MEMO

Date: 3/4/2024
To: Energy Trust Board of Directors
From: Dan Rubado, Sr. Project Manager – Evaluation
Subject: Billing Analysis of Residential Heat Pump Water Heaters, 2017-2021

EXECUTIVE SUMMARY

Energy Trust analyzed the energy impacts of heat pump water heaters installed in single-family homes in heating zone 1 (areas of the state with relatively mild winters, such as Western Oregon) supported by Energy Trust from 2017 to 2021. The analysis was conducted using our in-house Residential Energy Billing Analysis (REBA) tool. On average, Energy Trust claimed 1,516 kWh of annual electricity savings per water heater installed. The sample sizes available for analysis were relatively small, particularly after data cleaning, and the variability in energy usage was high. These factors combined to create high uncertainty in the energy savings results. Thus, they should be interpreted with caution.

Electricity savings were statistically significant at 1,255 kWh per year (+/- 1,225 kWh) on average—about 10% of household electricity usage. This is 83% of the 1,516 kWh savings claimed per unit by Energy Trust, though not statistically different due to low precision. The low precision of the savings estimate means true savings may be lower, higher or the same as the savings claimed.

There was weak evidence suggesting both space heating interactions and customers switching from gas to electric water heating could have affected electricity savings estimates to varying degrees.

- Electricity savings appeared to be lower in electric heated homes than gas heated homes, indicating a potential space heating interaction that reduced savings. However, we did not see a corresponding increase in gas usage in gas heated homes that would have confirmed the impact of space heating interactions.
- Homes that were suspected of switching from gas to electric water heaters appeared to save gas compared to homes with electric water heaters, indicating a potential impact on the electricity savings results. Fuel switching is outside the scope of Energy Trust's influence and the presence of such homes in the sample serves to bias the energy savings estimates. To obtain more reliable results, we would need more definitive data on the type of water heater being replaced so that instances of fuel switching could be reliably removed.

Although fuel switching and space heating interactions may have been partly responsible for the slightly lower than expected electricity savings results, we can only speculate on whether the differences observed between groups are meaningful.

Based on the findings of this analysis, we do not recommend making any adjustments to the savings claimed for heat pump water heater projects at this time. Once sufficient projects become available, we

will revisit this analysis to obtain results with better precision. However, because most heat pump water heaters are now incentivized through retail channels as point of purchase discounts, we no longer receive customer information for most projects, putting future analysis into question. In addition, analysis using hourly AMI data from Energy Trust's partner electric utilities could substantially reduce the uncertainty and help to isolate the impact of heat pump water heaters on electricity usage. Further investigation should also be conducted into the impacts of water heater fuel switching and space heating interactions on billing analysis results and energy savings estimates.

INTRODUCTION

Energy Trust developed a Residential Energy Billing Analysis (REBA) tool to evaluate energy savings from efficiency measures it funds in residential buildings. This report summarizes our analysis of electricity and gas savings impacts from heat pump water heaters installed in Oregon homes from 2017 to 2021. Energy Trust's Residential program supports the installation of heat pump water heaters through several different measure delivery channels—retail discounts at point of sale, midstream distributor discounts, direct install by community partners for residents with low incomes, and rebates for contractor-installed units. On average, Energy Trust claimed 1,516 kWh of annual electricity savings per heat pump water heater incentivized during this period, although there was some variability in the expected savings based on the specific measure configuration and program year. These heat pump water heater measures and savings claims assume a baseline condition of a new electric water heater being installed.

To heat water, heat pump water heaters use a compressor and refrigeration cycle to draw heat from the air into the water tank and exhaust cold air. Unless ducting is installed, these water heaters will pull heat out of the space they're located in and cool it down. The expected savings for Energy Trust's heat pump water heater measures incorporate assumptions about how common different water heater installation locations are (garage, unheated basement, conditioned space, etc.).[1] Significant space heating penalties were quantified for water heaters installed in conditioned space, but this was assumed to occur in slightly less than half of installations. Additional assumptions were made about the distributions of tank size and climate zone for installed water heaters, which also influence savings.

Expected savings varied depending on the assumed climate zone, installed location, tank size, space heating fuel and system type, and cooling technology. Overall expected savings values were computed by applying weighted averages based on the expected frequency of each scenario. In the earlier program years included in this billing analysis, savings were broken out by water heater efficiency tier and incentive delivery channel,[2] but the deemed savings were blended for later program years, with the addition of a minimum efficiency tier requirement. In addition, different deemed savings values were assigned for the different incentive delivery channels based on assumed leakage rates of water heaters outside of Energy Trust's electric service area. Table 1 lists the weighted average deemed savings values listed in Energy Trust's Measure Approval Documents (MAD versions 52.2 and 52.3) and claimed by the Residential program for different heat pump water heater installation scenarios in different years.

Table 1: Deemed savings for heat pump water heaters by program year and installation scenario.

Program Year	Delivery Channel	Efficiency Tier	Tank Size (gallons)	Leakage Rate	Expected Savings (kWh/yr)
2017-2019	Contractor	1	<55	0%	1,318
2017-2019	Contractor	2	<55	0%	1,512
2017-2019	Contractor	3-5	Any size	0%	1,600
2017-2019	Distributor	1	<55	5%	1,138

[1] This is important because the heating and cooling system interactions differ by installed location and HVAC system type and impact the expected energy savings. For instance, if the heat pump water heater is installed in conditioned space, this results in a need for more space heating in winter but less cooling in summer, resulting in a net energy penalty that that reduces the energy savings from the water heater.

[2] For retail and distributor incentives, Energy Trust uses assumed leakage rates to account for the portion of incentivized water heaters that leave Energy Trust's electric service area.

2017-2019	Distributor	2	<55	5%	1,512
2017-2019	Distributor	3-5	Any size	5%	1,600
2017-2019	Retail	1	<55	13%	1,138
2017-2019	Retail	2	<55	13%	1,512
2017-2019	Retail	3-5	Any size	13%	1,600
2020-2022	All	3-5	Any size	0%	1,364

METHODS

The REBA tool establishes energy savings using monthly energy usage data from utility bills to conduct pre-post analysis of whole home energy usage. First, the tool selects treated homes that received the measures of interest. Energy usage data are weather normalized through an automated process using site-level weather regression models and typical meteorological year data,[3] similar to the methods established by CalTRACK.[4] Normalized annual energy usage is computed for each treated site in both the year prior to measure installation (baseline) and the year following installation (post-installation). The site-level change in annual energy usage is simply computed as the difference in weather normalized usage between the baseline and post-installation periods. The average change in annual energy usage among homes that received treatment is then evaluated against the average change in energy usage during the same period in a comparison group of similar homes that did not receive the measure. This analytical process compares heat pump water heater installations to the pre-existing conditions in a home, which in most, but not all, cases is probably an old electric water heater. This is somewhat different than the measure assumptions, which assume a new electric water heater would have been installed in the absence of the heat pump water heater.

The REBA tool selects a comparison group of untreated homes that did not receive any Energy Trust-funded upgrades during the analysis period using a site-level, nearest neighbor matching technique. So, for each treated home, matched non-participant homes are selected from within the same geographic area that had very similar monthly energy usage patterns during the baseline period to the treated home. The weather normalized annual energy usage and change in annual energy usage for comparison group homes are estimated using the same procedures as for treated homes. For this analysis, 10 matched comparison homes were selected for each treated home. The REBA tool estimates annual energy savings attributable to the heat pump water heaters installed in the treated homes as the difference in the average change in annual energy usage between the treatment and comparison group homes (difference-in-differences).

