MEMO

Date: August 18, 2021
To: Board of Directors
From: Dan Rubado, Sr. Project Manager, Planning & Evaluation
Jackie Goss, Sr. Engineer, Planning & Evaluation
Subject: **Summary of Recurve Analysis of Ducted Heat Pump Upgrade Impacts**

EXECUTIVE SUMMARY

Energy Trust used an impact analysis tool built by Recurve Analytics to evaluate energy savings from high efficiency ducted heat pumps installed in single-family and manufactured homes by trade ally contractors from 2013 to 2018. Energy savings for two primary installation scenarios were analyzed for each home type—homes replacing an existing heat pump (referred to as “upgrades”) and conversions from an electric forced air furnace (referred to as “conversions”). This report focuses on the impact of heat pump upgrade projects. Energy Trust discontinued its heat pump upgrade measures in 2018 due to increasing cost-effectiveness challenges. Weather-normalized annual energy usage prior to installation was compared with the year immediately following installation. The change in annual energy usage was evaluated against changes in energy usage during the same time period in a comparison group of future participants.

The implicit baseline for this analysis (that is, the system that the efficient case was compared against to compute savings) is the existing condition system (what was in place prior to the upgrade). This contrasts with the assumption of the deemed savings analysis for these measures, where a market average efficiency (market baseline) heat pump was used as the point of comparison to compute savings. Using a market baseline assumes customers are already going to replace their existing heat pump system (possibly due to failure) and the incentive is intended to encourage customers to upgrade from a market baseline model to a high efficiency model. Deemed savings were therefore computed as the difference in energy consumption of a high efficiency heat pump compared to the energy consumption of a market baseline heat pump.

Since a market baseline system is likely more efficient than the existing systems that were replaced, the observed savings in this analysis would be higher than expected when compared to the deemed savings. Further complicating matters, the existing conditions encompassed in this analysis are not known and may have included nonfunctional heat pump systems and non-electric heating systems, such as oil furnaces. In addition, three-quarters of heat pump upgrades included commissioning and controls measures on top of the heat pump installation. This suggests a direct comparison between the analysis findings and deemed savings would be misleading. To address this, we estimated a range of possible savings for the efficient case compared to a market baseline system, using two extreme existing condition scenarios to create adjustment factors. In addition, we simply reported the observed energy savings of heat pump upgrades as compared to the existing conditions.

Projects in site-built homes saved 1,520 kWh per year (8 percent) and those in manufactured homes saved 2,150 kWh per year (14 percent) compared with the existing conditions. We estimate that site-built homes saved between 100 and 760 kWh per year compared to a market baseline system, while manufactured homes saved between 140 and 1,080 kWh per year. This results in a realization rate between 7 and 55 percent for site-built homes and 10 and 78 percent for manufactured homes. Projects completed in heating zone 2 appeared to have higher savings than those in heating zone 1, which aligns with our expectations based on the colder climate of heating zone 2. Commissioning and advanced control incentives were associated with a small increase in electricity savings of about 200 kWh, resulting in a roughly 40 percent realization rate. Pre-installation heating loads in the analysis sample were closer to what we might expect to see in homes with electric forced air furnaces, rather than heat pumps. This could be explained if the existing heat pumps that were replaced were very inefficient, undersized, or had inoperable compressors. A properly sized, efficient, new heat pump would have a large opportunity for energy savings in these scenarios compared to the existing condition. However, that opportunity is substantially reduced once a market baseline is assumed as the point of comparison.

If Energy Trust wishes to develop new heat pump upgrade measures and rescreen them for cost-effectiveness, savings estimates adjusted for a market baseline would need to be used to match the assumptions of prior heat pump upgrade measures. We recommend conducting a thorough review of heat pump commissioning activities and advanced controls installations to determine what the most effective practices are and how much energy they save. There may be certain services that are more effective or that can be improved.

Introduction

Energy Trust used an impact analysis tool built by Recurve Analytics to evaluate electric savings from high efficiency ducted heat pumps[1] installed in single-family and manufactured homes from 2013 to 2018. Energy Trust's Residential program has provided incentives for ducted heat pump systems installed by trade ally contractors since 2005 to replace existing heat pumps (referred to as "upgrades") and to convert electric forced air furnace (eFAF) systems (referred to as "conversions"). This report focuses on the impact of heat pump upgrade projects.

Heat pump installations are driven by trade ally contractors who promote the technology and use Energy Trust incentives to help make sales. Trade allies must meet certain requirements, agree to meet Energy Trust standards, and remain in good standing. Energy Trust provides trade allies with training, prescribes installation and commissioning requirements, and conducts quality assurance inspections to ensure that the expected energy savings are achieved. Energy Trust discontinued its incentives for residential heat pump upgrades in 2018—updated savings analysis from the RTF, installation costs, and utility avoided costs combined to make these projects no longer cost-effective. Energy Trust maintained incentives for heat pump conversions and has expanded its campaign to replace eFAF systems in recent years.

During the analysis period, there were two tiers of incentives and deemed savings values claimed by the program for heat pump upgrades, based on the Heating Season Performance Factor (HSPF) as a measure of system efficiency. The deemed savings analysis for heat pump upgrades assumed the existing heat pump was being replaced with a new heat pump, so a market baseline[2] system with HSPF of 8.5 was used

[1] Residential ducted heat pumps are also known as air source heat pumps and central heat pump systems.
[2] Market baseline refers to the average efficiency level of equipment sold in the market.

for comparison. Using a market baseline assumes customers are already going to replace their existing heat pump system (possibly due to failure) and the incentive is intended to encourage customers to upgrade from a market baseline model to a high efficiency model. Deemed savings were therefore computed as the difference in energy consumption of a high efficiency heat pump compared to the energy consumption of a market baseline heat pump. For site-built homes in the 2013 to 2018 program years, the deemed savings claimed for heat pump upgrades was 571 kWh per year for systems with HSPF values of 9.0 to 9.49 and 1,340 kWh per year for systems with HSPF values of 9.5 and above.

Internal Energy Trust documents show that the deemed savings underpinning these measures was based on a somewhat flawed analysis from 2007 that was subsequently updated but never fundamentally changed. Savings were computed using estimated coefficient of performance (COP) values for different HSPF levels. An unrealistically high heating load (18,800 kWh per year) for the baseline efficiency heat pump system was used as the basis for the analysis. Different COP values were then applied to the baseline heat pump's estimated heating load to compute savings for moving to a more efficient heat pump. The resulting savings values were then adjusted using a 50 percent realization rate gleaned from a billing analysis of heat pump upgrade projects from the early 2000s.[3]

The weighted average deemed savings over this period, based on project volume, was 1,010 kWh. While there were no measures explicitly intended for heat pump upgrades in manufactured homes during this period, the site-built measures were used to claim savings in that setting. Although Energy Trust's measure analysis acknowledged that savings in heating zone 2 were likely higher, the deemed savings were ultimately assumed to be the same as in heating zone 1, due to a lack of data from heating zone 2 to quantify the additional savings. The deemed savings values for heat pump upgrade projects are summarized in Table 1.

Table 1: Heat pump upgrade deemed savings values and project counts by installation scenario

Years in Effect	Project Type	Home Type	Incentive Design	Heating Zone	HSPF	Deemed Savings (kWh)	Project Count	Percent of Projects
2013-2018	Upgrade	Site-built	Rebate	All	9.0+	571	2,327	43.5%
2013-2018	Upgrade	Site-built	Rebate	All	9.5+	1,343	3,026	56.5%
2013-2018	Upgrade	Site-built	Rebate	All	Weighted Average	1,010	5,353	100%

In addition to the installation scenarios and deemed savings values listed above, heat pump projects may also receive additional incentives if the contractor performs commissioning activities or installs advanced controls in accordance with Energy Trust guidelines. These commissioning activities are associated with additional deemed savings that are claimed by the Residential program on top of the heat pump savings. Seventy-seven percent of projects received incentives for qualifying heat pump commissioning activities or advanced controls during the time period analyzed. Deemed savings values for commissioning and controls measures varied somewhat over time and depending on the activities completed and heating zone. The baseline for commissioning measures assumes that new heat pumps are not fully commissioned

[3] Itron. 2006. 2003-2004 Home Energy Savings Program Residential Impact Evaluation: For the Energy Trust of Oregon, Inc. Retrieved on 7/9/2021 from: https://www.energytrust.org/wp-content/uploads/2016/11/2003_2004_HES_Impact.pdf

and that they have standard, not advanced, controls installed. Deemed savings ranged from 450 to 1,210 kWh per year and had a weighted average, based on project volume, of 500 kWh. When added to the weighted average deemed savings for 77 percent of heat pump upgrades, the overall expected savings per home was 1,390 kWh per year, on average. For projects known to have received commissioning measures, the weighted average deemed savings were 1,560 kWh per year.

Methods

Electric savings for heat pump upgrades were analyzed separately for site-built and manufactured homes. The Recurve impact analysis tool uses monthly utility billing data to conduct pre/post analyses of whole home energy usage. Energy usage data are weather normalized using typical meteorological year data. Normalized annual energy usage in the year immediately preceding the installation is compared with that of the year immediately following installation. The change in normalized annual energy usage is then evaluated against changes in energy usage during the same time period in a comparison group—homes that received the same services in later years (future participants). These calculations provide an estimate of the average annual energy savings resulting from the measures, given typical weather conditions. Lastly, several standard data screens are applied to remove atypical homes from the analysis.

The Recurve snapshot reports that follow this memo, and the summary of results below, show that overall electricity savings for heat pump upgrades were somewhat higher than expected from the deemed savings. However, as noted above, the implicit baseline in this analysis is the existing condition system, prior to a new heat pump being installed. This contrasts with the market baseline system assumed by the deemed savings. Since the market baseline system, with an HSPF of 8.5, is likely more efficient than the existing systems that were replaced, the observed savings in this analysis would be higher than expected when compared to the deemed savings. This suggests that a direct comparison between the analysis findings and deemed savings values would be misleading and probably overly optimistic. Further complicating matters, the existing conditions encompassed in this analysis may have included nonfunctional heat pump systems and non-electric heating systems, such as oil furnaces.

