	2	19,899	418	(-6,278, 7,114)	2.1	7,294	(2,745, 11,844)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Cadmus looked at energy savings by TMY baseline period consumption binned at 5,000 kWh intervals. Table 61 and Table 62 show that the lower end of consumers (less than 10,000 kWh/year) had on average negative energy savings. It's difficult to draw any conclusions about the higher end of consumers because there are fewer sites, but between 15,000 kWh and 25,000 kWh there are on average much higher savings than the unstratified group of participants.

Table 61. Single Family Average TMY Energy Savings and Installation Costs by Baseline Consumption

Pre-Period TMY Consumption [kWh]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(0, 5,000]	82	86	3,829	-1,632	(-2,044, -1,219)	-44.7	5,511	(5,121, 5,901)
(5,000, 10,000]	379	398	7,905	-157	(-454, 139)	-2.1	5,518	(5,312, 5,724)
(10,000, 15,000]	535	563	12,505	648	(351, 946)	5.5	5,853	(5,665, 6,040)
(15,000, 20,000]	344	363	17,285	1,540	(1,132, 1,948)	9.4	5,902	(5,674, 6,129)
(20,000, 25,000]	156	173	22,202	1,875	(1,111, 2,640)	9.4	6,027	(5,601, 6,454)
(25,000, 30,000]	58	62	27,075	2,173	(678, 3,667)	8.6	6,841	(6,049, 7,632)
(30,000, 50,000]	29	31	34,853	2,999	(408, 5,590)	9.2	6,379	(5,262, 7,496)

Table 62. Single Family Average TMY Energy Savings and Installation Costs by Baseline Consumption*

Pre-Period TMY Consumption [kWh]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(0, 5,000]	34	34	3,958	-1764	(-2,510, -1,019)	-44.6	5,134	(4,735, 5,533)
(5,000, 10,000]	232	232	7,937	95	(-313, 503)	1.2	5,603	(5,382, 5,823)
(10,000, 15,000]	336	336	12,468	992	(602, 1,382)	8	5,912	(5,706, 6,118)
(15,000, 20,000]	248	248	17,370	1,677	(1,180, 2,173)	9.7	6,112	(5,843, 6,381)
(20,000, 25,000]	110	110	22,139	2,329	(1,383, 3,275)	10.5	5,922	(5,517, 6,326)
(25,000, 30,000]	37	37	27,293	1,497	(-635, 3,629)	5.5	6,359	(5,736, 6,982)
(30,000, 50,000]	25	25	35,141	3,036	(2, 6,070)	8.6	6,697	(5,478, 7,916)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Multifamily participants have a similar trend; the low end (less than 10,000 kWh) saw below average savings and the high end (between 10,000 kWh and 20,000 kWh) were above average. These savings values are shown in Table 63 and Table 64.

Table 63. Multifamily Average TMY Energy Savings and Installation Costs by Baseline Consumption

Pre-Period TMY Consumption [kWh]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(0, 5,000]	15	19	4,017	-402	(-989, 184)	-12.7	5,496	(4,374, 6,618)
(5,000, 10,000]	58	64	7,612	848	(355, 1341)	12.3	4,668	(4,294, 5,043)
(10,000, 15,000]	32	41	12,402	2,366	(1,448, 3,285)	24.4	5,433	(4,414, 6,453)
(15,000, 20,000]	9	15	16,375	1,673	(251, 3,095)	17	5,916	(2,501, 9,330)

Table 64. Multifamily Average TMY Energy Savings and Installation Costs by Baseline Consumption*

Pre-Period TMY Consumption [kWh]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(0, 5,000]	9	9	4,093	-615	(-1,395, 165)	-15	6,424	(5,366, 7,482)
(5,000, 10,000]	52	52	7,614	1,170	(654, 1,686)	15.4	4,756	(4,469, 5,042)
(10,000, 15,000]	24	24	12,441	2,448	(1,497, 3,398)	19.7	5,956	(5,258, 6,655)
(15,000, 20,000]	6	6	16,534	2,246	(-58, 4550)	13.6	5,837	(4,013, 7,662)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Results from segmenting the analysis by the number of indoor units per DHP are shown in Table 65 and Table 66. The labeling in the configuration column indicates the number of outdoor units first, then the number of indoor units. It is evident that installing more indoor units increases installation costs. However, it is unexpected that energy savings would have the opposite trend. Intuitively it makes sense that more capacity would have a greater displacement of less efficient systems and increase savings, but this analysis shows that one-to-one systems had the highest savings on average. Multifamily dwelling did not see the same trend in energy savings by number of indoor units. In Table 67 and Table 68, systems with two indoor units had the highest energy savings.

Table 65. Single Family Average TMY Energy Savings and Installation Costs by DHP System Configuration

DHP System Configuration	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1-1	928	928	13,410	1,050	(804, 1,296)	7.8	4,780	(4,694, 4,867)
1-2	369	369	13,890	635	(206, 1,064)	4.6	7,204	(7,042, 7,366)
1-3	145	145	14,825	458	(-148, 1,064)	3.1	8,931	(8,615, 9,248)

Table 66. Single Family Average TMY Energy Savings and Installation Costs by DHP System Configuration*

DHP System Configuration	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1-1	658	658	14,063	1,277	(979, 1,575)	9.1	4,766	(4,674, 4,857)
1-2	231	231	14,698	793	(197, 1,389)	5.4	7,178	(6,967, 7,389)
1-3	99	99	15,697	826	(60, 1,592)	5.3	8,779	(8,457, 9,101)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 67. Multifamily Average TMY Energy Savings and Installation Costs by DHP System Configuration

DHP System Configuration	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1-1	74	74	8,886	1,371	(920, 1,823)	15.4	4,538	(4,329, 4,746)
1-2	22	22	10,510	2,091	(869, 3,312)	19.9	7,179	(6,607, 7,751)
1-3	5	5	8,731	-845	(-2,825, 1,135)	-9.7	8,263	(7,652, 8,875)