Several standard data screens are applied to remove homes from the analysis that are missing data, are outliers in energy usage, have inconsistent occupancy, have unusual usage patterns, or are otherwise unsuitable for billing analysis. We also restricted the analysis to homes where no other efficiency measures were installed during the analysis period to isolate the energy impact of heat pump water

[3] TMYx data files are typical meteorological data derived from hourly weather data through 2021 from NOAA's Integrated Surface Database using the TMY/ISO 15927-4:2005 methodologies. https://climate.onebuilding.org/

[4] CalTRACK methods describe a process of arriving at a calculation of avoided energy use related to the implementation of one or more energy efficiency measures, such as an energy efficiency retrofit, using monthly billing data, as well as interval data from smart meters. https://www.caltrack.org/

heaters. These screens are applied symmetrically to all treatment and comparison sites. Sites are removed from the analysis for the following reasons:

- Utility billing data not found for site
- Less than nine months of valid billing data available for either baseline or post-install year
- Weather normalization process failed for either baseline or post-install year
- Baseline energy usage in the top or bottom 1% of treated sites
- Post-install annual energy usage is more than double or less than half of baseline year
- Weather regression model has R-square value <0.25 for either baseline or post-install year
- Other measures installed during analysis period with aggregate deemed electricity savings >100 kWh per year for the electricity analysis and gas savings >10 therms for the gas analysis

We analyzed both annual electricity and gas savings for heat pump water heater projects. Gas savings were analyzed to estimate the impact of water heater fuel switching and space heating interactions. While space heating interactions should be included in savings estimates to capture the whole home impact, fuel switching is outside the scope of Energy Trust's influence and the presence of homes that switched from gas to electric water heaters in the sample will only serve to bias the energy savings estimates. We also analyzed energy savings for a number of subgroups based on space heating fuel, water heating fuel, home type and heating zone.[5] The results presented in this summary focus on projects located in site built single-family homes located in heating zone 1 because they represented the vast majority of projects with valid data. These factors may be influential in energy savings, so we don't want to present the results as applying to all homes in Oregon—they specifically apply to site built homes in heating zone 1.

It should be noted that the sample size of projects available for analysis was relatively small, particularly after attrition, and the variability in energy usage was high. These factors combined mean the results of this analysis have a high degree of uncertainty and should be interpreted with caution.

RESULTS

Electricity Savings

Electricity usage was analyzed for homes that installed heat pump water heaters to better understand the impact of this technology on electricity usage.

Overall

For heat pump water heaters installed in single-family homes in heating zone 1 from 2017 to 2021, average electricity savings were estimated at **1,255 kWh per year** (+/- 1,225 kWh) or 10% of whole home baseline electricity usage. After attrition, there were 121 treated homes available in the analysis sample with mean baseline electricity usage of 12,030 kWh per year. Attrition from the analysis is presented in Table 2 and shows most homes eliminated from the analysis had insufficient electricity usage data to be weather normalized or their energy usage did not correlate closely to weather.

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[5] Heating zones are geographic areas defined by the Regional Technical Forum, based on the number of heating degree-days during a typical winter. Heating zone 1 represents areas of the state with relatively mild winters, such as Western Oregon. Heating zones 2 and 3 represent areas of the state with cold winters, like the mountains and Central and Eastern Oregon.

Table 2: Attrition table for overall electricity savings analysis.

Analysis Stage	Treatment Site N
Initial list of all heat pump water heater treatment sites	329
Treatment sites with no other measures exceeding 100 kWh installed	256
Treatment sites filtered to selected measure combinations: one water heater per site	254
Treatment sites matched to energy usage data	247
Treatment sites with weather normalized energy usage data	179
Treatment sites with weather model $R^2 > 0.25$	137
Treatment sites with full pre- and post-installation years of energy usage data	134
Treatment sites after removing top and bottom 1% of annual energy usage	130
Final model treatment sites before filters applied	128
Final model treatment sites after filters applied: single-family home + heating zone 1	121

Based on the average expected savings of 1,516 kWh, the savings realization rate was 83%. While the savings appear to be lower than expected, the estimate is very uncertain, demonstrated by the wide confidence interval, and is not significantly different from the expected savings value. In addition, the baseline for our analysis was the existing condition water heater, which included gas systems, in some cases. This differs from the assumed baseline that the deemed savings are based on, which is a new electric water heater. While the efficiency of an old, existing water heater is likely similar to that of a new one, and the majority of sites were likely replacing an old electric water heater, the presence of gas water heaters in some homes in the analysis sample during the baseline period indicates that water heater fuel switching occurred. Thus, the results of the overall analysis are not directly comparable to the assumptions and estimated savings of Energy Trust's measure.

Figure 1 shows the treated homes in the analysis sample were heavily concentrated in Western Oregon, primarily the Portland Metro area. Figure 2 shows the comparison group homes were well matched to the monthly electricity usage profile of the treated homes. Figure 3 clearly shows the separation between the treatment and comparison groups in the distributions of the change in annual electricity usage. While the distributions do substantially overlap, the substantial shift to the left in the treatment group distribution indicates savings attributable to the heat pump water heaters. Figure 4 compares the overall electricity savings estimate and confidence interval with the expected savings value.

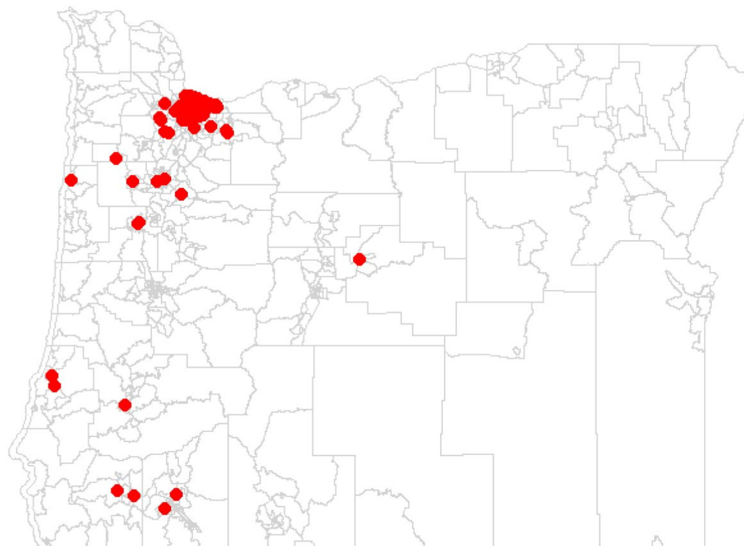


Figure 1: Spatial distribution of analysis sample for Energy Trust funded heat pump water heaters in Oregon, 2017-2021.[6]

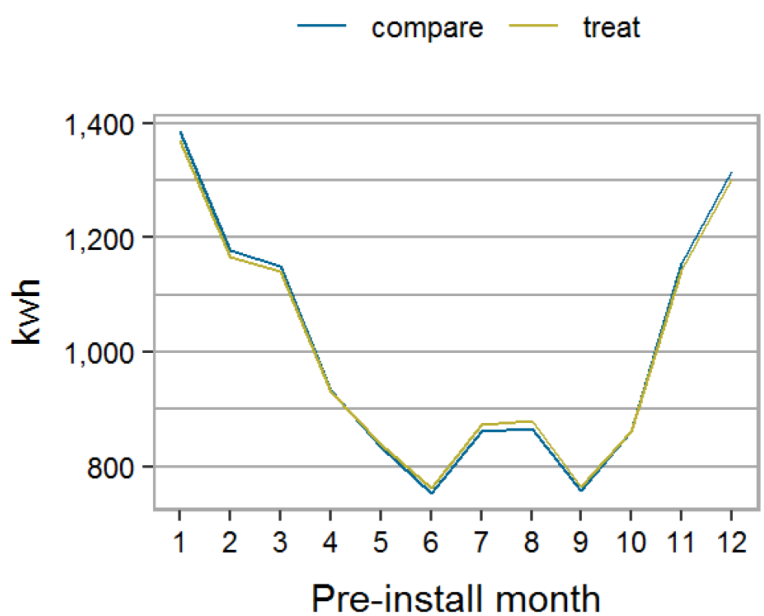


Figure 2: Mean monthly electricity usage for treated and comparison homes in the baseline year.