In the case of nonfunctional heat pumps, pre-installation energy usage would be quite high if occupants relied on the system's backup resistance heat or portable electric heaters prior to installing the new heat pump. This means the pre-installation energy usage would be more like an electric forced air furnace than a heat pump. In this scenario, the observed savings would be higher than expected when compared to the deemed savings and a market baseline. In the case of fuel switching from non-electric systems, pre-installation electricity usage would be quite low, and the new heat pump would result in a significant increase in electricity usage. This would result in negative savings and is not a scenario that would ideally be included in a pre-post analysis. Unfortunately, we were unable to assess the prevalence of either of these scenarios, but the relatively high pre-installation heating loads indicate that fuel switching was probably uncommon. In addition, without running energy simulations, we have no information about the expected heating load of a market baseline system to compare to the heating loads of existing systems included in this analysis. We also do not have any data on the HSPF values for the existing equipment or the exact HSPF values for the installed equipment.

Given these limitations, translating the observed savings from the analysis to savings with a market baseline would be fraught and rely on many assumptions. To address this, we estimated a conservative range of possible savings values for the efficient case versus a market baseline system, using two extreme existing condition scenarios and simple assumptions to create adjustment factors. In the first scenario, we assumed that 100 percent of existing systems were heat pumps with inoperable compressors, performing similar to eFAF systems with an HSPF of 3.4.[4] The second scenario assumed that 100 percent of existing systems were operable heat pumps with HSPF of 7.7, the minimum efficiency level of a prior heat pump equipment standard. The true existing conditions were probably somewhere in between these extremes. Each of these scenarios was used to compute an adjustment factor, based on the share of observed HSPF improvement attributable to shifting from a market baseline efficiency heat pump to a high efficiency system with average HSPF of 9.5.

Scenario 1 assumed an overall improvement from the existing conditions to the efficient case from an HSPF of 3.4 to 9.5. Scenario 2 assumed an overall improvement from an HSPF of 7.7 to 9.5. For both scenarios, we calculated the portion of the HSPF improvement attributable to the shift from a market baseline (8.5) to a high efficiency system (9.5). This resulted in two adjustment factors for converting the observed savings, with an existing condition baseline, into savings estimates with a market baseline. The following equation was used to develop the adjustment factors:

$$Adj = \frac{(HSPF_{EE} - HSPF_{MB})HSPF_{EC}}{(HSPF_{EE} - HSPF_{EC})HSPF_{MB}}$$

where:

$$HSPF_{EE} = HSPF\ rating\ of\ average\ energy\ efficient\ system = 9.5$$

$$HSPF_{MB} = HSPF\ rating\ of\ market\ baseline\ system = 8.5$$

$$HSPF_{EC} = HSPF\ rating\ of\ average\ existing\ condition\ system$$

$$= 3.4\ for\ scenario\ 1$$

$$= 7.7\ for\ scenario\ 2$$

The resulting adjustment factor was 6.6 percent for scenario 1 and 50.3 percent for scenario 2. These adjustment factors were applied to the observed savings from the analysis to estimate a range of possible savings values for the efficient case compared to a market baseline system. In addition, we simply reported the observed energy savings of heat pump upgrades as compared to the existing conditions.

We analyzed heat pump project savings overall and by several factors, including heating zone[5], home size, heat pump commissioning status, electric utility, and installer. Many of the analyses spanned across heating zones because projects in heating zone 2 were less common, and so that we could identify the impact of other factors.

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[4] HSPF is based on a unit conversion from the assumed COP of 1.0 for electric resistance heat: Avg COP = Heat transferred / electrical energy supplied = (HSPF * 1055.056 J/BTU) / (3600 J/watt-hour) = 0.29307111. The HSPF for a system with COP of 1.0 is equivalent to 1.0 / 0.29307 = 3.4.

[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 (combined hereafter into zone 2) represent areas of the state with cold winters, like the mountains and Central and Eastern Oregon.

Heat Pump Upgrade Results

Overall Savings

Heat pump upgrade projects completed between 2013 and 2018 in site-built homes saved an average of 1,520 kWh per year (+/-120) or 8 percent of pre-installation electricity usage. When adjusted to assume a market baseline, the estimated savings ranged from 100 kWh to 760 kWh per year, with a midpoint of 430 kWh. There were 3,187 site-built homes analyzed in the treatment group. These homes had average annual pre-installation electricity usage of 19,290 kWh, with estimated heating loads of 6,790 kWh (35 percent of usage). They were widely distributed across Energy Trust's electric service territory in Oregon.

Heat pump upgrade projects in manufactured homes saved an average of 2,150 kWh per year (+/-350) or 14 percent of pre-installation electricity usage. When adjusted to assume a market baseline, the estimated savings ranged from 140 kWh to 1,080 kWh per year, with a midpoint of 610 kWh. There were 193 manufactured homes analyzed in the treatment group. These homes had average annual pre-installation electricity usage of 15,530 kWh, with estimated heating loads of 5,940 (38 percent of usage). They were concentrated in the metro areas of Western and Central Oregon.

The results for heat pump upgrade projects by home type are shown in Chart 1, below. The black whisker lines at the ends of the bars represent the 90 percent confidence intervals for the savings estimates.

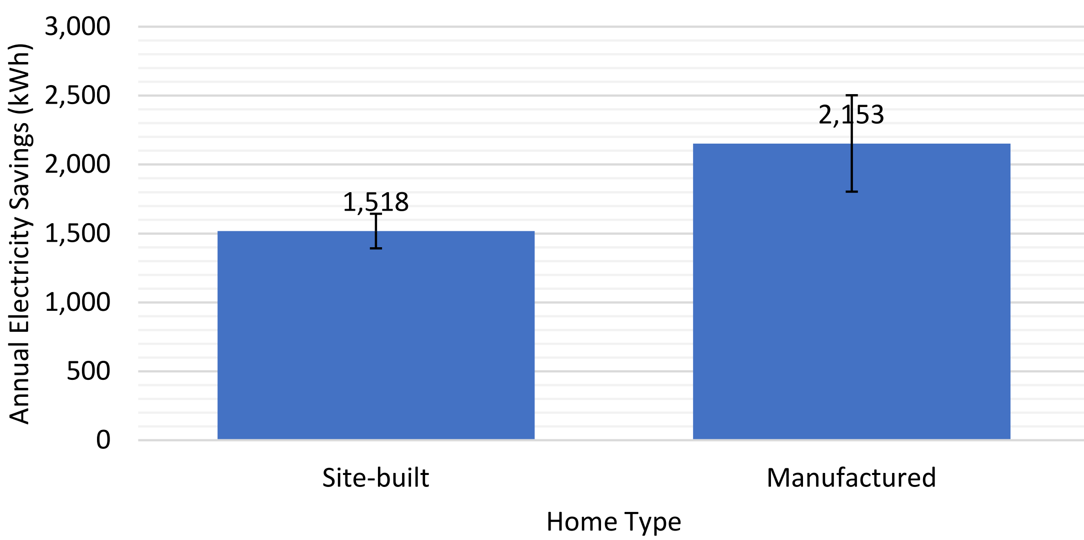


Chart 1: Electric savings for heat pump upgrades by home type

These results show that heat pump upgrade savings were higher than the deemed savings, overall, especially among manufactured homes. Projects in manufactured homes saved 630 kWh more than those in site-built homes, on average, a significant difference. However, the majority of these projects also received commissioning incentives (77 percent). When adjusted to assume a market baseline, single-family projects did not perform well compared to the overall deemed savings of 1,390 kWh per year, which includes the weighted average deemed commissioning savings. Estimated realization rates ranged from 7 to 55 percent, with a midpoint of 31 percent. Manufactured homes performed slightly better compared to the deemed savings, with estimated realization rates ranging from 10 to 78 percent, with a midpoint of 44 percent.

That the relatively robust overall savings results did not result in strong realization rates can be explained by the high portion of savings attributable to simply replacing the existing conditions with a new heat pump. As discussed above, an upgrade from existing conditions is likely to save more than an upgrade from the market baseline heat pump assumed in the deemed savings values. The observed savings for high efficiency heat pumps replacing the existing conditions would need to be much higher than the deemed savings for there to be a large amount of savings attributable to the increase in efficiency from a market baseline to high efficiency heat pump.

In the sections below, we examine the impact of the following factors on the realized savings for heat pump upgrades:

- Heating zone
- Home size
- Installation contractor
- Electric utility
- Commissioning status

Heating Zone Impact

For site-built homes in heating zone 1, heat pump upgrades saved an average of 1,490 kWh per year (+/-130) or 8 percent of pre-installation electricity usage. When adjusted to assume a market baseline, the estimated savings ranged from 98 to 750 kWh per year, with a midpoint of 420 kWh. There were 2,973 site-built homes analyzed in heating zone 1. These homes had average annual pre-installation electricity usage of 19,250 kWh with estimated heating loads of 6,690 kWh (35 percent of usage). They were distributed across heating zone 1 in Oregon. Heating zone 1 results were similar to the overall results because 93 percent of site-built homes in the treatment group were located in heating zone 1.

For site-built homes in heating zone 2, heat pump upgrades saved an average of 2,150 kWh per year (+/-540) or 11 percent of pre-installation electricity usage. When adjusted to assume a market baseline, the estimated savings ranged from 140 kWh to 1,080 kWh per year, with a midpoint of 610 kWh. There were 199 site-built homes analyzed in heating zone 2. These homes had average annual pre-installation electricity usage of 20,330 kWh with estimated heating loads of 8,010 kWh (39 percent of usage). They were concentrated in Central Oregon. Heating zone 2 savings were significantly higher, on average, than the overall results.

The results for site-built homes by heating zone are shown in Chart 2, below. The gray reference line shows the overall average savings.