Table 68. Multifamily Average TMY Energy Savings and Installation Costs by DHP System Configuration*

DHP System Configuration	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1-1	67	67	9,005	1,426	(972, 1,879)	15.8	4,567	(4,342, 4,793)
1-2	21	21	9,967	1,972	(732, 3,213)	19.8	7,181	(6,581, 7,781)
1-3	4	4	9,874	-629	(-3,109, 1,852)	-6.4	8,318	(7,537, 9,099)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Single and multifamily energy savings and installation costs by DHP capacity are shown in Table 69, Table 70, Table 71, and Table 72. The capacities shown in the first column are measured in BTUs per hour and represent the total capacity of all DHP systems at a site. These results show a similar trend to that of the previous tables grouping savings by the number of indoor units; this is in part because systems with multiple units tend to have higher capacity. It is also the case that lower capacity systems have on average lower installation costs.

Table 69. Single Family Average TMY Energy Savings and Installation Costs by Total DHP Capacity per Site

Total Site Capacity [Btu/h]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(6,000, 12,000]	190	198	13,485	1,267	(772, 1,761)	9.8	4,124	(3,952, 4297)
(12,000, 18,000]	514	533	12,939	982	(652, 1,312)	7.9	4,914	(4,786, 5,042)
(18,000, 24,000]	401	414	13,950	998	(605, 1,390)	7.4	5,980	(5,823, 6,137)
(24,000, 30,000]	207	219	14,190	144	(-371, 659)	1.1	6,672	(6,377, 6,968)
(30,000, 36,000]	166	187	15,249	-258	(-902, 386)	-1.9	7,984	(7,607, 8,361)
(36,000, 54,000]	46	61	17,005	691	(-820, 2,202)	5.4	7,208	(6,263, 8,153)

Table 70. Single Family Average TMY Energy Savings and Installation Costs by Total DHP Capacity per Site*

Total Site Capacity [Btu/h]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(6,000, 12,000]	118	118	14,334	1,494	(827, 2,160)	10.4	4,112	(3,903, 4,322)
(12,000, 18,000]	345	345	13,802	1,549	(1,134, 1,964)	11.2	4,985	(4,854, 5,116)
(18,000, 24,000]	276	276	14,714	1,378	(881, 1,875)	9.4	6,116	(5,922, 6,309)
(24,000, 30,000]	130	130	14,393	-60	(-743, 622)	-0.4	6,755	(6,432, 7,077)
(30,000, 36,000]	96	96	15,163	-393	(-1,231, 445)	-2.6	8,515	(8,103, 8,927)
(36,000, 54,000]	22	22	18,102	1,690	(-863, 4,242)	9.3	8,704	(7,162, 10,245)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 71. Multifamily Average TMY Energy Savings and Installation Costs by Total DHP Capacity per Site

Total Site Capacity [Btu/h]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(6,000, 12,000]	11	11	8,544	2,575	(1,474, 3,677)	30.1	3,813	(3,546, 4,080)
(12,000, 18,000]	15	15	10,970	1,760	(527, 2,994)	16	5,075	(4,484, 5,666)
(18,000, 54,000]	7	8	13,022	2,238	(-78, 4,555)	19.6	6,827	(5,765, 7,888)

Table 72. Multifamily Average TMY Energy Savings and Installation Costs by Total DHP Capacity per Site*

Total Site Capacity [Btu/h]	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
(6,000, 12,000]	11	11	8,544	2,575	(1,474, 3,677)	30.1	3,813	(3,546, 4,080)
(12,000, 18,000]	14	14	11,010	1,843	(609, 3,077)	16.7	5,152	(4,532, 5,772)
(18,000, 54,000]	5	5	12,420	3,321	(242, 6,401)	26.7	8,765	(8,139, 9,390)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Cadmus tabulated results by installation year, these are shown in Table 73 and Table 74 for single family participants and Table 75 and Table 76 for multifamily participants. It is interesting to observe that in both cases savings increase from year to year. This could be the result of better targeting of participants or program changes, but the data made available for this study were insufficient to identify the cause.

Table 73. Single Family Average TMY Energy Savings and Installation Costs by Installation Year

Installation Year	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
2015	631	666	13,586	712	(417, 1,008)	5.5	5,654	(5,493, 5,814)
2016	626	659	13,702	635	(336, 934)	4.9	6,018	(5,826, 6,211)
2017	326	351	14,850	1,084	(644, 1,525)	7.9	5,814	(5,568, 6,060)

Table 74. Single Family Average TMY Energy Savings and Installation Costs by Installation Year*

Installation Year	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
2015	400	400	14,034	963	(581, 1,346)	6.9	5,709	(5,527, 5,891)
2016	393	393	14,428	1,069	(663, 1,475)	7.4	6,037	(5,830, 6,245)
2017	229	229	15,338	1,280	(698, 1,862)	8.3	6,002	(5,742, 6,262)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 75. Multifamily Average TMY Energy Savings and Installation Costs by Installation Year

Installation Year	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
2015	42	59	9,084	578	(34, 1,122)	8.9	5,363	(4,286, 6,439)
2016	46	56	9,829	1,579	(799, 2,358)	19.6	4,879	(4,329, 5,428)
2017	31	32	10,453	1,988	(1,187, 2,790)	19.6	4,951	(4,421, 5,482)

Table 76. Multifamily Average TMY Energy Savings and Installation Costs by Installation Year*

Installation Year	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
2015	29	29	9,090	938	(226, 1,649)	10.3	5,500	(4,926, 6,073)
2016	34	34	8,714	1,299	(529, 2,068)	14.9	5,359	(4,893, 5,824)
2017	29	29	10,079	2,175	(1,350, 3,000)	21.6	5,117	(4,547, 5,687)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Results by region are shown in Table 77, Table 78, Table 79, and Table 80.