[6] One site located in Central Oregon, which is within heating zone 2, persisted in the analysis sample after the heating zone 1 filter was applied. This may have been due to a miscoded heating zone or incorrect site zip code recorded in the project tracking database.

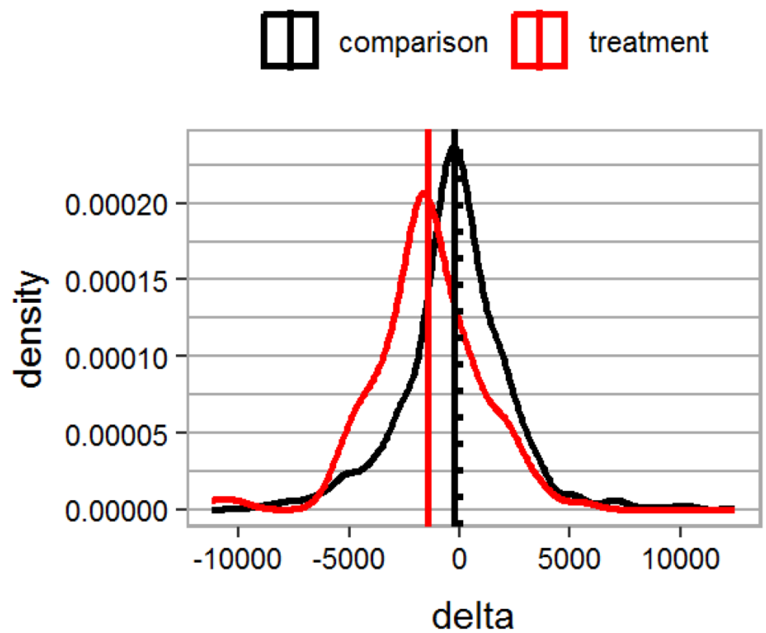


Figure 3: Distribution of change in annual electricity usage for treated and comparison homes.

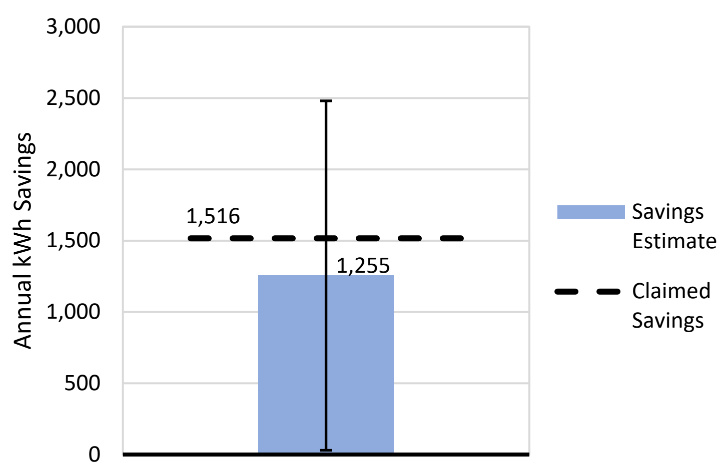


Figure 4: Overall electricity savings for heat pump water heaters, compared to expected.

<u>*Space heating fuel*</u>

We subset the electricity savings for heat pump water heaters by space heating fuel into electric- or gas-heated homes to compare savings estimates between these two groups. Space heating fuel was recorded in the incentive application forms at the time of the project or during prior projects.

For electric-heated single-family homes in heating zone 1, average electricity savings from 2017 to 2021 were estimated at **780 kWh per year** (+/- 1,771 kWh) or 6% of baseline electricity usage. For gas-heated homes, average electricity savings were **1,668 kWh per year** (+/- 1,474) or 17% of baseline electricity usage. There were 50 electric-heated and 56 gas-heated treatment homes analyzed with mean baseline electricity usage of 13,841 kWh per year and 9,794 kWh per year, respectively. Based on the average expected savings of 1,516 kWh, the savings realization rates were 51% for electric-heated homes and

110% for gas-heated homes. While the savings estimates appear to be quite different between electric- and gas-heated homes, there is a high degree of uncertainty, demonstrated by the wide, overlapping confidence intervals, and they are not significantly different. Figure 5 shows the comparison of electricity savings estimates between electric- and gas-heated homes and to the expected savings.

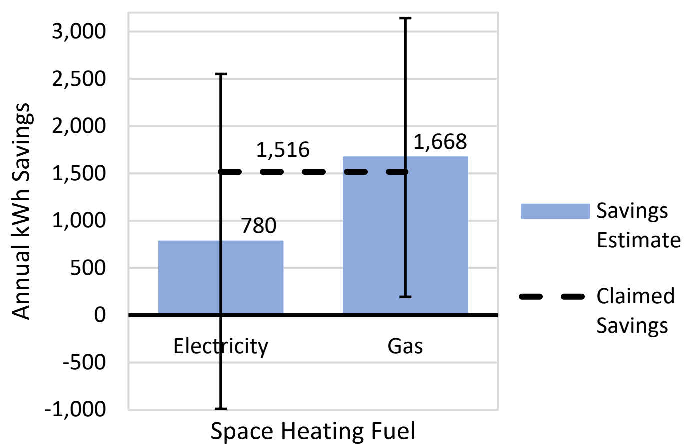


Figure 5: Electricity savings for heat pump water heaters by space heating fuel, compared to expected.

This comparison allowed us to look for the potential impacts of space heating interactions on heat pump water heater energy savings. If meaningful interactions were occurring between installed heat pump water heaters and home heating systems, then we would expect that the realized electricity savings would be lower for electric-heated homes than gas-heated homes. In fact, that is what the results suggest, although we cannot draw any firm conclusions from the comparison due to the low precision of the estimates and lack of statistical difference.

Water heating fuel

We subset the electricity savings for heat pump water heaters by water heating fuel, into homes with electric or gas water heat in the baseline period, to compare savings estimates between these two groups. Baseline water heating fuel was estimated for each home based on the presence of a gas meter and the average daily gas usage during the summer cooling season, when no gas space heating was expected. This algorithm is subject to about 15% misclassification, which may affect the results.

For single-family homes in heating zone 1 with electric water heat in the baseline period, average electricity savings from 2017 to 2021 were estimated at **1,260 kWh per year** (+/- 1,361 kWh) or 10% of baseline electricity usage. For homes with gas water heat in the baseline period, average electricity savings were **1,183 kWh per year** (+/- 2,686) or 10% of baseline electricity usage. There were 89 treated homes with electric water heat and 32 treated homes with gas water heat analyzed, with mean baseline electricity usage of 12,104 kWh per year and 11,823 kWh per year, respectively. Based on the average expected savings of 1,516 kWh, the savings realization rates were 83% for homes with electric water heat and 78% for homes with gas water heat in the baseline. The savings estimates by baseline water heating fuel were very close, with completely overlapping confidence intervals. Figure 6 compares electricity savings between homes with electric and gas water heat in the baseline period and to the expected savings.