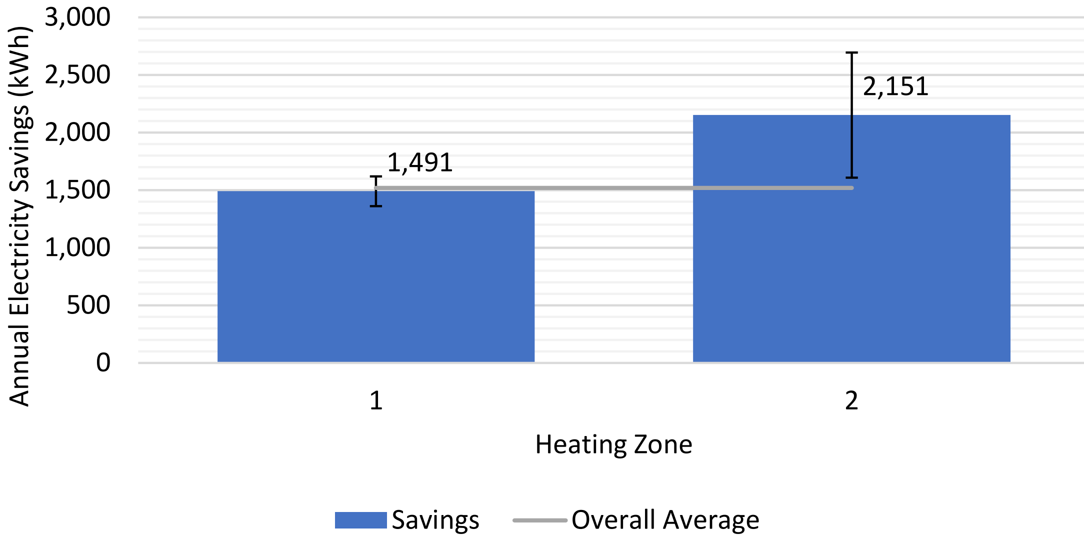


Chart 2: Electric savings for heat pump upgrades in site-built homes by heating zone

For manufactured homes in heating zone 1, heat pump upgrades saved an average of 2,140 kWh per year (+/-370) or 14 percent of pre-installation electricity usage. When adjusted to assume a market baseline, the estimated savings ranged from 140 kWh to 1,080 kWh per year, with a midpoint of 610 kWh. There were 174 manufactured homes analyzed in heating zone 1. These homes had average annual pre-installation electricity usage of 15,309 kWh with estimated heating loads of 5,850 kWh (38 percent of usage). They were concentrated in the metro areas of Western Oregon. Heating zone 1 results were similar to the overall results because 90 percent of manufactured homes in the treatment group were located in heating zone 1.

Electricity savings could not be assessed for manufactured homes in heating zone 2 due to a small number of projects.

The results indicate that heat pump upgrade projects achieved significantly higher electric savings in heating zone 2 than in heating zone 1, in line with our expectations, due to the colder climate of heating zone 2 and higher pre-installation heating loads. When adjusted to assume a market baseline, site-built projects in heating zone 1 did not perform well compared to the overall deemed savings of 1,390 kWh per year, with estimated realization rates ranging from 7 to 54 percent, with a midpoint of 31 percent. Homes in heating zone 2 performed slightly better, with estimated realization rates ranging from 10 to 78 percent, with a midpoint of 44 percent. Manufactured homes in heating zone 1 also performed somewhat better than their single-family counterparts, with estimated realization rates ranging from 10 to 78 percent, with a midpoint of 44 percent.

<u>Home Size Impact</u>

Home size information was only available for 62 percent of site-built homes in the treatment group, so we could only assess savings by home size for a subset (n=1,980). Average electricity savings for homes with square footage data available was 1,760 kWh per year, 240 kWh higher than the overall average for all site-built homes. As a result, this analysis likely overestimates savings for each home size category somewhat, but we have no reason to believe that the collection of home size information was biased, so the overall trend and differences between categories is still informative.

For site-built homes, electricity savings for heat pump upgrades were relatively similar across home sizes, with a moderate, but insignificant, difference in savings between homes in the smallest and largest size categories. Homes less than 1,200 square feet (n=108) saved the least, with an average of 1,640 kWh per year (+/-530) or 11 percent of pre-installation electricity usage. Homes from 1,200 to 1,999 square feet (n=788) saved an average of 1,700 kWh per year (+/-200) or 10 percent of pre-installation electricity usage. Homes from 2,000 to 2,999 square feet (n=728) saved an average of 1,680 kWh per year (+/-260) or 8 percent of pre-installation electricity usage. Lastly, homes of 3,000 square feet and larger (n=356) saved an average of 2,110 kWh per year (+/-600) or 8 percent of pre-installation electricity usage. When adjusted to assume a market baseline, the estimated savings for homes under 3,000 square feet ranged from 110 kWh to 850 kWh per year, with a midpoint of 480 kWh, while larger homes saved between 140 and 1,060 kWh per year, with a midpoint of 600 kWh. The average annual pre-installation electricity usage increased dramatically with home size, from 15,600 kWh for the smallest homes to 28,090 kWh for the largest homes. The estimated annual heating loads increased similarly with size from 4,950 kWh to 9,030 kWh (32 to 35 percent of total usage). All home size categories had relatively robust treatment group sample sizes for this analysis (n>100).

The results by home size in site-built homes are shown in Chart 3, below. The gray reference line shows the overall average savings for homes with square footage data available.

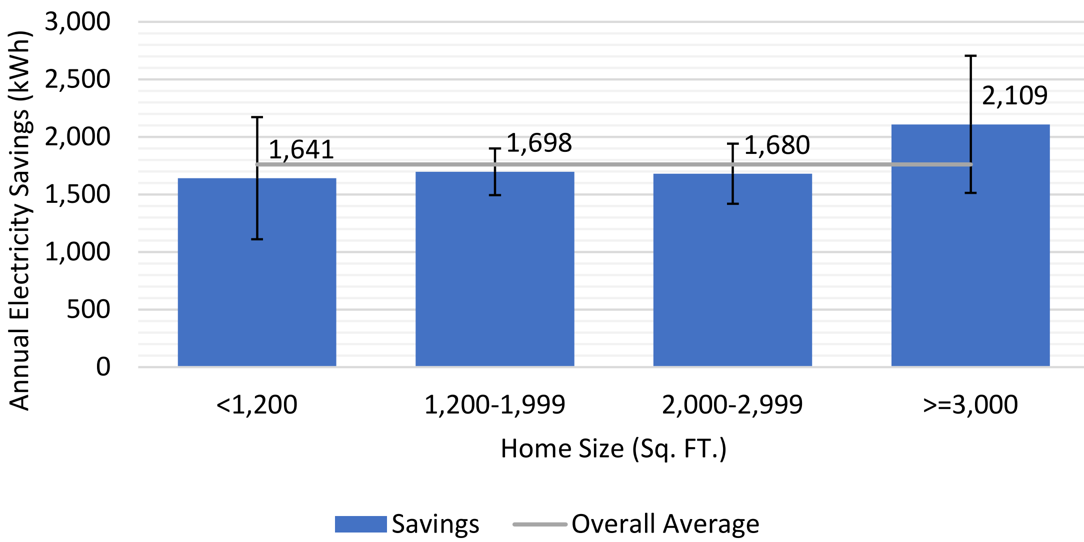


Chart 3: Electric savings for heat pump upgrades in site-built homes by home size[6]

Electricity savings could not be assessed for manufactured homes by home size due to the relatively small number of total projects.

The results show that absolute heat pump upgrade savings were 470 kWh higher in the largest homes than in the smallest homes, although this difference was not statistically significant. In addition, the percent savings for the largest homes was about 25 percent lower than for the smallest homes. The adjusted savings assuming a market baseline showed the same trend, with estimated midpoint realization

[6] Square footage data were only available for 62 percent of homes and the average energy savings for these homes was significantly higher than the overall average. Thus, these results overestimate savings for the population of homes in each size category.

rates around 35 percent for homes up to 3,000 square feet, increasing to 43 percent for homes 3,000 square feet and above. It is intuitive that larger homes with higher electricity usage and heating loads would have higher savings potential, particularly if the systems replaced were substantially larger. However, the differences in savings do not appear to be statistically significant, so may simply be a result of higher variability and lower precision among the smallest and largest homes.

Installation Contractor Impact

We analyzed electricity savings by installation contractor for site-built homes. However, there were many contractors active in this market, so the project sample size for each contractor was relatively small, making it difficult to compare results between them. In addition, there are likely to be many complex factors that are more influential to savings than installation quality, and some important factors may be inseparable from the contractor's business, such as heat pump brand, heating zone of projects, home sizes, frequency of replacing inoperable systems, etc. With these limitations in mind, we found that four of the top five installation contractors appeared to realize higher heat pump upgrade savings, on average, than their counterparts. These contractors worked in homes with higher-than-average pre-installation electricity usage, which may partially explain the difference. One of the top five contractors appeared to realize lower savings, on average, than their counterparts, but they also installed heat pumps in homes with lower-than-average pre-installation electricity usage. The remaining contractors, which had lower project volumes, realized roughly the same level of savings, in aggregate, as the overall average.

Electricity savings could not be assessed for manufactured homes by installation contractor due to the relatively small number of total projects.

Electric Utility Impact

For site-built homes that were customers of Portland General Electric (PGE), heat pump upgrades saved an average of 1,440 kWh per year (+/- 160) or 7 percent of pre-installation electricity usage, similar to the overall average. When adjusted to assume a market baseline, the estimated savings ranged from 90 kWh to 720 kWh per year, with a midpoint of 410 kWh. There were 1,799 site-built homes analyzed in PGE territory—56 percent of the treatment group. These homes had average annual pre-installation electricity usage of 19,220 kWh, with estimated heating loads of 6,820 kWh. They were distributed across PGE's service territory in the Portland and Salem metro areas.

For site-built homes that were customers of Pacific Power, heat pump upgrades saved an average of 1,630 kWh per year (+/-190) or 8 percent of pre-installation electricity usage, similar to the overall average. When adjusted to assume a market baseline, the estimated savings ranged from 110 kWh to 820 kWh per year, with a midpoint of 460 kWh. There were 1,388 site-built homes analyzed in Pacific Power territory—44 percent of the treatment group. These homes had average annual pre-installation electricity usage of 19,400 kWh, with estimated heating loads of 6,760 kWh. They were distributed across Pacific Power's Oregon territory, with a concentration of projects in Southern Oregon.

The results by electric service territory in site-built homes are shown in Chart 4, below. The gray reference line shows the overall average savings.