Table 77. Single Family Average TMY Energy Savings and Installation Costs by Region

Region	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Portland Metro & Hood River	605	641	13,190	890	(605, 1,176)	7.2	6,608	(6,392, 6,824)
Willamette Valley	473	497	14,559	860	(505, 1,216)	6.2	5,434	(5,261, 5,606)
Southern Oregon	294	317	14,376	679	(160, 1,198)	5.1	5,130	(4,921, 5,339)
Central Oregon	142	149	13,845	-278	(-888, 331)	-2.1	5,644	(5,370, 5,919)
North Coast	51	54	12,180	940	(-375, 2,255)	8.2	4,989	(4,588, 5,389)
Eastern Oregon	18	18	17,259	2,800	(837, 4,762)	16.2	5,528	(4,690, 6,366)

Table 78. Single Family Average TMY Energy Savings and Installation Costs by Region*

Region	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Portland Metro & Hood River	345	345	13,964	1,329	(941, 1,717)	9.5	6,637	(6,398, 6,876)
Willamette Valley	295	295	15,073	998	(532, 1,464)	6.6	5,505	(5,306, 5,704)
Southern Oregon	225	225	14,660	1,131	(535, 1,728)	7.7	5,376	(5,141, 5,612)
Central Oregon	114	114	14,180	14	(-684, 711)	0.1	5,889	(5,577, 6,202)
North Coast	30	30	13,400	1,722	(-385, 3,830)	12.9	5,450	(4,861, 6,040)
Eastern Oregon	13	13	16,582	2,919	(257, 5,581)	17.6	5,566	(4,605, 6,527)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 79. Multifamily Average TMY Energy Savings and Installation Costs by Region

Region	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Portland Metro & Hood River	91	110	8,526	1,020	(496, 1,544)	14.5	5,374	(4,771, 5,976)
Willamette Valley	17	23	14,105	1,838	(815, 2,862)	17.6	3,864	(3,089, 4,640)
Central Oregon	7	7	12,008	2,545	(741, 4,350)	21.2	5,678	(4,206, 7,150)
Southern Oregon	4	7	14,495	1,972	(39, 3,904)	23.8	4,048	(1,266, 6,831)

Table 80. Multifamily Average TMY Energy Savings and Installation Costs by Region*

Region	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Portland Metro & Hood River	74	74	8,474	1,114	(631, 1,597)	13.1	5,422	(5,108, 5,736)
Willamette Valley	11	11	12,418	2,962	(1,615, 4,308)	23.8	4,542	(3,477, 5,607)
Central Oregon	6	6	12,274	2,869	(1,145, 4,593)	23.4	5,958	(4,304, 7,612)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 81 and Table 82 summarize energy savings and costs by home area for single family participants. These results show higher energy saving among homes smaller than 1,500 square feet. Similar data were collected for multifamily participants but too few sites were available to identify any trends.

Table 81. Single Family Average TMY Energy Savings and Installation Costs by Home Area

Home Area	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Less than 1,000 sq. ft.	76	76	10,744	2,056	(1,357, 2,754)	19.1	4,979	(4,695, 5,263)
1,000 - 1,500 sq. ft.	221	229	12,665	1,210	(755, 1,666)	9.9	5,849	(5,590, 6,107)
1,500 - 2,000 sq. ft.	108	121	14,796	903	(294, 1,512)	6.8	6,002	(5,552, 6,452)
2,000 - 2,500 sq. ft.	35	42	16,074	464	(-840, 1,768)	3.5	5,512	(4,578, 6,445)
More than 2,500 sq. ft.	37	47	15,838	-697	(-1,986, 593)	-5.6	6,180	(5,119, 7,242)

Table 82. Single Family Average TMY Energy Savings and Installation Costs by Home Area*

Home Area	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Less than 1,000 sq. ft.	34	34	11,515	2,937	(1,717, 4,156)	25.5	4,997	(4,595, 5,400)
1,000 - 1,500 sq. ft.	71	71	12,817	2,618	(1,770, 3,466)	20.4	5,905	(5,501, 6,309)
1,500 - 2,000 sq. ft.	28	28	16,539	1,927	(825, 3,028)	11.7	6,826	(5,972, 7,679)
2,000 - 2,500 sq. ft.	8	8	17,954	3,172	(939, 5,404)	17.7	5,303	(4,624, 5,982)
More than 2,500 sq. ft.	5	5	16,428	-3,658	(-8,682, 1,366)	-22.3	9,972	(6,177, 13,767)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 83, Table 84, Table 85, and Table 86 display results for single family and multifamily participants stratified by home vintage.

Table 83. Single Family Average TMY Energy Savings and Installation Costs by Home Vintage

Home Vintage	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1960's	71	77	14,588	1,304	(472, 2,136)	9.7	6,089	(5,423, 6,755)
1970's	125	131	13,619	1,281	(661, 1,902)	9.9	5,916	(5,491, 6,342)
1980's	51	51	12,580	457	(-417, 1,331)	3.6	6,656	(5,956, 7,355)
1990's	49	55	12,570	1,051	(163, 1,939)	9.4	5,279	(4,780, 5,779)
2000 or more recently	29	33	14,403	909	(-132, 1,950)	7.2	5,287	(4,785, 5,790)

Table 84. Single Family Average TMY Energy Savings and Installation Costs by Home Vintage*

Home Vintage	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1960's	24	24	13,737	1,905	(-100, 3,909)	13.9	6,227	(5,169, 7,286)
1970's	33	33	13,910	2,791	(1,521, 4,061)	20.1	6,190	(5,465, 6,915)
1980's	12	12	13,243	1,809	(402, 3,217)	13.7	5,508	(4,299, 6,718)
1990's	20	20	11,758	1,800	(683, 2,918)	15.3	5,861	(4,985, 6,738)
2000 or more recently	14	14	14,345	1,289	(-195, 2,772)	9	6,584	(5,710, 7,459)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Table 85. Multifamily Average TMY Energy Savings and Installation Costs by Home Vintage