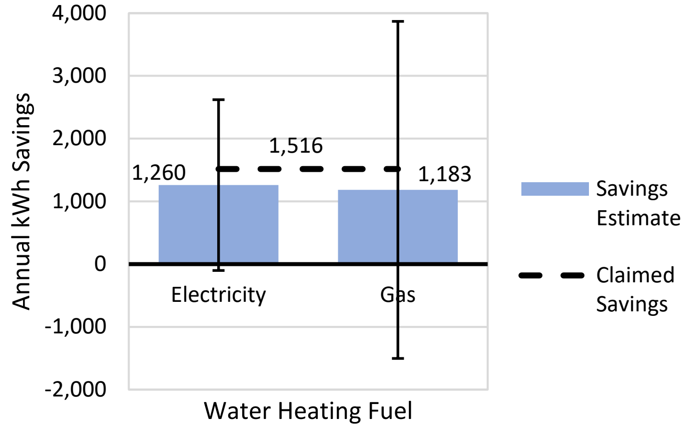


Figure 6: *Electricity savings for heat pump water heaters by water heating fuel, compared to claimed.*

This comparison allowed us to look at the potential impacts of fuel switching from gas to electric water heat on overall heat pump water heater energy savings. For the best comparison to Energy Trust's deemed savings homes identified as having gas water heat in the pre-installation period are likely to have switched fuels when they installed a heat pump water heater. Thus, we would expect the realized electricity savings for this group to be negative, since they added a large new electric load, rather than reducing their electricity usage. Ideally, we would remove cases of fuel switching from our analysis to better understand the impact of heat pump water heaters compared to an electric baseline, which is the assumption used in Energy Trust's savings analysis. However, the results were very similar between the water heating fuel groups, and the results for homes with electric water heaters in the pre-installation period are almost identical to the overall results. This suggests that homes flagged as switching from gas to electric water heat still saved a similar amount of electricity, which is counterintuitive.

These anomalous results could simply be due to random variation in energy use, especially since the confidence interval for homes with gas water heat is very wide and includes large negative values. It may also be due to misclassification of the baseline water heating fuel, putting our ability to distinguish sites that switched water heating fuels into question. In any event, we cannot draw firm conclusions from this comparison due to the low precision of the savings estimates and wide confidence intervals. Without more reliable data on pre-installation water heater fuel and more precise results by water heating fuel, it is impossible to understand the degree to which water heater fuel switching may be impacting the results.

Gas Savings

The purpose of analyzing gas savings for an electric efficiency measure is to understand the magnitude of water heater fuel switching and space heating interactions that occurred in the sample, so we can better interpret our electricity savings results. Ideally, cases of fuel switching would be removed from the analysis, but since we have imperfect data on prior water heating fuel, we are using several indicators to assess how widespread the problem is and how much it may be affecting the results.

<u>*Overall*</u>

For heat pump water heaters installed in single-family homes with gas meters in heating zone 1, from 2017 to 2021, average gas savings were estimated at **15 therms per year** (+/- 72 therms) or 3% of baseline gas usage. After attrition, there were 83 treated homes analyzed with mean baseline gas usage of 533 therms per year. Attrition from the analysis is presented in Table 3 and shows that most homes eliminated from the analysis could not be matched to valid gas usage data (primarily homes with no gas service) or had insufficient gas usage data to be weather normalized.

Table 3: Attrition table for overall gas savings analysis.

Analysis Stage	Treatment Site N
Initial list of all heat pump water heater treatment sites	329
Treatment sites with no other measures exceeding 10 therms installed	296
Treatment sites filtered to selected measure combinations: one water heater per site	294
Treatment sites matched to energy usage data	136
Treatment sites with weather normalized energy usage data	101
Treatment sites with weather model $R^2 > 0.25$	99
Treatment sites with full pre- and post-installation years of energy usage data	91
Treatment sites after removing top and bottom 1% of annual energy usage	89
Final model treatment sites before filters applied	85
Final model treatment sites after filters applied: single-family home + heating zone 1	83

Gas impacts for heat pump water heaters were expected to be -2 therms on average across all scenarios and as much as -32 therms for gas-heated homes with water heaters installed in conditioned space. However, Energy Trust did not claim any of these negative gas interactions, so a realization rate cannot be defined. While gas savings appear to be greater than zero, the estimate is very uncertain and is not significantly different from zero. In this case, if we could verify that positive gas savings occurred, it would likely indicate fuel switching from gas to electric water heat. Thus, it seems likely that some homes did switch water heating fuel with the installation of their heat pump water heater, but the magnitude of the effect is relatively small and uncertain when looking across all sites with gas service in the sample. The overall reductions in resulting gas usage may also be partially masked by increased gas usage in gas heated homes from water heater space heating interactions.

Figure 7 shows the comparison group homes were almost perfectly matched to the monthly gas usage profile of the treated homes. Figure 8 shows the nearly complete overlap of the distributions of the change in annual gas usage between the treatment and comparison groups in the distributions. The slight left shift in the distribution of treated homes suggests a small minority of homes may be reducing gas usage when installing a heat pump water heater—most likely by switching water heating fuel.

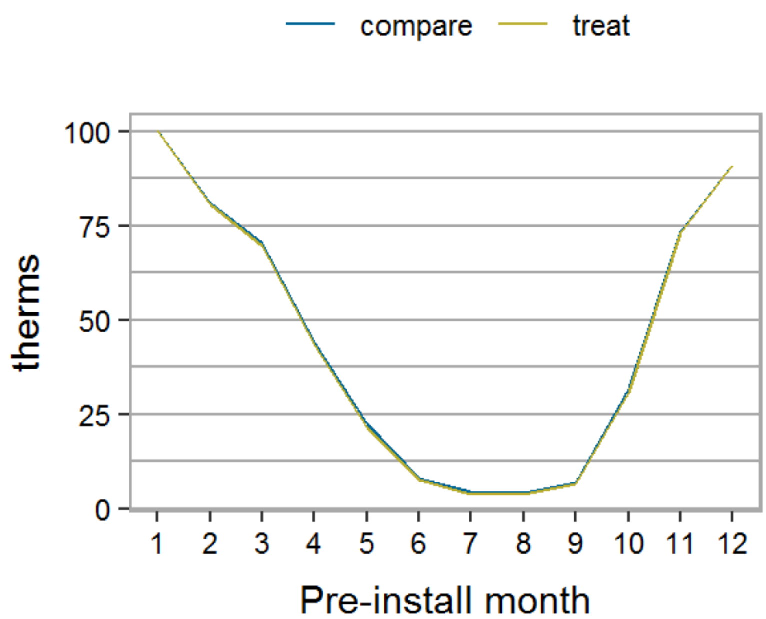


Figure 7: Mean monthly gas usage for treated and comparison homes in the baseline year.

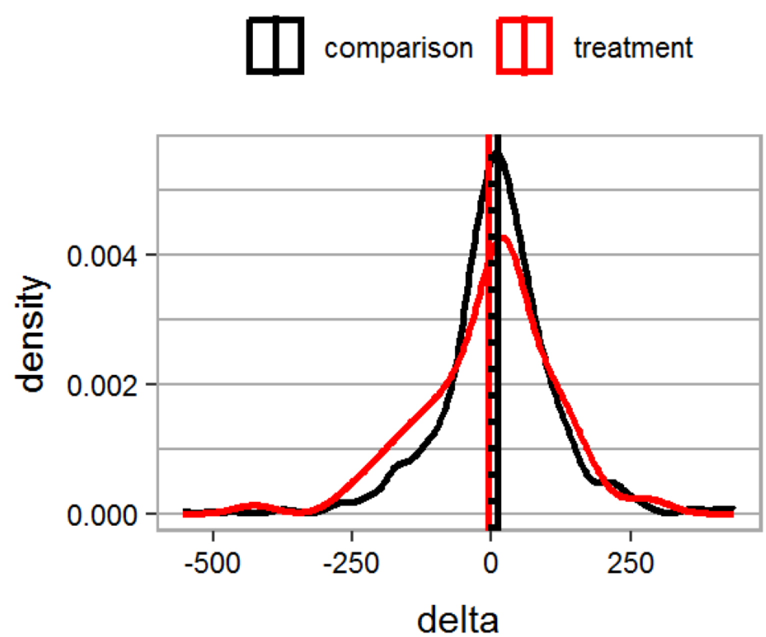


Figure 8: Distribution of change in annual gas usage for treated and comparison homes.