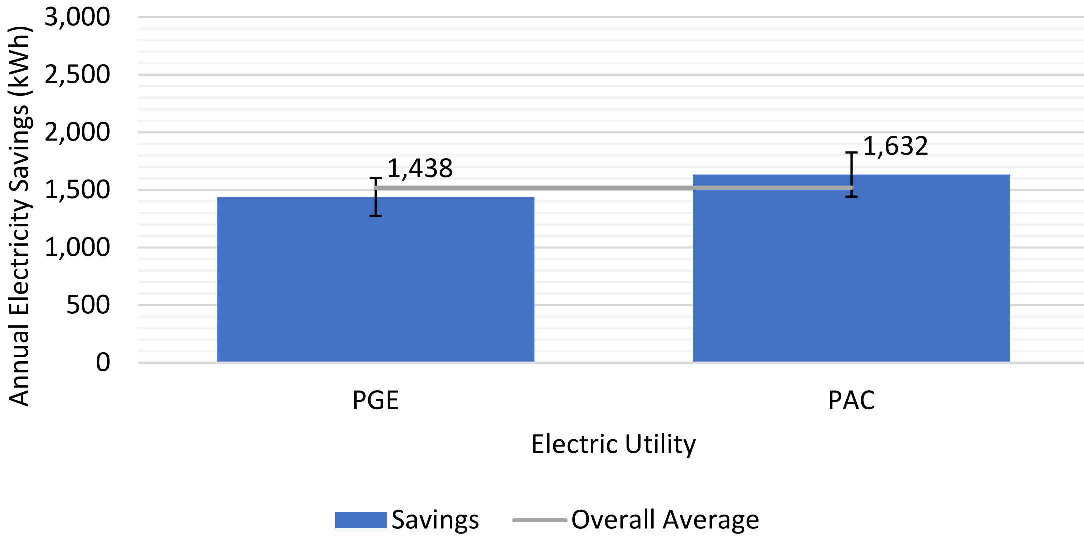


Chart 4: Electric savings for heat pump upgrades in site-built homes by electric utility

For manufactured homes that were customers of PGE, heat pump upgrades saved an average of 1,860 kWh per year (+/-690) or 12 percent of pre-installation electricity usage, similar to the overall average. When adjusted to assume a market baseline, the estimated savings ranged from 120 kWh to 930 kWh per year, with a midpoint of 530 kWh. There were 59 manufactured homes analyzed in PGE territory—31 percent of the treatment group. These homes had average annual pre-installation electricity usage of 15,050 kWh, with estimated heating loads of 6,280 kWh. They were distributed across PGE's service territory in the suburban areas of the Portland and Salem metro areas, with the notable exceptions of the cities of Beaverton, and Hillsboro. There were relatively few projects available for this analysis, so the precision of the savings estimate was moderately low and the results may be unreliable.

For manufactured homes that were customers of Pacific Power, heat pump upgrades saved an average of 2,250 kWh per year (+/-420) or 14 percent of pre-installation electricity usage, similar to the overall average. When adjusted to assume a market baseline, the estimated savings ranged from 150 kWh to 1,130 kWh per year, with a midpoint of 640 kWh. There were 134 manufactured homes analyzed in Pacific Power territory—69 percent of the treatment group. These homes had average annual pre-installation electricity usage of 15,740 kWh, with estimated heating loads of 5,790 kWh. They were concentrated in Southern Oregon.

The results by electric territory in manufactured homes are shown in Chart 5, below. The gray reference line shows the overall average savings.

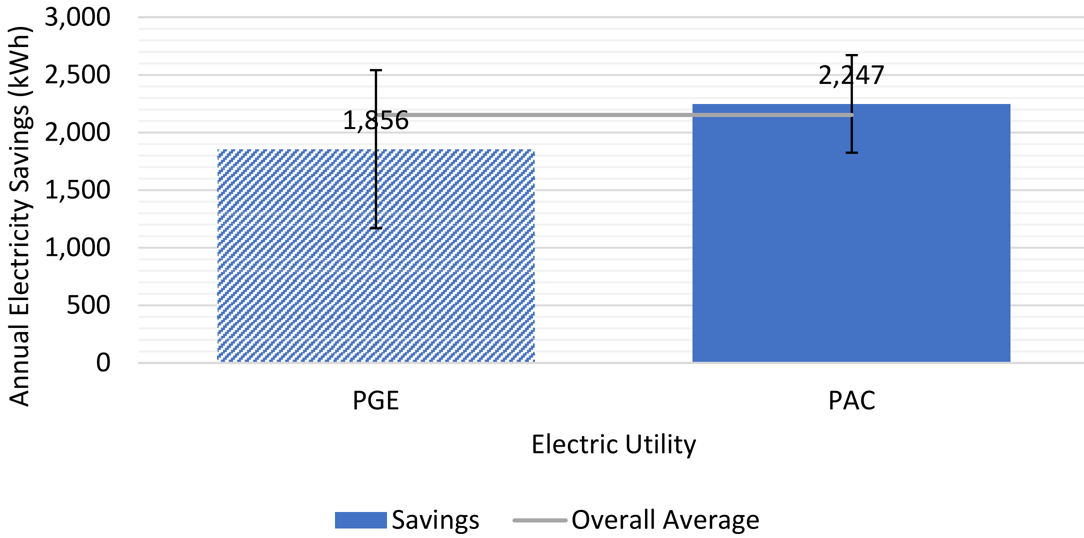


Chart 5: Electric savings for heat pump upgrades in manufactured homes by electric utility[7]

Electric utility impact in heating zone 1. For site-built homes within PGE territory in heating zone 1, heat pump upgrades saved an average of 1,470 kWh per year (+/-170) or 8 percent of pre-installation electricity usage. For site-built homes within Pacific Power territory in heating zone 1, heat pump upgrades saved an average of 1,520 kWh per year (+/-200) or 8 percent of pre-installation electricity usage. Both of these estimates are similar to the average savings for heating zone 1.

Electric utility impact in heating zone 2. For site-built homes within Pacific Power territory in heating zone 2, heat pump upgrades saved an average of 2,240 kWh per year (+/-570) or 11 percent of pre-installation electricity usage. This estimate was similar to the average savings for heating zone 2. There were an insufficient number of site-built homes within PGE territory in heating zone 2 (n=17) to produce a meaningful estimate of electricity savings.

The results by electric utility and heating zone in site-built homes are shown in Chart 6, below. The gold reference line shows the average savings in heating zone 1 and the green reference line shows the average savings in heating zone 2.

[7] Note: the savings estimate for manufactured homes in PGE territory is based on relatively few observations (n=59), so the results may be unreliable.

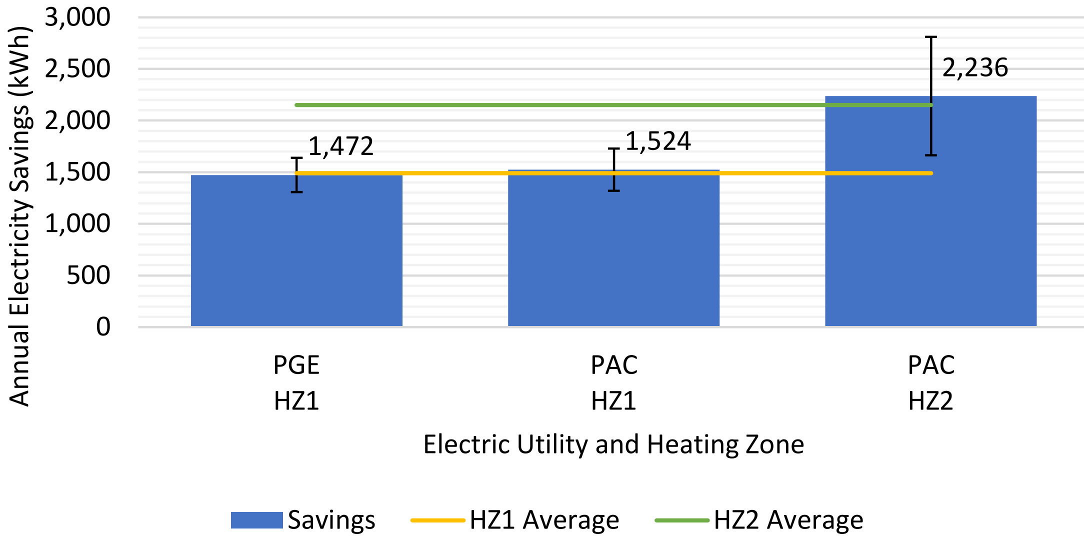


Chart 6: Electric savings for heat pump upgrades in site-built homes by electric utility & heating zone[8]

For manufactured homes, electricity savings for heat pump upgrades were not assessed by both electric utility and heating zone, due to the relatively low number of projects.

These results show that heat pump upgrade savings were slightly higher overall in Pacific Power territory than in PGE territory—190 kWh higher for site-built homes and 390 kWh for manufactured homes. However, these differences were not statistically significant and are mostly attributable to differences in climate between the two utility territories. When the analysis was constrained to heating zone 1, site-built homes in PGE territory saved roughly the same as those in Pacific Power territory (50 kWh less). Within heating zone 2, savings in site-built homes in Pacific Power territory were similar to the average for heating zone 2 overall (80 kWh more). When adjusted to assume a market baseline, site-built homes in heating zone 1 had midpoint realization rates of 30 percent in PGE territory and 31 percent in Pacific Power territory, based on the weighted average deemed savings value of 1,390 kWh. The similarity in savings and realization rates between utility territories, after accounting for climate, points to cross-territory similarities between homes that have heat pumps as the existing condition heating and cooling equipment.

Commissioning Impact

In site-built homes, heat pump upgrades where incentives were provided for commissioning services or advanced controls saved an average of 1,580 kWh per year (+/-130) or 8 percent of pre-installation electricity usage. This estimate is very similar to the overall results for heat pump upgrades. When adjusted to assume a market baseline, the estimated savings ranged from 100 kWh to 790 kWh per year, with a midpoint of 450 kWh. There were 2,449 projects analyzed that received incentives for some type of commissioning—77 percent of treatment group homes. These site-built homes had average annual pre-installation electricity usage of 19,150 kWh, with estimated heating loads of 6,760 kWh. They were distributed across Energy Trust's electric territory in Western and Central Oregon.

[8] Note: savings could not be reliably estimated for PGE customers in heating zone 2, due to a low sample size (n=17).

In site-built homes, heat pump upgrades that did not receive incentives for commissioning services saved an average of 1,380 kWh per year (+/-230) or 7 percent of pre-installation electricity usage. Although this estimate appears to be slightly lower than the overall average savings, it is not significantly different. When adjusted to assume a market baseline, the estimated savings ranged from 90 kWh to 700 kWh per year, with a midpoint of 390 kWh. There were 741 projects analyzed that did not receive any commissioning incentives—23 percent of treatment group homes. These site-built homes had average annual pre-installation electricity usage of 19,920 kWh, with estimated heating loads of 6,880 kWh. They were distributed across Energy Trust's electric service territory in Western and Central Oregon.

The results by commissioning status in site-built homes are shown in Chart 7, below. The gray reference line shows the overall average savings.