Home Vintage	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1960's	5	6	7,077	-881	(-2,924, 1,163)	-14.9	5,457	(4,528, 6,386)
1970's	8	8	7,247	2,001	(608, 3,394)	27.6	4,510	(4,170, 4,849)
1980's	4	4	6,684	1,498	(544, 2,452)	22.4	4,518	(4,123, 4,913)
1990's	3	3	8,124	21	(-893, 935)	0.3	4,258	(1,879, 6,637)
2000 - 2008	2	2	8,794	-756	(-2,679, 1,167)	-8.6	5,518	(1,362, 9,675)

Table 86. Multifamily Average TMY Energy Savings and Installation Costs by Home Vintage*

Home Vintage	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
1960's	3	3	8,696	-12	(-3,567, 3,542)	-0.1	6,573	(5,167, 7,978)
1970's	6	6	7,078	1,746	(754, 2,738)	24.7	4,630	(4,206, 5,054)
1980's	2	2	7,190	1,620	(-385, 3,626)	22.5	4,406	(3,491, 5,322)
1990's	3	3	8,124	21	(-893, 935)	0.3	4,258	(1,879, 6,637)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Cadmus surveyed participants about the type of outdoor unit mounting that was used in DHP installations. The choices survey respondents had were bracket-mounted to the building, freestanding on a concrete slab, or other. Too few multifamily data were collected to make any recommendations, but there is some evidence of cost savings in single family homes where the outdoor unit was bracket-mounted to the house. Single family results are summarized in Table 87 and Table 88.

Table 87. Single Family Average TMY Energy Savings and Installation Costs by Outdoor Unit Mounting

Outdoor Unit Mounting	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Slab	396	429	12,982	1,001	(658, 1,344)	8.4	5,841	(5,610, 6,072)
Bracket	56	66	14,440	-55	(-1,118, 1,008)	-0.4	4,893	(4,411, 5,376)
Other	39	43	15,091	1,610	(592, 2,628)	11.8	5,523	(4,858, 6,187)

Table 88. Single Family Average TMY Energy Savings and Installation Costs by Outdoor Unit Mounting*

Outdoor Unit Mounting	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Slab	119	119	13,049	2,300	(1,609, 2,991)	17.6	5,909	(5,556, 6,262)
Bracket	16	16	16,161	2,245	(408, 4,081)	13.9	5,442	(4,654, 6,230)
Other	14	14	15,575	2,400	(1,244, 3,555)	15.4	6,698	(5,336, 8,059)

*Sites with multiple DHPs or documented supplemental fuel usage excluded

Where sample sizes were large enough, Cadmus segmented results using multiple variables. Table 89 summarizes DHP systems with a single indoor unit grouped by room type. Previous tables showed that single indoor unit systems and systems installed in living rooms each had higher savings, and combining these attributes shows still higher savings. In Table 90 these results are further refined by including only program participants known not to have used supplemental fuels, which also increases savings significantly.

Table 89. Single Family Average TMY Energy Savings and Installation Costs by Room Type with One-to-One DHP System Configuration

Room Type	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Living Room	218	218	12,401	1,653	(1,172, 2,133)	13.3	4,647	(4,513, 4,781)
Bedroom	13	13	15,670	-412	(-1,819, 994)	-2.6	5,835	(4,054, 7,616)
Kitchen	9	9	11,774	220	(-1,797, 2,238)	1.9	4,724	(4,120, 5,328)
Other	6	6	10,951	484	(-1,700, 2,667)	4.4	3,961	(3,143, 4,778)
Dining Room	4	4	10,938	-1,876	(-4,205, 454)	-17.1	4,373	(3,187, 5,558)
Sunroom	3	3	18,409	-2,626	(-11,831, 6,578)	-14.3	4,130	(3,667, 4,593)
Basement	3	3	12,555	-615	(-3,511, 2,281)	-4.9	4,535	(3,931, 5,140)
Garage	2	2	20,580	3,668	(1,224, 6,112)	17.8	3,500	(1,198, 5,803)

Table 90. Single Family Average TMY Energy Savings and Installation Costs by Room Type and Heating System Type with One-to-One DHP System Configuration without Supplemental Fuel Usage

Room Type	Site [Count]	DHP [Count]	TMY Pre-Usage [kWh/Site]	Savings [kWh/DHP]	Savings Confidence Interval at 90%	Savings [%]	Cost [$/DHP]	Cost Confidence Interval at 90%
Living Room: Baseboard	71	71	12,694	2,180	(1,452, 2,908)	17.2	4,724	(4,484, 4,965)
Living Room: Furnace	9	9	14,198	6,719	(4,018, 9,421)	47.3	4,693	(3,988, 5,398)
Bedroom: Baseboard	6	6	21,518	-581	(-3,394, 2,233)	-2.7	3,881	(3,298, 4,465)
Kitchen: Baseboard	3	3	10,368	1,564	(-1,680, 4,807)	15.1	5,581	(4,323, 6,840)

Conclusions and Recommendations

The study found a high prevalence of supplemental fuel usage during the baseline period that negatively impacts program savings. In Table 48, single family homes with a wood or pellet stove saw average savings of -174 kWh/DHP. Similarly, a weighted average of natural gas systems in Table 48 (furnaces, fireplaces, and other) have average savings of -437 kWh/DHP. The survey data presented in Table 20 showed these types of systems comprised greater than 20% of documented heating systems, and separate analysis showed 14% of all single-family homes included in the analysis received natural gas service. A billing analysis conducted with records of electric consumption does not account for fuel switching and will underestimate energy savings of individuals shifting away from supplemental fuels and towards electricity.