<u>*Space heating fuel*</u>

We subset the gas savings for heat pump water heaters by space heating fuel into electric- or gas-heated homes to compare savings estimates between these two groups. However, there were an insufficient number (n=12) of electric-heated homes in the analysis sample to produce meaningful results and we do not present them here.

For gas-heated single-family homes in heating zone 1, average gas savings were **4 therms per year** (+/- 77) or 1% of baseline gas usage. There were 69 gas-heated treatment homes analyzed with mean baseline gas usage of 690 therms per year. While the savings estimate appears to be essentially zero for this group, there is a high degree of uncertainty, demonstrated by the wide confidence intervals. Figure 9 compares the gas savings for gas-heated homes to the overall gas savings.

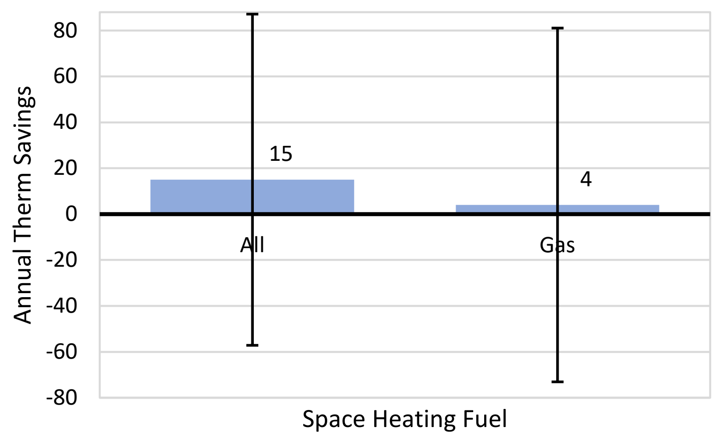


Figure 9: Gas savings for heat pump water heaters in gas-heated homes compared to overall gas savings.

This scenario allowed us to investigate the potential impacts of space heating interactions of heat pump water heaters separately from their electricity savings. If meaningful interactions were occurring between installed heat pump water heaters and gas heating systems, then we would expect to see an increase in gas usage in these homes (gas penalty). Although we do not see an increase in gas usage, the gas savings for gas-heated homes appear to be very slightly lower than the overall gas savings, although we cannot draw any firm conclusions due to the very low precision of the estimates and overlap of the confidence intervals. It is possible that the countervailing effects of a gas penalty from space heating interactions and a gas reduction from water heater fuel switching are cancelling one another out to some degree and obscuring the impacts of these two factors in this scenario. Without more precise results by space and water heating fuel, it is impossible to disentangle the impact of these factors and understand their salience to the electricity savings analysis.

Water heating fuel

We subset the gas savings for heat pump water heaters by water heating fuel into homes with electric or gas water heat in the baseline period to compare savings estimates between these two groups.

For single-family homes in heating zone 1 with electric water heat in the baseline period, average gas savings from 2017 to 2021 were estimated at **-5 therms per year** (+/- 51 therms) or -1% of baseline gas usage. For homes with gas water heat in the baseline period, average gas savings were **42 therms per year** (+/- 115) or 6% of baseline gas usage. There were 46 treated homes with electric water heat and 37 treated homes with gas water heat analyzed, with mean baseline gas usage of 382 therms per year and 718 therms per year, respectively. While the gas savings estimates for homes with electric and gas water heat appear to diverge, there is a high degree of uncertainty, demonstrated by the wide, overlapping confidence intervals, and they are not significantly different. Figure 10 compares gas savings between homes with electric and gas water heat in the baseline period.

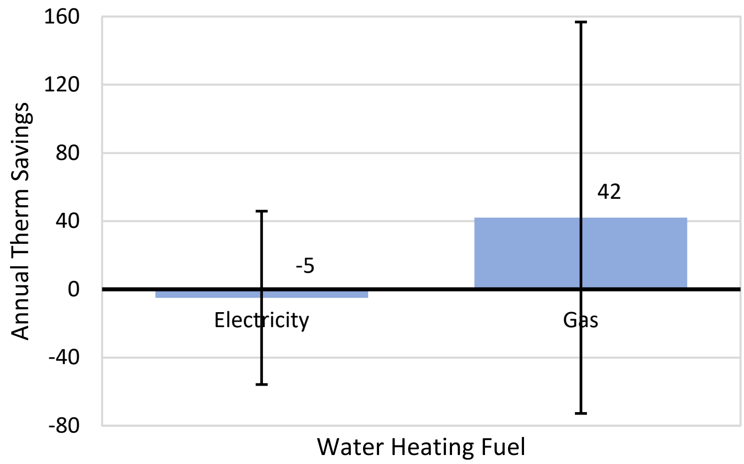


Figure 6: *Gas savings for heat pump water heaters by water heating fuel.*

This comparison allowed us to look for the potential impacts of fuel switching from gas to electric water heat separately from heat pump water heater electricity savings. If meaningful amounts of fuel switching were occurring, then we would expect to see significant gas savings for homes with gas water heat in the baseline period, since these homes would be switching a large gas load to electricity. In fact, there was a substantial decrease in gas usage in homes with gas water heat that was not present in homes with electric water heat, suggesting that fuel switching is occurring and impacting gas loads. However, we cannot draw any firm conclusions from the comparison due to the low precision of the estimates and wide confidence intervals. Without more reliable data on pre-installation water heater fuel and more precise results by water heating fuel, it is impossible to understand the impact of this factors and its salience to the electricity savings analysis.

Savings Summary

Table 4 summarizes the savings results for heat pump water heaters installed in single-family homes in heating zone from 2017 to 2021 for a variety of scenarios. We assessed the reliability of each energy savings estimate, based on the relative precision and sample size available, and assigned a reliability rating to each estimate from very high to very low. Savings were not assessed for groups with less than 30 sites available in the analysis sample. The reliability ratings are defined in Table 5, below.

Table 4: Summary of heat pump water heater energy savings estimates, 2017-2021.

Fuel Analyzed	Analysis Group	N[1]	Baseline Annual Usage[2]	Savings Estimate[3]	90% Conf. Interval[4]	Relative Precision[5]	% Savings[6]	RR[7]	Reliability Rating[8]
Electricity	All	121	12,030	1,255	25, 2484	98%	10%	83%	Low
	Ele. heat	50	13,841	780	-997, 2558	227%	6%	51%	Very low
	Gas heat	56	9,794	1,668	189, 3148	88%	17%	110%	Low
	Ele. water heat	89	12,104	1,260	-106, 2625	108%	10%	83%	Very low
	Gas water heat	32	11,823	1,183	-1516, 3883	227%	10%	78%	Very low
	<1900 SqFt	74	10,683	1,030	-414, 2473	140%	10%	68%	Very Low
	≥1900 SqFt	31	14,442	1,592	-640, 3824	140%	11%	105%	Very low
Gas*	All	83	533	15	-58, 88	481%	3%	--	Very low
	Ele. space heat	*12*	--	--	--	--	--	--	--
	Gas space heat	69	512	4	-74, 82	1,927%	1%	--	Very Low
	Ele. water heat	46	382	-5	-56, 45	1,017%	-1%	--	Very Low
	Gas water heat	37	718	42	-74, 157	273%	5.8%	--	Very Low
	<1900 SqFt	53	458	23	-49, 94	307%	5.0%	--	Very Low
	≥1900 SqFt	38	471	5	-84, 94	1,771%	1.1%	--	Very Low

* Gas savings were analyzed only for the subset of homes with gas meters present.