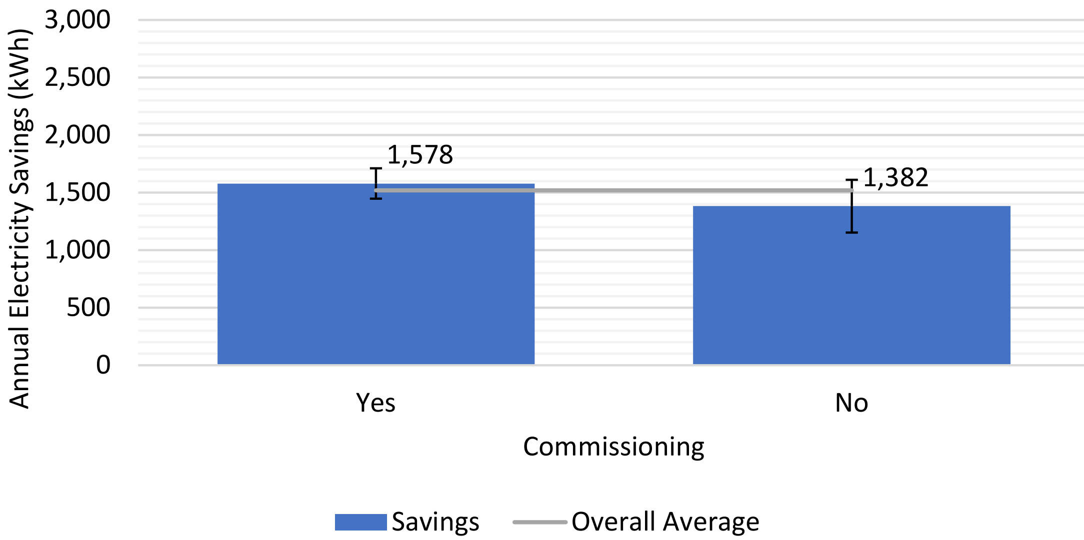


Chart 7: Electric savings for heat pump upgrades in site-built homes by commissioning status

In manufactured homes, heat pump upgrades that received incentives for commissioning services saved an average of 2,180 kWh per year (+/-360) or 14 percent of pre-installation electricity usage, similar to the overall average. When adjusted to assume a market baseline, the estimated savings ranged from 140 kWh to 1,100 kWh per year, with a midpoint of 620 kWh. There were 148 projects analyzed that received some type of commissioning incentives—77 percent of treatment group homes. These manufactured homes had average annual pre-installation electricity usage of 15,290 kWh, with estimated heating loads of 5,740 kWh. They were distributed across Energy Trust's electric territory in Western Oregon, with a concentration in Southern Oregon.

Electricity savings could not be assessed for manufactured homes that did not receive heat pump commissioning incentives, due to a small number of projects.

Commissioning impact in heating zone 1. For site-built homes in heating zone 1, heat pump upgrades that received commissioning incentives saved an average of 1,560 kWh per year (+/-140) or 8 percent of pre-installation electricity usage. Those that did not receive commissioning incentives saved an average of 1,280 kWh per year (+/-240) or 6 percent of pre-installation electricity usage, slightly lower than the heating zone 1 average, but not significantly different.

Commissioning impact in heating zone 2. For site-built homes in heating zone 2, heat pump upgrades that received commissioning incentives saved an average of 2,040 kWh per year (+/-620) or 10 percent of pre-installation electricity usage. Those that did not receive commissioning incentives saved an average of 2,320 kWh per year (+/-800) or 11 percent of pre-installation electricity usage. This savings estimate may be unreliable, due to a relatively small number of projects in heating zone 2 without commissioning (n=78) and a low level of precision. Both savings estimates are similar to the heating zone 2 average.

The results for site-built homes by commissioning status and heating zone are shown in Chart 8, below. The gold reference line shows the average savings in heating zone 1 and the green reference line shows the average savings in heating zone 2.

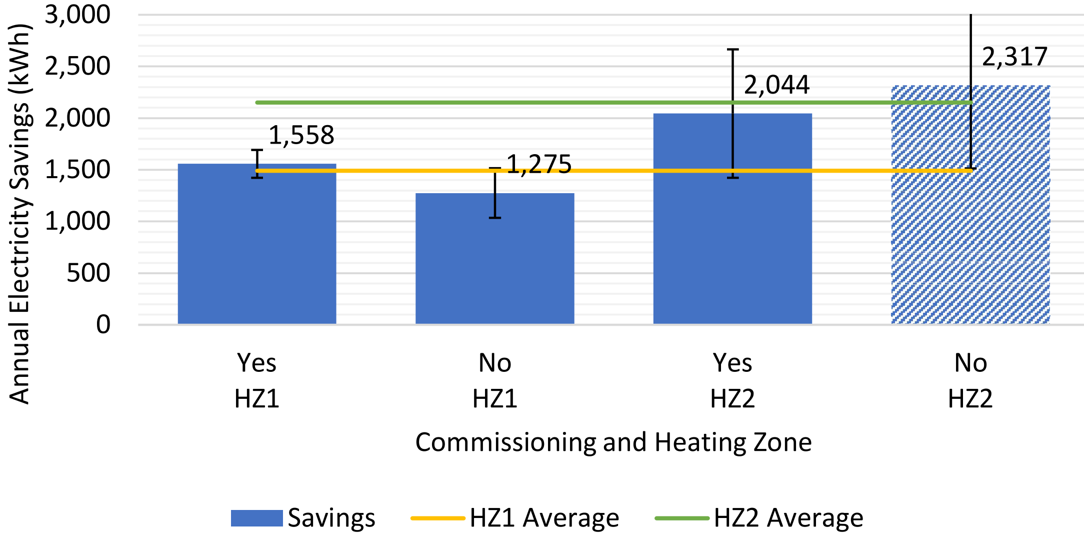


Chart 8: Electric savings for heat pump upgrades in site-built homes by commissioning status and heating zone[9]

Electricity savings for heat pump upgrades in manufactured homes were not assessed by both commissioning status and heating zone, due to the relatively low number of projects.

Commissioning impact for PGE customers. For site-built homes in PGE territory, heat pump upgrade projects that received commissioning incentives saved an average of 1,490 kWh per year (+/-180) or 8 percent of pre-installation electricity usage. Projects in PGE territory that did not receive commissioning incentives saved an average of 1,390 kWh per year (+/-320) or 7 percent of pre-installation electricity usage. These estimates are both similar to the average savings in PGE territory.

Commissioning impact for Pacific Power customers. For site-built homes in Pacific Power territory, heat pump upgrade projects that received commissioning incentives saved an average of 1,730 kWh per year (+/- 200) or 9 percent of pre-installation electricity usage. Projects in Pacific Power territory that did not receive commissioning incentives saved an average of 1,490 kWh per year (+/-340) or 7 percent of pre-installation usage. Although projects that received commissioning appear to have slightly higher savings

[9] Note: the savings estimate for homes in heating zone 2 that did not receive commissioning incentives is based on relatively few observations (n=78), so the results may be unreliable.

than those that did not, the difference is not significant, and both estimates are similar to the average savings in Pacific Power territory.

The results for site-built homes by commissioning status and utility territory are shown in Chart 9, below. The gold reference line shows the average savings in PGE territory and the green reference line shows the average savings in Pacific Power territory.

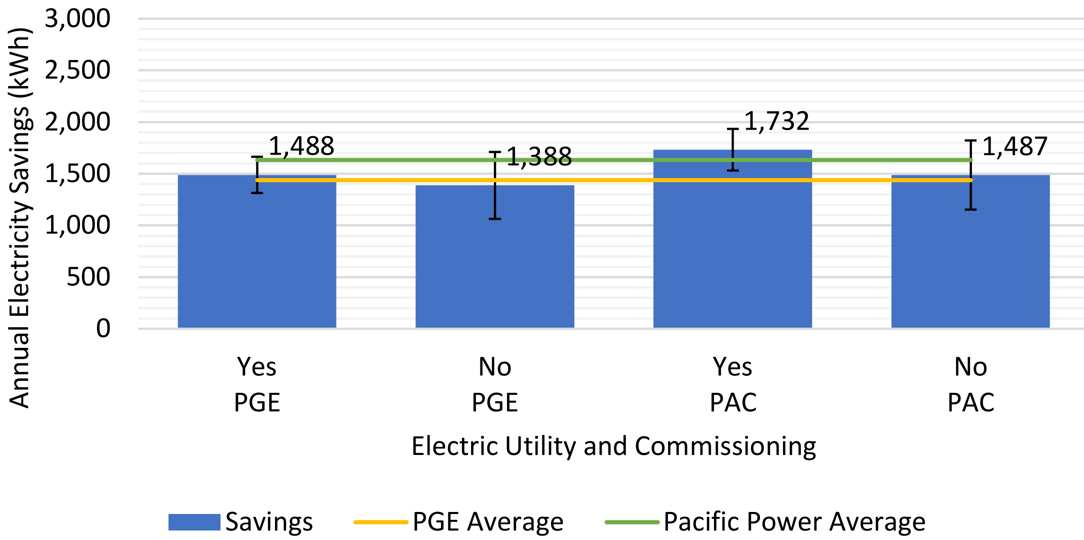


Chart 9: Electric savings for heat pump upgrades in site-built homes by commissioning status and electric utility

Electricity savings for heat pump upgrades in manufactured homes were not assessed by both commissioning status and electric utility, due to the relatively low number of projects.

These results show that heat pump upgrade projects in site-built homes that received incentives for commissioning activities may have saved slightly more electricity than those that did not. Overall, commissioned projects saved 200 kWh per year more than non-commissioned projects, on average, although the difference was not statistically significant. Based on the weighted average deemed savings value of 500 kWh, the realization rate for commissioning services was 40 percent. Projects receiving commissioning measures assumed higher deemed savings, with a weighted average of 1,510 kWh, while projects with no commissioning had weighted average deemed savings of 1,010 kWh. After adjusting the results to assume a market baseline, the estimated realization rate for projects that received commissioning ranged from 7 to 53 percent, with a midpoint of 30 percent. Due to the lower deemed savings for projects without commissioning, these projects performed slightly better, with an estimated realization rate between 9 and 69 percent, with a midpoint of 39 percent.

Within heating zone 1, projects that received commissioning saved 280 kWh per year more than those that did not. This difference approached statistical significance. Within heating zone 2, non-commissioned projects appeared to save 270 kWh more than commissioned projects. However, the difference was not significant, and the precision of the savings estimates was low, so this apparent reversal in the trend may simply be due to random chance. When breaking out the analysis by electric utility, both PGE and Pacific Power customers that received incentives for commissioning saved slightly more than those that did not. In PGE territory, commissioned projects saved 100 kWh more than non-commissioned projects, on average, but the difference was not significant. In Pacific Power territory, commissioned projects saved 240 kWh more than non-commissioned projects, on average. Again, this difference was not significant, but it does suggest the presence of a small but consistent trend.