Recommendation: Documenting all heating fuels used in an individual's home would allow the cohort of supplemental fuel users to be separately analyzed when calculating program savings. This data could be collected during installation, through surveys, from utility gas records, or from participation in other efficiency programs. Developing a savings estimate for these individuals could be done by modeling TMY heating consumption based on their post-period usage and then assuming a less efficient electric baseline system. Alternatively, a non-energy benefit could be calculated based on the reduction in supplemental fuel usage.

Recommendation: Better targeting of individuals with electric baseline systems and of housing stock would also serve to diminish the negative impacts of supplemental fuel users. One option for accomplishing this targeting would be to emphasize in marketing materials the savings benefits of switching from electric baseboard or electric furnaces to DHPs and utilize existing housing stock market knowledge.

The study found the incidence of DHPs installed in previously unconditioned spaces to negatively impact program savings. Table 48 shows an average savings of 259 kWh/DHP for single family homes where at least one of the spaces conditioned by a DHP was previously unheated. If homeowners planned to purchase a less efficient heating system in the event of not receiving an incentive to install a DHP, then the assumed baseline of a billing analysis would be incorrect and underestimate savings for that site. A similar incorrect assumption can be made for cooling systems. Table 29 shows survey responses indicating more than 20% of single-family participants would have purchased a window or central AC if they hadn't installed a DHP system. Table 53 shows that individuals that purchased a DHP instead of a minimum efficiency window AC would save on average an additional 200 kWh/DHP. The equivalent figure for multifamily dwellings is approximately 130 kWh/DHP.

Recommendation: Similar to the first recommendation for addressing supplemental fuel users, it would be helpful to document when a DHP was installed in an unconditioned space. Depending on the space type, it may be reasonable to assume the space would have been heated by a different system if a DHP had not been installed. It's more difficult when considering cooling systems to know if the space would have remained unconditioned and surveys could be used to better understand a customer's decision process. The data could be combined with assumed baseline systems and modeled post-period consumption to better estimate savings for these individuals.

The use of less efficient heating and cooling systems in addition to DHPs negatively impacts program savings. Table 23 and Table 24 show single family homeowners are using less efficient heating and cooling systems to condition the rooms served by DHPs. In some cases, there may be practical reasons for this but increasing the use of DHPs over other electric systems will increase energy savings. Table 34 and Table 35 show a similar trend for multifamily survey respondents.

Recommendation: Educating homeowners and renters to operate their DHPs in place of other systems could serve to increase program savings. This could be accomplished through contractors or marketing materials. Advanced automatic controls also have potential to address this issue, although the technology to coordinate multiple HVAC systems may not be readily available or inexpensive enough for wide adoption. It was evident from Table 57 that programmable thermostats are not currently contributing to savings but this shouldn't be mistaken for a lack of potential. It would be valuable to conduct a pilot exploring more advanced control systems to quantify this potential.

The study found evidence that installing DHPs in primary living spaces will positively impact program savings. Table 59 shows living rooms in single family homes had higher than average annual savings at 1118 kWh/DHP and Table 60 shows that this number increases to 2,528 kWh/DHP when looking specifically at sites without supplemental fuels or multiple outdoor units. This may result from increased usage in spaces more frequently occupied. If this is the cause, then it could be worth placing some restrictions on the types of spaces where DHPs are installed. A challenge with these types of restrictions is that it can be ambiguous how particular spaces should be classified and also occupancy of a space type can vary widely by individual.

Recommendation: Encourage the installation of DHPs in primary living spaces through contractors and marketing materials.

The study found sites with low annual energy consumption to have lower than average savings. Table 61 and Table 63 show single and multifamily participants with TMY baseline period usage less than 5,000 kWh to have negative saving per DHP installation. The result for multifamily participants is more variable because of the smaller sample. However, as a group these installations are lowering program savings and are not cost-effective.

Recommendation: Inform homeowners and renters that the return on the investment in a DHP requires having a sufficient heating load and using the systems with some frequency. If they are installing units in homes or apartments that are sporadically occupied or only require minimal heating, then an existing system or a different type of system may be a better option.

The study found evidence that DHP systems with a single indoor unit are more cost-effective. Table 65 showed above average savings among DHPs with a single indoor unit in single-family homes. A similar trend was observed in Table 69 among sites with lower total DHP capacity. These results are counterintuitive because it is reasonable to expect additional capacity would further displace less efficient systems. It may be premature to conclude systems with a single indoor unit actually save more energy, but the data at least suggests they are more cost-effective in single family residences. Table 67 showed higher savings in multifamily homes for systems with two indoor units, but the cost-effectiveness for single and double head systems is similar.

Recommendation: Consider offering smaller incentives for additional indoor units.

Increased thermal comfort is an important benefit of DHPs that negatively impacts program savings. Table 17 shows that greater than 60% of single-family survey respondents indicated thermal comfort was a motivation for installing a DHP. Table 31 shows this same number for multifamily survey respondents was greater than 50%. It was also clear from Table 18 and Table 19 that homeowners believed the spaces conditioned by DHPs were warmer during the winter and cooler during the summer. A billing analysis assumes the level heating and cooling provided by a DHP is the same as that provided by the baseline system, and when a homeowner increases the comfort level, the impact will be to lower savings estimates. However, there are real but difficult to quantify benefits to improving thermal comfort that should not be ignored when evaluating a DHP program.

Recommendation: Benchmark the value of improved thermal comfort and include this as a non-energy benefit or assume the increased level heating and cooling would have been provided by a less efficient alternative system and calculate savings using this baseline.

The study found evidence of increased installation costs associated with mounting DHP outdoor units on concrete slabs. There are many practical limitations to consider when installing a DHP, and most systems were reported as having been installed on a concrete slab, but in Table 87 apparent cost savings do correlate with bracket mounting of outdoor units.