[1] Final treatment group sample size available for analysis. Only groups with n≥40 are reported, so sample sizes for individual groups may not sum to overall N. Comparison home Ns are 10 times the treated home Ns.

[2] Mean weather normalized annual energy usage in kWh or therms during the baseline period.

[3] Estimated weather normalized annual electricity savings in kWh or therms.

[4] Confidence interval of savings estimate at 90% confidence level.

[5] Precision of savings estimate at 90% confidence level expressed as a percentage of the savings estimate.

[6] Energy savings as a percentage of baseline annual usage.

[7] Realization rate. The estimated energy savings expressed as a percentage of the claimed savings.

[8] Reliability rating of savings estimate, based on relative precision and sample size.

Table 5: Definitions of reliability ratings applied to energy savings estimates.

Reliability Rating	Rel. Precision Criteria (@ 90% Conf.)		Sample Size Criteria
Very high	<10%	AND	≥200
High	<20%		≥120
Moderate	<50%		≥80
Low	<100%		≥50
Very Low	≥100%		≥30
Not reported	Any		<30

CONCLUSIONS & RECOMMENDATIONS

Electricity savings from heat pump water heaters installed in single-family homes in heating zone 1 were significant at 1,255 kWh per year (+/- 1,225 kWh) on average—about 10% of household electricity usage. Although this is only 83% of the 1,516 kWh savings per unit claimed by Energy Trust, it is not statistically different due to low precision. Because of the high uncertainty of the results, limited sample size and unknown impact of fuel switching from gas water heating, we have low confidence in the savings estimate and are not able to make any strong conclusions or recommendations. We can only speculate on whether any of the observed differences in savings between groups are meaningful or can be compared to Energy Trust's claimed savings for heat pump water heater measures.

The low precision of savings estimates is due to the relatively small sample of projects available for analysis and high variability in electricity and gas usage. The low sample size was a product of two primary factors—attrition in the analysis and the transition to midstream incentives. Due to the availability and quality of monthly utility billing data, including the data screens listed in the introduction, roughly half of heat pump water heaters installed during the period analyzed were excluded from this analysis. A bigger issue was that starting in 2018, the Residential program shifted most incentives for heat pump water heaters to midstream discounts. This means that rather than having individual customers or contractors apply for rebates by providing Energy Trust information about a project, water heater retailers and distributors are simply paid a per unit incentive to discount the cost to buyers. In this midstream system, customer site information is generally not recorded and installation locations are not known, except for some of the larger distributors involved in the program. Although many midstream projects are reflected in these results, retail discounts are not.

The high variability observed in year-over-year changes in electricity and gas usage added noise to the analysis, making it more difficult to identify the impacts of heat pump water heaters. This may have been partly due to a subset of participants that switched from gas to electric water heaters, which would cause large changes in fuel use counter to the savings claimed. Homes that had large swings in heating and cooling usage from year to year that were not adequately adjusted by the weather normalization procedure may also have been a factor. To obtain more reliable results, we would need more definitive data on the type of water heater being replaced so that instances of fuel switching could be reliably removed. We would also need to analyze a substantially larger sample of projects, possibly starting further back in time or waiting until more water heater installations accrue in the future.

The sample available for analysis forced us to focus on single-family homes in heating zone 1 because they represented nearly all installations. With larger sample sizes, we could potentially estimate heat pump water heater savings for the general population of homes in Oregon and for specific groups we were unable to analyze here—manufactured homes and homes in heating zone 2. Larger sample sizes would also improve our estimates of savings by space and water heating fuels and allow cross-tabulations of those factors and further investigation of the hypothesized fuel switching and heating interaction factors that may be impacting heat pump water heater savings.

Although we have low confidence in the slight deviation of observed electricity savings from the expected savings, we wanted to investigate the potential impacts of fuel switching and space heating interactions on overall heat pump water heater savings. We accomplished this by slicing the energy savings by space and water heating fuel and analyzing changes in gas usage for treated homes that had gas service. There was some weak evidence, and sometimes confusing results, suggesting both factors could be at play, to varying degrees. For instance, electricity savings appeared to be lower in electric heated homes than gas heated homes, where electric space heating interactions would be expected to lower savings. However, we did not see a corresponding increase in gas usage in gas heated homes that would have confirmed the impact of space heating interactions.

For fuel switching, gas savings for homes that switched from gas water heaters appeared to be higher than those with electric water heaters in the baseline, indicating fuel conversions may indeed be impacting the electricity savings results in this analysis. On the other hand, we expected to see negative electricity savings for homes that switched from gas water heaters, but savings appeared to be similar to homes that did not switch fuels. However, there was a high degree of uncertainty in these results and random variations in energy usage may have obscured the true effect, especially since the confidence interval for electricity savings in fuel switching homes contained large negative values. Another issue with the fuel switching analysis is the baseline water heating fuel was determined empirically using a seasonal fuel usage algorithm. During testing we observed a misclassification rate of 10-15%. However, if misclassification of water heating fuel was higher in the analysis sample, then sub-setting the results based on this variable may not produce meaningful results. Also, 10-15% misclassification may be too high for our purpose of separating out homes that switched from gas to electric water heating and determine heat pump water heater electricity savings compared to an electric water heater baseline. In that case, we will need more accurate pre-installation water heating fuel data to properly exclude cases of fuel switching from our analysis and better assess heat pump water heater savings.

Fuel switching and space heating interactions may have been partly responsible for the slightly lower than expected electricity savings results and the small reductions in gas usage observed. However, we were unable to quantify the impacts of either of these factors on energy savings or determine their prevalence in the sample with any certainty. In addition, the low precision of the overall heat pump water heater savings estimate means that the true savings may be the same, or higher, than the claimed savings value. Based on the findings of this analysis, we do not recommend making any adjustments to the savings claimed for heat pump water heater projects. However, additional investigation of potential energy savings impacts from fuel switching and space heating interactions should be conducted. Once a sufficient number of projects become available, we will revisit this analysis to obtain results with better precision. However, because most heat pump water heaters are now incentivized through retail channels as point of purchase discounts, we no longer receive customer information for most projects, putting future analysis into question. In addition, analysis using hourly AMI data from Energy Trust’s partner electric utilities could substantially reduce the uncertainty and help to isolate the impact of heat pump water heaters on electricity usage.

APPENDIX A:

Residential Energy Billing Analysis Tool Output Report for Heat Pump Water Heater Electricity Savings – Site-built homes in heating zone 1, 2017-2021

Heat pump water heater measures installed between 2017 and 2021

Introduction

Energy Trust developed a billing analysis tool to evaluate energy savings from efficiency measures it funds that are installed in residential buildings. This report summarizes our analysis of electric savings conducted on treated homes that installed **Heat pump water heater from 2017 to 2021** in homes with the following shared characteristic(s): HeatingZone is '1' & MarketName is 'Site Built Home','Single Family Home'.