That commissioning activities did not appear to save as much energy as expected, when done in conjunction with heat pump upgrades, could have several explanations. First, it may simply be due to random variability in energy usage or confounding factors related to commissioning that are not accounted for in this analysis. It may also be that the commissioning activities associated with Energy Trust incentives are already common practice in the industry, or at least among trade ally contractors. In this case, there would be less real-world difference between projects that received commissioning incentives and those that did not. Alternatively, it could be that the requirements for heat pump commissioning measures are not faithfully adhered to by the contractors doing the installations. In this case, homes where commissioning activities are performed do not receive the full benefit of commissioning.

Lastly, it may be that heat pump commissioning measures simply do not save much energy in heat pump upgrade projects, particularly in heating zone 2. When adjusted to assume a market baseline, the difference in savings between commissioned and non-commissioned projects was further reduced. There may also be additional factors at work that are not accounted for in this analysis that could drive differences in savings between commissioned and non-commissioned projects. Although heat pump commissioning activities may add a small amount of savings to heat pump upgrades, we did not have enough statistical power to precisely estimate the impact, given the available sample size and variability in savings.

Trends over Time

We analyzed electric savings for heat pump upgrades in site-built homes by installation year to see if there were changes occurring over time. To minimize year-to-year variance introduced by the comparison group, and better detect any trends, we analyzed only the treatment group's change in normalized annual electricity usage, as a proxy for savings. There was no clear trend, so it appears that electric savings have remained relatively consistent over time. The time trend is shown in Chart 10, below. The gray reference line shows the overall average change in normalized usage and the dotted orange line shows the fitted linear model.

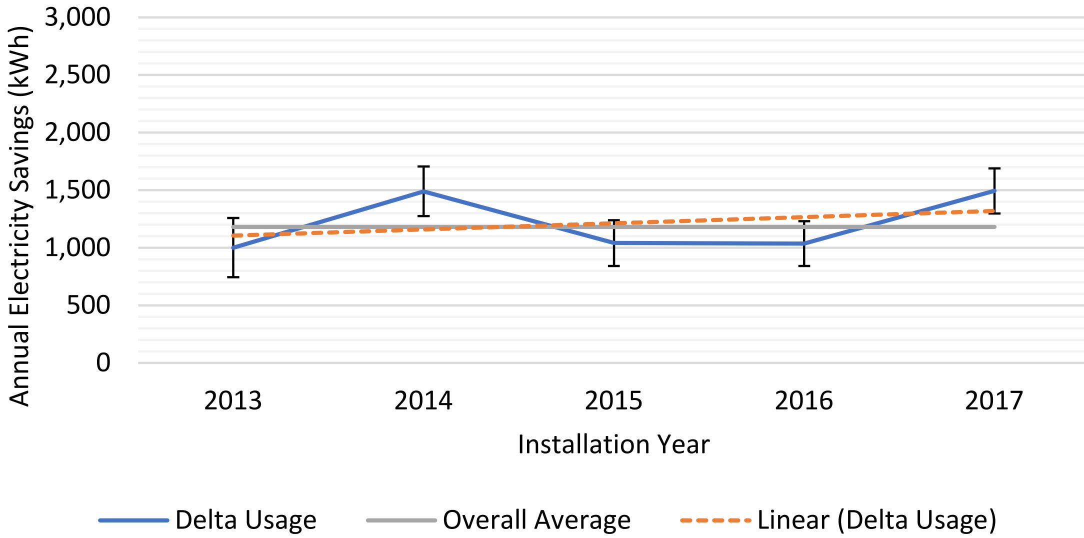


Chart 10: Change in normalized annual electricity usage for heat pump upgrades in site-built homes by year, 2013-2017

We next anlayzed the trend in electric savings by installation year in manufactured homes. Due to a relatively small number of projects overall, we combined annual estimates into two-year bins to improve the precision of the results. To minimize year-to-year variance introduced by the comparison group, and better detect any trends, we analyzed only the treatment group's change in normalized annual electricity usage, as a proxy for savings. Electric savings for heat pump upgrades in manufactured homes were flat over time. The time trend is shown in Chart 11, below. The gray reference line shows the overall average change in normalized usage and the dotted orange line shows the fitted linear model.

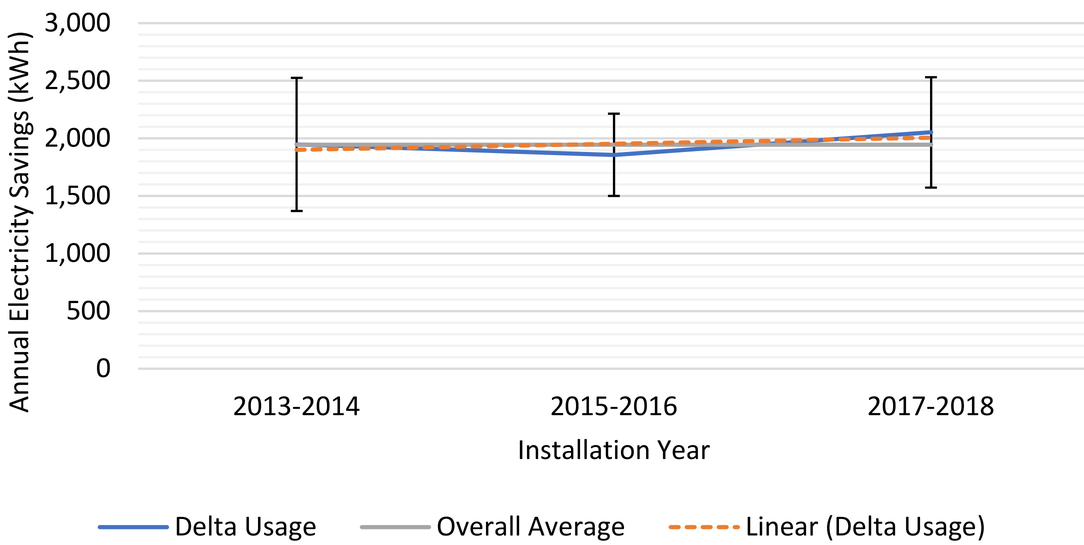


Chart 11: Change in normalized annual electricity usage for heat pump upgrades in manufactured homes by year, 2013-2018

Reliability of Results

We assessed the results for each analysis scenario based on sample size, magnitude of savings, and relative precision, and assigned a confidence rating from low to very high. While we have high or moderate confidence in many of the results, there are a few scenarios where we have low confidence in the value of the point estimate due to low precision, small sample size, or both. However, in most cases, the less reliable point estimates seem to fit roughly into a larger pattern of results. Scenarios with treatment group sample sizes less than 60 homes or very low precision were considered to be too unreliable to assess and are not reported here (with one minor exception). For the adjusted savings estimates and realization rates assuming a market baseline, a number of assumptions were used and a rather simplistic adjustment factor was applied. Although we present a range of adjusted savings based on two extreme existing condition baseline scenarios, there is additional uncertainty inherent in these estimates. The precision of the underlying savings estimates and potential errors in assumptions are not fully captured in the range of adjusted savings values. However, these savings ranges provide reasonable bookends for heat pump upgrade savings compared to a market baseline.

Summary of Results

In Table 2, below, we summarize the results of the various heat pump upgrade scenarios analyzed in site-built homes. In Table 3, we summarize heat pump upgrade savings in manufactured homes. Results are provided for electrically heated homes that installed a heat pump between 2013 and 2018. All savings and energy usage values are listed in annual kWh.

Table 2: Summary of heat pump upgrade electric savings (kWh) in site-built homes

Heating Zone	Utility	Cx Status	Home Size	N*	Pre-Install Energy Usage	Pre-Install Heating Usage	Average Savings†	Absolute Precision†	Percent Savings†	Conf. Rating
All	All	All	All	3,187	19,289	6,792	1,518	±125	8%	Very High
1	All	All	All	2,973	19,253	6,687	1,491	±129	8%	Very High
2	All	All	All	199	20,332	8,012	2,151	±543	11%	Moderate
All	PGE	All	All	1,799	19,215	6,815	1,438	±164	7%	High
All	PAC	All	All	1,388	19,404	6,761	1,632	±191	8%	High
All	All	Yes	All	2,449	19,150	6,764	1,578	±132	8%	Very High
All	All	No	All	741	19,920	6,884	1,382	±229	7%	High
All	All	All	<1,200	108	15,605	4,954	1,641	±530	11%	Moderate
All	All	All	1,200-1,999	788	16,617	5,826	1,698	±203	10%	High
All	All	All	2,000-2,999	728	20,010	6,820	1,680	±261	8%	High
All	All	All	≥3,000	356	28,093	9,032	2,109	±595	8%	Moderate
1	PGE	All	All	1,776	19,325	6,726	1,472	±166	8%	High
1	PAC	All	All	1,197	19,194	6,634	1,524	±204	8%	High
2	PAC	All	All	182	20,669	7,282	2,236	±573	11%	Moderate
1	All	Yes	All	2,317	19,131	6,660	1,558	±135	8%	Very High
1	All	No	All	656	19,732	6,784	1,275	±241	6%	High
2	All	Yes	All	121	19,767	8,341	2,044	±622	10%	Moderate
2	All	No	All	78	21,209	7,408	2,317	±805	11%	Low

Heating Zone	Utility	Cx Status	Home Size	N*	Pre-Install Energy Usage	Pre-Install Heating Usage	Average Savings†	Absolute Precision†	Percent Savings†	Conf. Rating
All	PGE	Yes	All	1,435	19,299	6,793	1,488	±175	8%	High
All	PGE	No	All	366	19,128	6,904	1,388	±324	7%	Moderate
All	PAC	Yes	All	1,014	18,970	6,723	1,732	±202	9%	High
All	PAC	No	All	377	20,998	6,864	1,487	±335	7%	Moderate

Note: results based on less than 60 treatment sites may be unreliable and were not assessed.

* N is the final treatment group sample size in the analysis. Future participant comparison group sample sizes tended to be slightly larger than treatment group sample sizes, for any given analysis.

† The savings, precision, and percent savings values are based on changes in annual energy usage compared to a future participant comparison group.

Table 3: Summary of heat pump upgrade electric savings (kWh) in manufactured homes

Heating Zone	Utility	Cx Status	N*	Pre-Install Energy Usage	Pre-Install Heating Usage	Average Savings†	Absolute Precision†	Percent Savings†	Conf. Rating
All	All	All	193	15,530	5,942	2,153	±350	14%	High
1	All	All	174	15,309	5,848	2,139	±371	14%	High
All	PGE	All	59	15,046	6,283	1,856	±686	12%	Very Low
All	PAC	All	134	15,744	5,793	2,247	±423	14%	High
All	All	Yes	148	15,289	5,740	2,179	±358	14%	High

* N is the final treatment group sample size in the analysis. Future participant comparison group sample sizes tended to be slightly larger than treatment group sample sizes, for any given analysis.