Recommendation: Encourage bracket mounting of outdoor units when it does not compromise an installation if it can be done less expensively.

APPENDIX A

CADMUS

Memorandum

To: Energy Trust of Oregon

From: Ari Jackson and John Walczyk, Cadmus

Subject: Short Interval Data Analysis

Date: October 31, 2019

This memo details a regression analysis of residential ductless heat pump (DHP) installations in the service territory of Portland General Electric (PGE). This analysis used hourly electric consumption data and machine learning algorithms to estimate the energy saving impacts of DHPs in single-family and multifamily applications. Comparisons are drawn with equivalent values calculated using the combination of monthly billing data and linear regression techniques. Hourly load shapes are also presented.

Background

Cadmus previously conducted a billing analysis of DHPs incentivized by Energy Trust of Oregon and installed in single-family and multifamily homes in 2015, 2016, and 2017. This monthly billing analysis used a difference-in-difference framework and multiple-linear regression modeling techniques to develop savings estimates resulting from DHP installations. A portion of the residences included in this analysis were serviced by PGE and additionally had hourly electric consumption data available. Cadmus provided a list of sites to include in a short interval data analysis to Energy Trust. Energy Trust requested hourly consumption data for the list of sites from PGE. The intent of this analysis was to apply the same analytical framework as the billing analysis but introduce machine learning algorithms and distributed cloud computing in order to increase the precision of savings estimates and provide a point of comparison with values calculated from monthly data. In addition, Energy Trust was interested in determining the timing of savings and hourly savings shapes to compare to past studies.

Data Sources

- **Advanced Metering Infrastructure Data (AMI)**: Data contained hourly records of energy consumption in residences within PGE's service territory. This data was requested for single and multifamily DHP participants as well as matched non-participants. Matched non-participants had similar monthly consumption in the baseline period and were eligible for a DHP incentive but did not participate in the DHP program.
- **Local Climatological Data (LDC)**: The LCD dataset was accessed from NOAA and contained hourly measurements of temperature, relative humidity, and other meteorological quantities recorded concurrently with the AMI data. These data were measured at the Portland International Airport (PDX).

- **Typical Meteorological Year 3 (TMY) Data:** TMY data was downloaded from the National Renewable Energy Laboratory and contained equivalent values to those of the LCD dataset and provided industry standard expected weather conditions at PDX.

Analytical Framework

Most AMI datasets included hourly energy usage beginning May 2018 and ending February 2019. While at least one year of pre- and post-install monthly utility billing data were available, the AMI data provided by PGE included only post-installation hourly consumption. The original intent of the AMI analysis was to apply difference-in-difference analysis framework to estimate savings from AMI data – and directly compare results to the analysis based on monthly data, using the same framework. However, the AMI dataset did not include pre-install consumption, so this comparison was not possible.

Cadmus modeled annual energy use for a typical year for the participant and non-participant groups to determine the difference in annual consumption between the groups. A key goal of this exploratory activity was to assess the validity of the approach, which could support future analysis efforts with similar data limitations. Cadmus and Energy Trust acknowledged the following assumptions must be valid:

- that pre-installation patterns of participants and non-participants' consumption are equivalent; and
- that post-installation patterns of consumption remained unchanged from the date of DHP installation through January 2019.

Cadmus was unable to validate either assumption due to AMI data limitations.

Modeling

Cadmus first aggregated hourly consumption for each combination of participant and resident type. Few points of delivery IDs (PODIDs) had data prior to May 2018, so all data before this timeframe was omitted from analysis. Most of the PODIDs had data available through January 2019. There were few gaps in data from May 2018 – January 2019. Table 1 shows the average number of PODIDs with AMI data during this period.

Table 1. AMI Analysis Average Number of PODIDs

	Single-Family	Multifamily
Count of PODIDS	552	43

Without pre-installation data, Cadmus estimated savings by first modeling post period consumption (from May 2018 through January 2019), used these models to predict TMY usage, and then differenced annual consumption of non-participants and participants. Cadmus applied a Random Forest Regression algorithm to a feature set of temperature, relative humidity, hour of the day, and day of the week. To prevent overfitting, Cadmus determined model hyperparameters using repeated k-fold cross validation. Model R-squared values are shown in Table 2.

Table 2. Regression Model R-Squared Values

	Participant	Non-Participant
Single-Family	0.963	0.962
Multi-Family	0.851	0.878

Results

Table 3 lists predicted TMY annual energy use and savings using AMI data and the savings estimates using monthly data. The differences in AMI data and monthly data savings estimates are significantly greater than the uncertainty in the savings values estimated using monthly data.

Table 3. Aggregate Regression Results

Analysis Group	AMI Non-Participant TMY Energy Usage [kWh/yr]	AMI Participant TMY Energy Usage [kWh/yr]	AMI Estimated TMY Energy Savings [kWh/yr]	Monthly Estimated TMY Energy Savings [kWh/yr]
Single-Family	13,181	13,072	109	787
Multifamily	7,206	6,938	268	1,443

As discussed above, the analytical framework of this analysis imposes limitations, mainly due to the duration of time between DHP installation (as early as 2015) and when AMI data was made available (May 2018). Any divergence in consumption patterns of the participant and non-participant groups over the 2015-2018 time period causes error in the savings estimate. This is especially relevant for multifamily residences because of the smaller number of PODIDs.

The decision to install a DHP may indicate an inherent difference between the participant and non-participant groups. Further research would be necessary to identify factors causing divergence in the participant and non-participant groups' annual energy use.

Figure 1 and Figure 2 present hourly participant and non-participant aggregate load shapes for single-family and multi-family groups.