The billing analysis tool uses monthly energy usage data from utility bills to conduct pre-post analysis of whole home energy usage. Energy usage data are weather normalized using site-level weather regression models and typical meteorological year data, similar to the methods established by CalTRACK. Normalized annual energy usage is computed for each site in both the year prior to measure installation (baseline) and the year following installation (post-install). The site-level change in annual energy usage is simply computed as the difference in usage between the baseline and post-install periods. The average change in annual energy usage among treated sites is then evaluated against the average change in energy usage during the same period in a comparison group of similar sites. The comparison group is selected from untreated homes using a site-level, nearest neighbor matching technique, based on baseline monthly energy usage of sites located in the same Census tract. The change in normalized annual energy usage for comparison group sites is arrived at using the same procedure as the treatment group. For this analysis, **10** matched comparison sites were selected for each treated site. The resulting difference in the change in annual energy usage (difference-in-differences) is the annual energy savings attributable to the measures installed at the treated sites. Several standard data screens are applied to remove homes from the analysis that are missing data, are outliers in energy usage, have inconsistent occupancy, have unusual usage patterns, or are otherwise unsuitable for billing analysis. These screens are applied symmetrically to all treatment and comparison sites. Sites are removed from the analysis for the following reasons:

- Utility billing data not found
- Less than 9 months of valid billing data available for either baseline or post-install year
- Weather normalization process failed for either baseline or post-install year
- Other measures installed during analysis period with aggregate deemed electricity savings > **100** kWh per year
- Baseline energy usage in the top or bottom 1 percent of treated sites
- Post-install annual energy usage is more than double or less than half of baseline year
- Weather regression model has R-square value < **0.25** for either baseline or post-install year

Site Attrition

Treament Sites	Analysis Stage
329	Initial list of all participants
256	Total participants with no other measures installed
254	Total participants filtered to selected measure combinations
247	Treatment sites matched to consumption data
179	Treatment sites with normalized consumption data
137	Treatment sites with R2 > 0.25
134	Treatment sites with full pre & post years of consumption
130	Treatment sites after removing top and bottom 1%
128	Final model treatment sites before filters
121	Final model treatment sites with filters

Expected Savings

1,516 kWh

Estimated Savings

1,255 kWh

Low Estimate

25 kWh

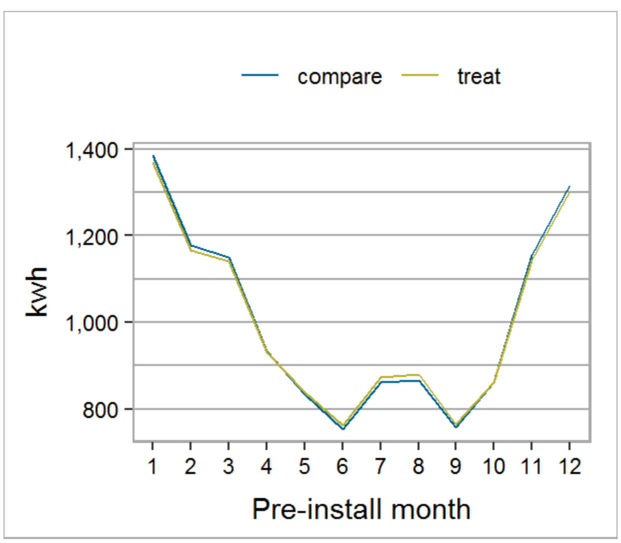
High Estimate

2,484 kWh

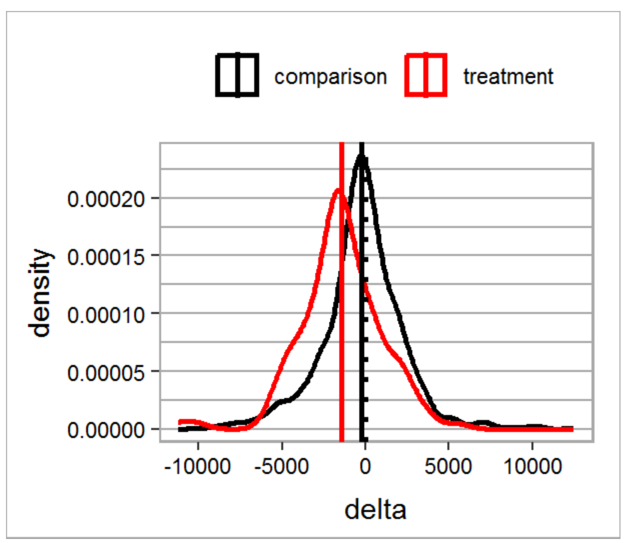
Analysis Results

term	estimate	std.error	statistic	p.value	conf.low	conf.high
(Intercept)	12,059	175	69	0	11,770	12,348
sample_period	−207	248	−1	0	−615	202
sample_group	−29	528	0	1	−898	841
sample_period:sample_group	**−1,255**	**747**	**−2**	**0**	**−2,484**	**−25**

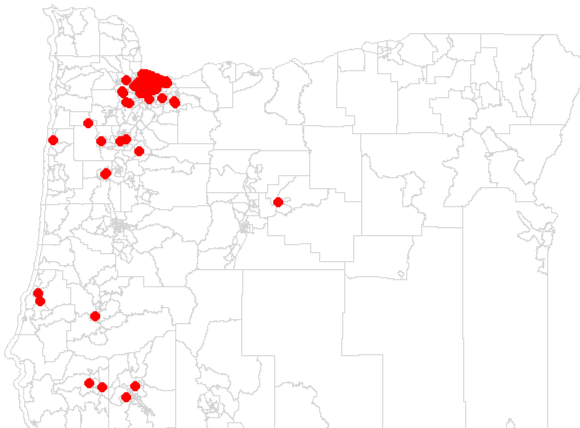
Baseline: Treatment and Comparison Group Mean Montly Consumption



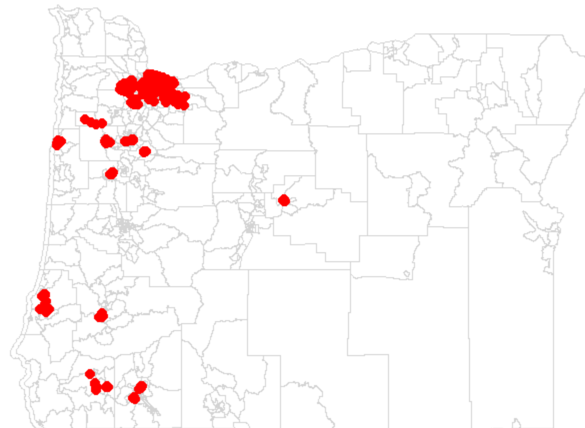
Post-install Consumption Change: Treatment & Comparison Groups



Treatment group spatial distribution



Comparison group spatial distribution



Model Adjusted r2

0.0023168

Model p-value

0.0447697

List of Individual Measures in Analysis
Community Partner Funded Direct Install HPWH Any Location or HZ
HPWH: $150, Tier 1, <55 Gallons, Retail
HPWH: $300, Tier 2, <55 Gallons, Retail
HPWH: $300, Tier 3/4/5, Retail
Heat Pump WH $300, Tier 2/3, <= 55 Gallons
Heat Pump WH Tier 3, All Tank Sizes
MIT HPWH Tier 3, All Tank Sizes
Midstream HPWH: Tier 3/4/5, Retail
SWR Heat Pump WH Tier 3, All Tank Sizes

APPENDIX B:

Residential Energy Billing Analysis Tool Output Report for Heat Pump Water Heater Gas Savings – Site-built homes in heating zone 1, 2017-2021

Energy Trust of Oregon

Heat pump water heater measures installed between 2017 and 2021

Introduction

Energy Trust developed a billing analysis tool to evaluate energy savings from efficiency measures it funds that are installed in residential buildings. This report summarizes our analysis of gas savings conducted on treated homes that installed **Heat pump water heater from 2017 to 2021** in homes with the following shared characteristic(s): HeatingZone is '1'.