† The savings, precision, and percent savings values are based on changes in annual energy usage compared to a future participant comparison group.

In Table 4, below, we summarize the adjusted heat pump upgrade savings in site-built homes, along with the deemed savings values, and estimated realization rates, assuming a market baseline. In Table 5, we summarize the adjusted heat pump upgrade savings in manufactured homes. The adjusted savings and realization rates are provided as ranges, computed from two extreme existing condition baseline scenarios, since the actual existing conditions are unknown. As described above, scenario 1 assumes that the existing condition baseline is 100% heat pumps with inoperable compressors acting as eFAF systems at the time of the upgrade project. Scenario 2 assumes that the existing condition baseline is 100% operable heat pumps with an average HSPF rating of 7.7. Both savings scenarios assume an efficient case with an average HSPF rating of 9.5 and a market baseline with an average HSPF rating of 8.5.

Table 4: Summary of adjusted heat pump upgrade electric savings (kWh) and realization rates assuming a market baseline in site-built homes

Analysis Group	Deemed Savings*	Scenario 1 Adjusted Savings**	Scenario 2 Adjusted Savings†	Midpoint Adjusted Savings	Scenario 1 Realization Rate**	Scenario 2 Realization Rate†	Midpoint Realization Rate
All	1,390	100	764	432	7%	55%	31%
Heating Zone 1	1,390	98	750	424	7%	54%	31%
Heating Zone 2	1,390	142	1,083	612	10%	78%	44%

Analysis Group	Deemed Savings*	Scenario 1 Adjusted Savings**	Scenario 2 Adjusted Savings†	Midpoint Adjusted Savings	Scenario 1 Realization Rate**	Scenario 2 Realization Rate†	Midpoint Realization Rate
PGE	1,390	95	724	409	7%	52%	29%
Pacific Power	1,390	108	821	464	8%	59%	33%
Commissioned	1,507	104	794	449	7%	53%	30%
Not Commissioned	1,007	91	696	393	9%	69%	39%
<1,200 Sq. Ft.	1,390	108	826	467	8%	59%	34%
1,200-1,999 Sq. Ft.	1,390	112	855	483	8%	61%	35%
2,000-2,999 Sq. Ft.	1,390	111	845	478	8%	61%	34%
≥3,000 Sq. Ft.	1,390	139	1,061	600	10%	76%	43%

* The deemed savings values listed are weighted averages based on the savings claimed for different heat pump upgrade and commissioning measures during the analysis period and their respective project volumes.

** Scenario 1 adjusted savings assume an existing condition where 100 percent of heat pump compressors were non-functional and were operating as eFAF systems.

† Scenario 2 adjusted savings assume an existing condition where 100 percent of heat pumps were fully functional and had a rated HSPF equivalent to the prior code minimum of 7.7.

Table 5: Summary of adjusted heat pump upgrade electric savings (kWh) and realization rates assuming a market baseline in manufactured homes

Analysis Group	Deemed Savings*	Scenario 1 Adjusted Savings**	Scenario 2 Adjusted Savings†	Midpoint Adjusted Savings	Scenario 1 Realization Rate**	Scenario 2 Realization Rate†	Midpoint Realization Rate
All	1,390	142	1,084	613	10%	78%	44%
Heating Zone 1	1,390	141	1,076	609	10%	77%	44%
PGE	1,390	122	934	528	9%	67%	38%
Pacific Power	1,390	148	1,131	639	11%	81%	46%
Commissioned	1,507	144	1,097	620	10%	73%	41%

* The deemed savings values listed are weighted averages based on the savings claimed for different heat pump upgrade and commissioning measures during the analysis period and their respective project volumes.

** Scenario 1 adjusted savings assume an existing condition where 100 percent of heat pump compressors were non-functional and were operating as eFAF systems.

† Scenario 2 adjusted savings assume an existing condition where 100 percent of heat pumps were fully functional and had a rated HSPF equivalent to the prior code minimum of 7.7.

Conclusions and Recommendations

The Recurve analysis of heat pump upgrade projects in electrically heated homes found the observed electric savings, compared to the existing conditions, were robust across the board, especially in manufactured homes where realized savings reached 14 percent of annual electricity usage, on average. In site-built homes, savings were 8 percent of annual usage, on average. In addition, energy savings appeared to be relatively consistent over the time period of the analysis. However, the analysis results presented in this memo implicitly use an existing condition baseline, whereas the deemed savings analysis assumed a market baseline system with HSPF of 8.5. The market baseline assumes that customers are already going to replace their existing heat pump system (possibly due to failure) and the incentive is intended to encourage customers to upgrade from a market baseline efficiency model to a high efficiency model. The market baseline is probably much more efficient than the typical existing condition system replaced. For this reason, the results of this analysis cannot be directly compared to the deemed savings values. We applied adjustment factors, based on assumed improvements in HSPF ratings, to translate the analysis results to savings versus a market baseline. When we compared the adjusted savings to the deemed savings values, it became clear that heat pump upgrades saved much less electricity than expected. That said, the adjustment factors themselves are imprecise, based on several assumptions, and provide only a broad range of potential savings. Further refinements to the adjustment factors may allow for more accurate assessment of the portion of savings resulting from the installed high efficiency heat pumps compared to the market baseline.

The observed pre-installation electricity usage and estimated heating loads in treated homes were relatively high for homes with air source heat pump systems and were closer to what we might expect to see in homes with eFAF systems. This could be explained if a substantial portion of the existing heat pumps replaced were in poor condition, were very inefficient, had compressors that were inoperable, or were significantly undersized relative to home heating requirements. In all cases, the existing system would have relied heavily on backup resistance heating to meet home heating loads during the pre-installation period and would more closely resemble an eFAF system. A properly sized and efficiently operating new heat pump would result in relatively large observed energy savings in these scenarios, compared to the existing conditions, because the use of backup resistance heat would be greatly reduced. However, those baseline conditions would also imply that most of the observed savings were coming from the replacement of the old system with a new heat pump, rather than the upgrade from a market baseline to high efficiency system.

In several recent heat pump retrofit evaluations, heat pump savings have suffered because newly installed heat pumps frequently displace the use of supplemental heating systems, like wood stoves.[10,11,12] So, rather than purely saving electricity, a subset of homes end up saving significant amounts of wood and other fuels, eating into the expected electricity savings. Although fuel conversions were explicitly allowed with the heat pump upgrade incentives, this does not appear to have been common, based on the relatively high pre-installation electric heating loads and robust savings overall. However, the prevalence of fuel conversion projects and displacement of secondary heating sources, like wood heat, is not known. Another potential issue impacting savings is that added cooling loads can cannibalize some of the winter heating savings from new heat pumps. Many of these homes likely had heat pumps capable of cooling prior to the upgrade, but homes with inoperable compressors may have seen a large increase in cooling

[10] Rubado D. 2021. Summary of Recurve Analysis of Ducted Heat Pump Conversion Impacts. Energy Trust of Oregon. Retrieved on 7/12/2021 from: https://energytrust.org/wp-content/uploads/2021/04/Summary-Memo-of-Recurve-Ducted-Heat-Pump-Conversion-Impacts-Final.pdf

[11] Jackson A, Walczyk J. 2019. Energy Trust of Oregon Residential Ductless Heat Pump Study. Cadmus Group. Retrieved on 7/12/2021 from: https://energytrust.org/wp-content/uploads/2019/10/Residential_Ductless_Heat_Pump_Study_Report.pdf

[12] Dorato S, Goodman P, Yaggie M, Esposito A. 2018. Bonneville Power Administration Impact Evaluation of Residential Ductless Heat Pump and Prescriptive Duct Sealing Measures. Navigant Consulting. Retrieved on 7/12/2021 from: https://www.bpa.gov/EE/Utility/Evaluation/Evaluation/Impact_Evaluation_of_Res_DHP_and_Prescriptive_Duct_Sealing_Measures_draft_report.pdf

after installation. On the other hand, the improved cooling efficiency of the new heat pumps may have increased the observed savings in some cases.

Projects completed in heating zone 2 appeared to have higher savings than those in heating zone 1, which aligns with our expectations, based on the colder climate and higher home heating requirements in heating zone 2. In addition, savings were slightly higher for Pacific Power customers than for PGE customers. However, this result appears to be mostly due to climate differences between the two service territories, because it did not persist after controlling for climate. This is an interesting contrast to the persistent difference that we observed between PGE and Pacific Power customers in heat pump conversion projects, where eFAFs were replaced with heat pumps.[13] This may be due to more consistent existing conditions among homes upgrading existing heat pump systems.

Home size was a minor factor in realized heat pump upgrade savings in site-built homes. Large homes, greater than 3,000 square feet, realized about 470 kWh more savings overall than smaller homes, less than 1,200 square feet. This difference was somewhat smaller when savings were adjusted for the market baseline. The middle two home size categories appeared to save about the same amount as the smallest sized homes. These findings make intuitive sense since larger homes had higher heating loads, thus more opportunity for savings, up to a point. In addition, savings as a percent of electricity usage decreased as home size increased, indicating that the increases in savings did not keep pace with increases in pre-installation electricity usage. Heat pump sizing practices are likely a factor in how much savings different size homes realize. To better assess the impact of heat pump sizing on energy performance, we would need more complete information than were available in the program data on system capacity, home size, and shell characteristics. A follow-up study would be needed to collect and analyze these data.

Commissioning and advanced control incentives were associated with a small, but not statistically significant, increase in electricity savings for heat pump upgrade projects in site-built homes. There were some inconsistencies in these results by heating zone and utility, but overall, commissioning incentives appeared to increase heat pump upgrade savings by about 200 kWh, less than the roughly 500 kWh savings expected. As a result, commissioning measures in site-built homes had a roughly 40 percent realization rate. Unfortunately, the results were insufficiently precise to provide a reliable savings estimate or realization rate.