Figure 1. Single-Family Average Power Consumption

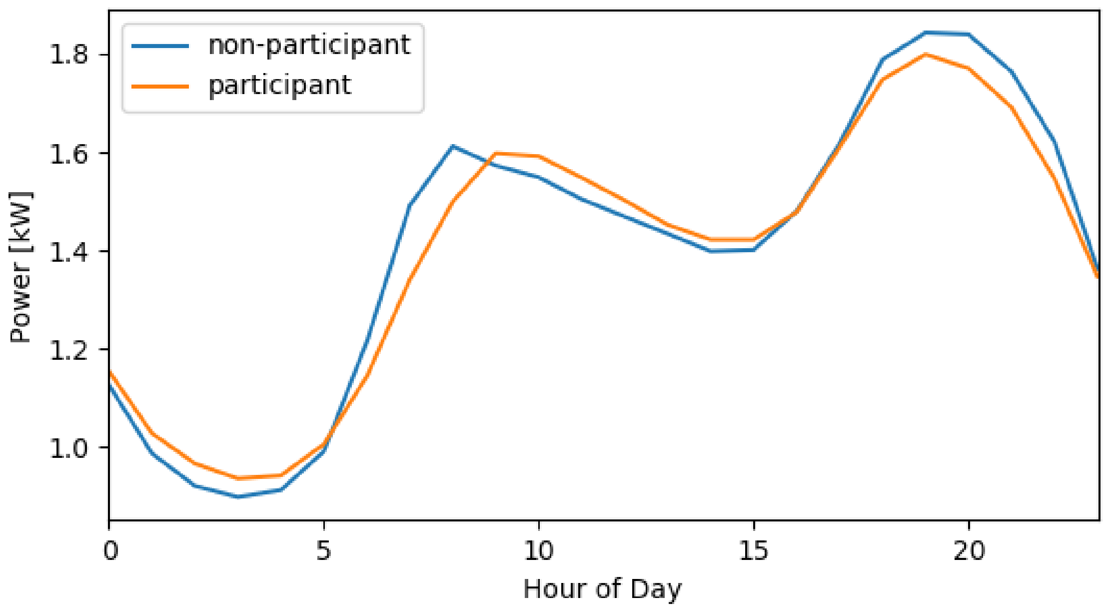
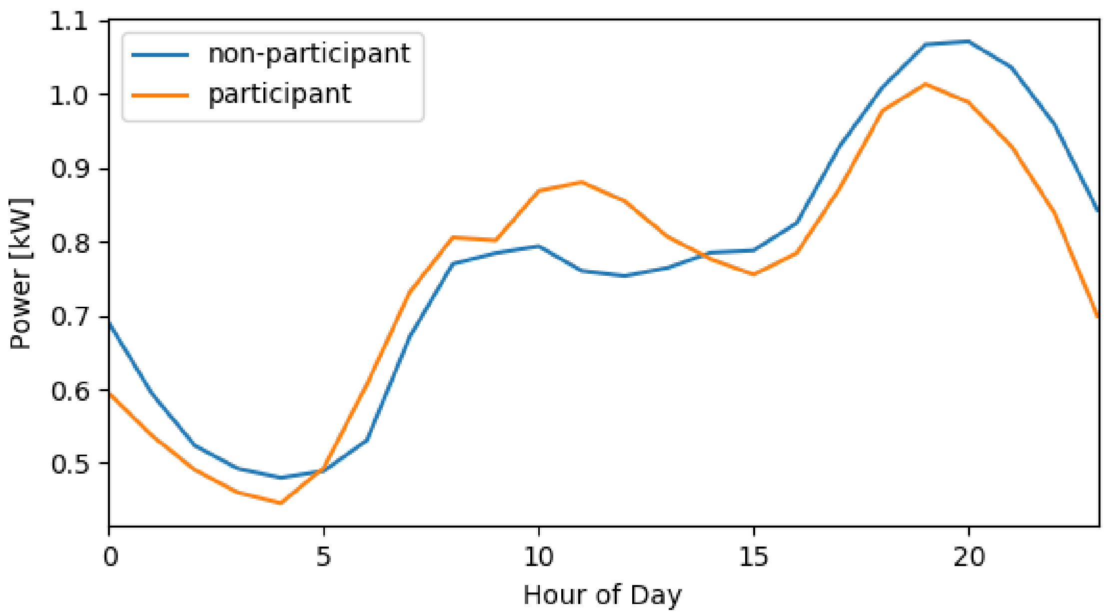


Figure 2. Multifamily Average Power Consumption



Hourly participant and non-participant aggregate load shapes for single-family homes are presented in Figure 3 for the months of June, July, and August and Figure 4 presents January and February load shapes. The participant group clearly shows higher usage during cooling months and lower usage during winter months. Figure 5 and Figure 6 show similar trends for the multi-family participant and non-participant groups.