The billing analysis tool uses monthly energy usage data from utility bills to conduct pre-post analysis of whole home energy usage. Energy usage data are weather normalized using site-level weather regression models and typical meteorological year data, similar to the methods established by CalTRACK. Normalized annual energy usage is computed for each site in both the year prior to measure installation (baseline) and the year following installation (post-install). The site-level change in annual energy usage is simply computed as the difference in usage between the baseline and post-install periods. The average change in annual energy usage among treated sites is then evaluated against the average change in energy usage during the same period in a comparison group of similar sites. The comparison group is selected from untreated homes using a site-level, nearest neighbor matching technique, based on baseline monthly energy usage of sites located in the same Census tract. The change in normalized annual energy usage for comparison group sites is arrived at using the same procedure as the treatment group. For this analysis, **10** matched comparison sites were selected for each treated site. The resulting difference in the change in annual energy usage (difference-in-differences) is the annual energy savings attributable to the measures installed at the treated sites. Several standard data screens are applied to remove homes from the analysis that are missing data, are outliers in energy usage, have inconsistent occupancy, have unusual usage patterns, or are otherwise unsuitable for billing analysis. These screens are applied symmetrically to all treatment and comparison sites. Sites are removed from the analysis for the following reasons:

- Utility billing data not found
- Less than 9 months of valid billing data available for either baseline or post-install year
- Weather normalization process failed for either baseline or post-install year
- Other measures installed during analysis period with aggregate deemed gas savings > **10** therms per year
- Baseline energy usage in the top or bottom 1 percent of treated sites
- Post-install annual energy usage is more than double or less than half of baseline year
- Weather regression model has R-square value < **0.25** for either baseline or post-install year

Site Attrition

Treament Sites	Analysis Stage
329	Initial list of all participants
296	Total participants with no other measures installed
294	Total participants filtered to selected measure combinations
136	Treatment sites matched to consumption data
101	Treatment sites with normalized consumption data
99	Treatment sites with R2 > 0.25
91	Treatment sites with full pre & post years of consumption
89	Treatment sites after removing top and bottom 1%
85	Final model treatment sites before filters
83	Final model treatment sites with filters

Expected Savings

0 Therms

Estimated Savings

15 Therms

Low Estimate

-58 Therms

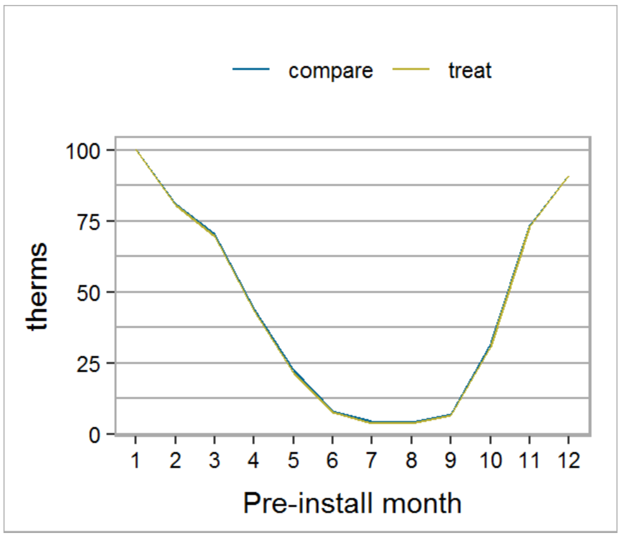
High Estimate

88 Therms

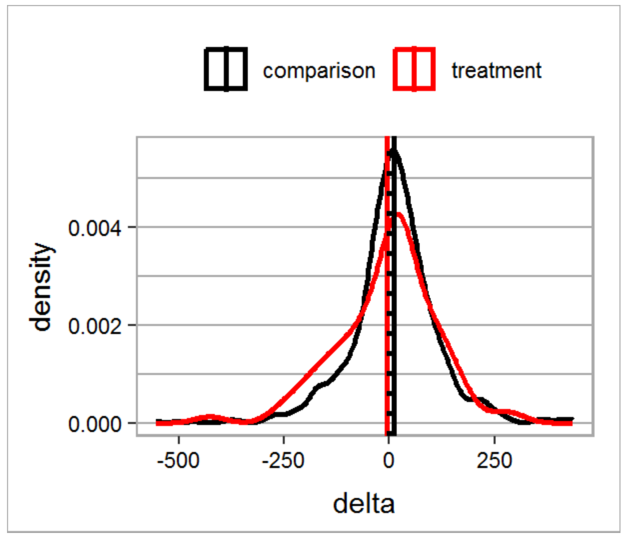
Analysis Results

term	estimate	std.error	statistic	p.value	conf.low	conf.high
(Intercept)	536	9	57	0	521	551
sample_period	10	13	1	0	−11	32
sample_group	−3	31	0	1	−54	49
sample_period:sample_group	**−15**	**44**	**0**	**1**	**−88**	**58**

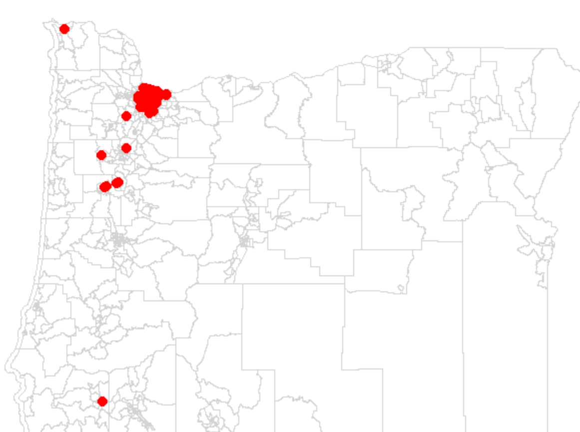
Baseline: Treatment and Comparison Group Mean Montly Consumption



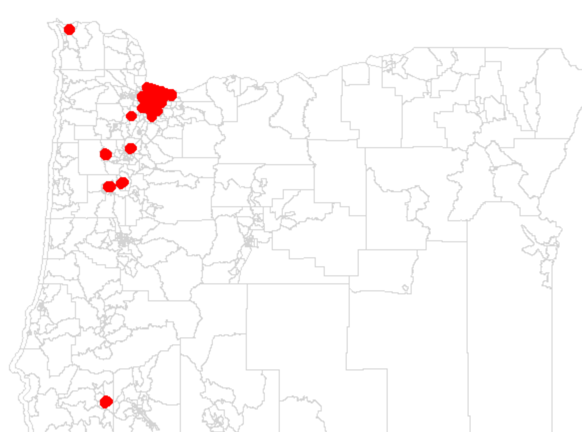
Post-install Consumption Change: Treatment & Comparison Groups



Treatment group spatial distribution



Comparison group spatial distribution



Model Adjusted r2

-0.0011736

Model p-value

0.8365858

List of Measures in Analysis
Community Partner Funded Direct Install HPWH Any Location or HZ
Community Partner Funded HPWH Tier 3, All Tank Sizes
HPWH: $150, Tier 1, <55 Gallons, Retail
HPWH: $300, Tier 2, <55 Gallons, Retail
HPWH: $300, Tier 3/4/5, Retail
Heat Pump WH $150, Tier 1, <= 55 Gallons
Heat Pump WH $300, Tier 2/3, <= 55 Gallons
Heat Pump WH Tier 3, All Tank Sizes
MIT HPWH Tier 3, All Tank Sizes
Midstream HPWH: Tier 3/4/5, Retail
SWR Heat Pump WH Tier 3, All Tank Sizes