Figure 3. Single-Family Average Power Consumption – June, July, August

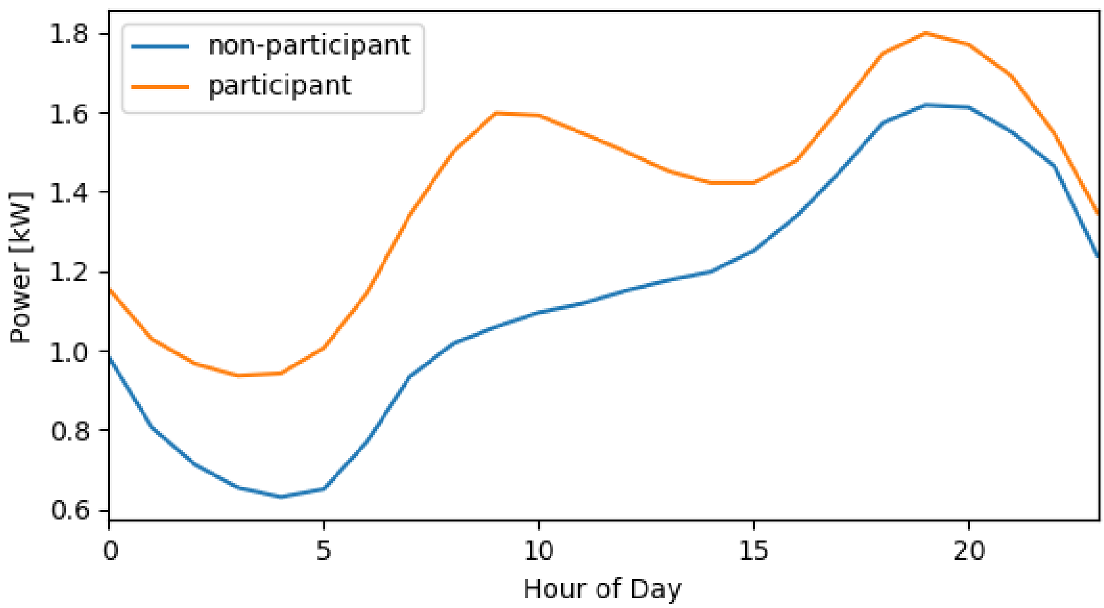


Figure 4. Single-Family Average Power Consumption – December, January

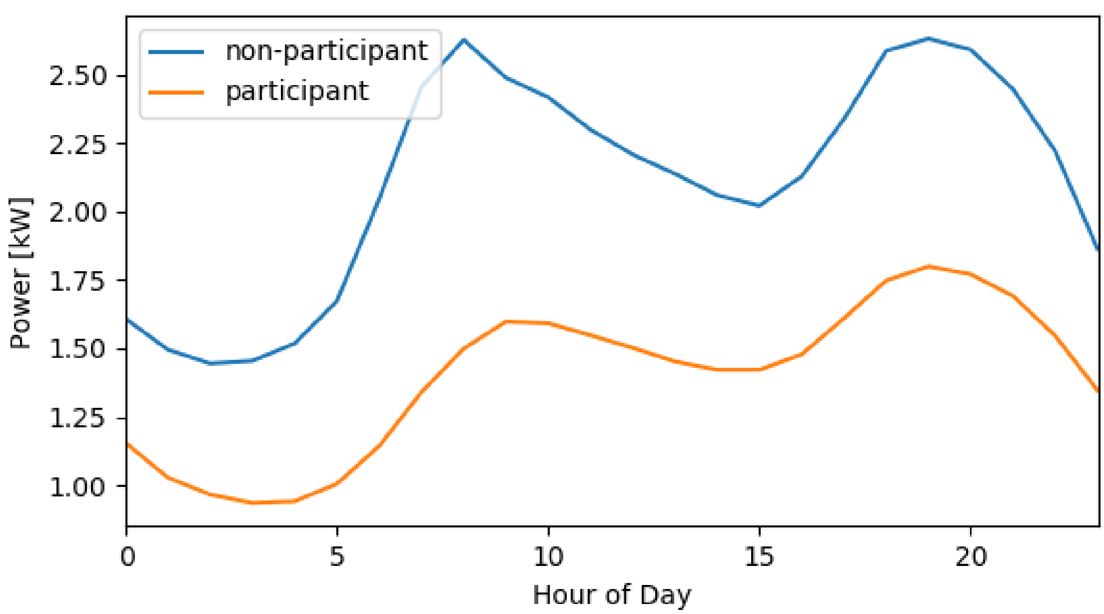


Figure 5. Multifamily Average Power Consumption – June, July, August

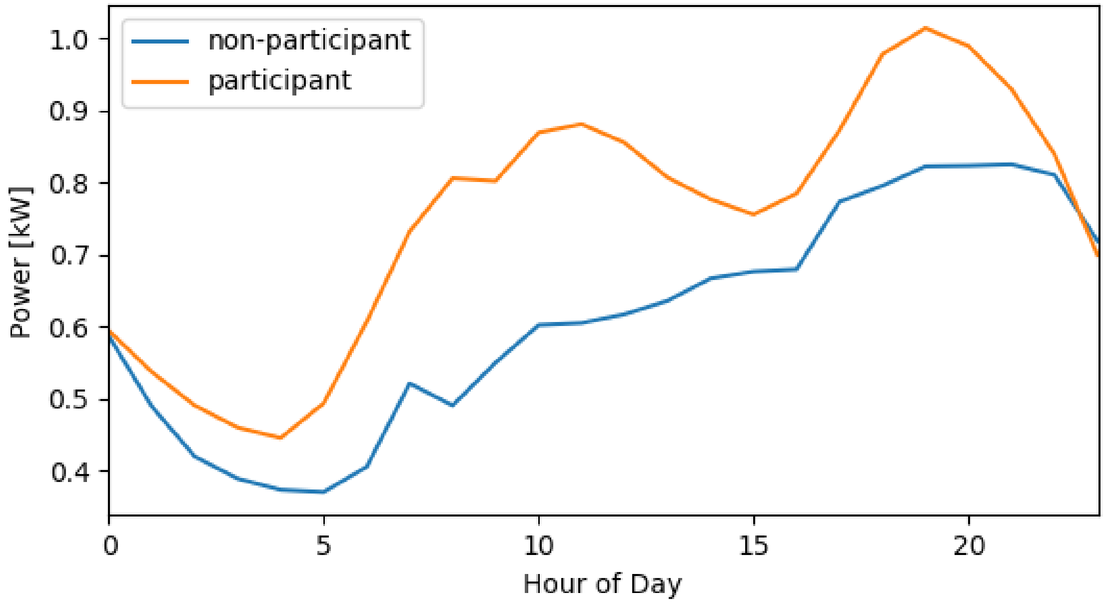


Figure 6. Multifamily Average Power Consumption – December, January