HSPF may be an important factor affecting energy performance and savings. Unfortunately, we were unable to assess its impact due to a high degree of missing information in program data. However, some reports have suggested that HSPF rating does not play a large role in heat pump energy performance or savings. The RTF has stated that they do not "know of any studies that have isolated the real-world efficiency improvements of single-speed heat pumps with HSPF ratings higher than 8.5."[14] This could also have implications for the accuracy of the adjustment factors we used, which were based on improvements in HSPF ratings. In addition, it may call into question the viability of any heat pump upgrade measure. The

[13] Rubado D. 2021. Summary of Recurve Analysis of Ducted Heat Pump Conversion Impacts. Energy Trust of Oregon. Retrieved on 7/12/2021 from: https://energytrust.org/wp-content/uploads/2021/04/Summary-Memo-of-Recurve-Ducted-Heat-Pump-Conversion-Impacts-Final.pdf

[14] Regional Technical Forum. 2020. Single-speed Air Source Heat Pumps: Energy Impacts of Efficiency Program Design Elements. Retrieved on 1/20/2021 from: https://nwcouncil.box.com/v/ASHPWhitePaperCleanDraft.

type of heat pump system, such as single-stage, multi-stage, variable capacity, or cold climate,[15] may also have an impact on savings, but we were not able to assess this factor, due to lack of data.

In reviewing the deemed savings analysis for heat pump upgrade measures from internal Energy Trust documents, we discovered that it was out of date and used several flawed assumptions and calculations. The deemed savings were updated at least twice, but the underlying analysis was never changed. The flaws in the analysis are significant enough that the deemed savings values are highly unreliable and should not be used in future Energy Trust measure development. Energy Trust's heat pump upgrade measures and their deemed savings values expired at the end of 2017 and Energy Trust discontinued their use in 2018. They have not been reinstated or replaced to date.

If Energy Trust wishes to develop new heat pump upgrade measures and rescreen them for cost-effectiveness, the observed savings results cannot be directly used. An adjustment factor, similar to the one we used, first needs to be applied to translate the existing condition baseline to a market baseline to match the assumptions of the prior heat pump upgrade measure. An accurate adjustment may be challenging, given the limited information we have regarding the existing condition systems included in the analysis sample. In addition, there was likely some heterogeneity in the existing condition systems, including non-electric heating systems (e.g. oil furnaces), systems in poor condition or with inoperable compressors, varying efficiency levels, and undersized systems. We attempted to capture these issues using two extreme baseline condition scenarios to create adjustment factors to compute a range of adjusted savings values, assuming a market baseline. After applying these factors, the adjusted savings were much lower across the board. However, the range of potential savings were higher for manufactured homes and homes in heating zone 2. Given this, it is possible that heat pump upgrades, compared to a market baseline, could lead to cost-effective savings in some scenarios.

We recommend conducting a thorough review of heat pump commissioning activities and advanced controls installations. This may involve collection of market data to understand how prevalent these services are and whether incentives are needed to improve the performance of heat pump projects. Further study of commissioning activities and advanced controls may also be needed to determine what the most effective practices are and how much energy they save. Although this analysis detected only minor savings from commissioning activities in general, there may be certain services that are more effective or that can be improved.

[15] Also known as "extended capacity" variable speed heat pumps. Energy Trust researched this technology separately in a 2018/2019 pilot study summarized in this report: https://www.energytrust.org/wp-content/uploads/2020/04/ECHP-Pilot-Wrap-up-Memo-v4.pdf.

Appendix A: Recurve Impact Analysis Reports

Heat Pump Upgrade Analysis Reports:

- Site-built homes – Overall results
- Manufactured homes – Overall Results

Impact Evaluation Report

Electricity Impact of Ductedheatpump-Site-Built in Program Year 2013, 2014, 2015, 2016, 2017, 2018

Result Summary

Measure: Ductedheatpump-Site-Built	Program Year: 2013, 2014, 2015, 2016, 2017, 2018		Fuel: Electricity	*Last Consumption Data Update:* Q1 2020 *Last Participation Data Update:* Q1 2020 *CalTRACK Version:* 2.0
Meter Data Filters:	DNAC: <100%	DNAC Percentile: Remove Top and Bottom 0.5%	Annual Consumption Percentile: Remove Top and Bottom 0.5%	
Model Filters:	Period Length: 11 Months or Longer	R-Squared: >0.5	CV(RMSE): < 1	
Metadata Filters:	Cooling Zone(s): All	Heating Zone(s): All	Heating Fuel: Electricity	Heat Pump Manufacturer: All
	Thermostat Name: All	Heat Pump Baseline: All	Multi Measure Filter: Single Measure Only	Heat Pump Adv. Controls or Commissioning: All
	Air / Duct type: All	Home size: All	Complex Duct Sealing: All	LikelyGasWaterHeating: All
Electric Provider: All	Contractor: All	Water Heating Fuel: All	Home Size (SqFt): All	Ducted heat pump type: Heatpumpupg

3,187 Treatment Meters	1180 +/- 93 kWh Average Normal Year Pre-Post Difference in Consumption per Participant	6 +/- 0 % Percent Normal Year Pre-Post Difference in Consumption per Participant	19,289 Mean Baseline Consumption (Electricity)	85% Realization Rate
8,610 Site-level Matched Meters	1215 +/- 102 kWh Average Savings Relative to Site-level Matched Comparison Group	6 +/- 1% Percent Savings Relative to Site-level Matched Comparison Group	13,578 Mean Baseline Consumption (Electricity)	88% Realization Rate
3,755 Future Participant Meters	1518 +/- 125 kWh Average Savings Relative to Future Participant Group	8 +/- 1% Savings Relative to Future Participant Group	18,420 Mean Baseline Consumption (Electricity)	110% Realization Rate

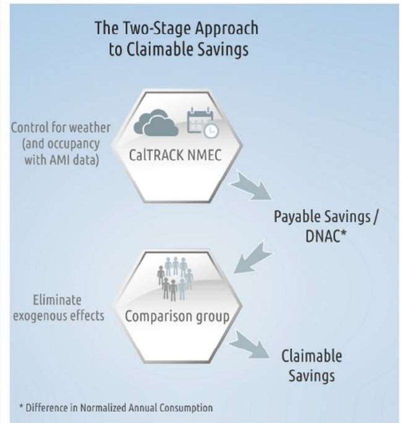
1. Introduction

This report contains the results of applying the two-stage approach (informed by the DOE's uniform methods chapter on whole building analysis) for calculating claimable savings to the selected portfolio of energy efficiency projects (see Figure). This approach begins with identification of two comparison groups for the treatment sample: (a) a site-level matched comparison group and (b) a future participant group. These groups are described below along with summary statistics (site locations, sample size, baseline consumption and baseline load disaggregation).

The CalTRACK methods are then applied to arrive at site-level savings, normalized for weather, and reflective of energy consumption changes for customers at the meter. Using a difference of differences for the treatment group with each comparison group accounts for population-level consumption changes (e.g. economic changes, rate changes, natural energy efficiency adoption etc.). The methods contained within this report are the outcome of a recent peer-reviewed study completed by Energy Trust of Oregon and Open Energy Efficiency (see "Methodology" section for more details).

The report includes the following sections:
Result Summary - Includes the overall portfolio results
Section 1. Introduction - Overview of report and the different groups included in the analysis
Section 2. Data Preparation - Data cleaning and sample attrition
Section 3. Modeling Results - CalTRACK model outputs and Difference in Normalized Annual Consumption (DNAC) results
Section 4. Methodology - Description of methods used in this report

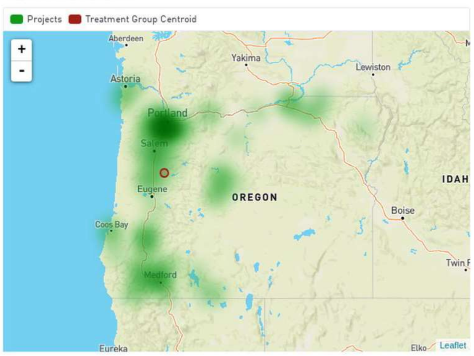
Two-Stage Approach



Treatment Group

The treatment group consists of sites that participated in the specified energy efficiency projects in the specified program year. Only sites that installed single measures are included in the treatment group. And this group includes the subset of sites that had sufficient data quality for modeling.

Treatment Site Locations

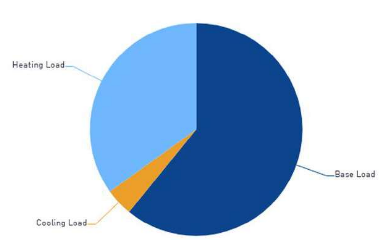


149.7 miles

80% of projects lie within this distance from treatment group centroid

3,187	19,289
Meters	Mean Baseline Consumption (Electricity)

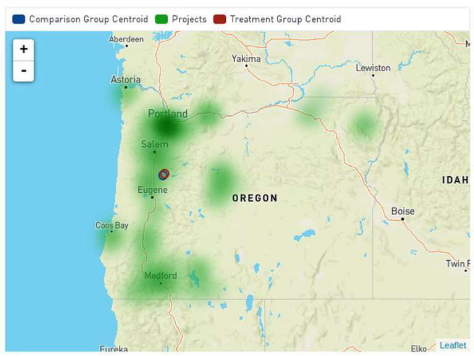
Load Disaggregation



Site-level Matched Comparison Group

This group includes comparison group sites that were matched at the site-level to treatment group sites. Each treatment group site is matched to five comparison group sites from the same zipcode, but only the sites with sufficient data quality were included in the group. Matching was performed using monthly consumption in the baseline period as detailed in the Methodology section.

Site-level Matched Site Locations

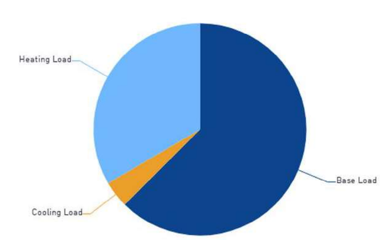


3.2 miles

Distance between treatment and comparison group centroids

8,610	13,578
Meters	Mean Baseline Consumption (Electricity)

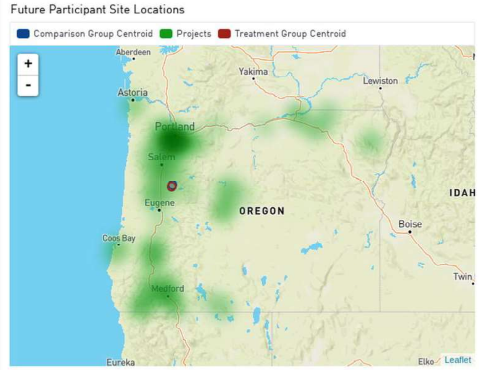
Load Disaggregation



Future Participant Group

The pool of sites that was used to create this group was composed of sites that installed the same measure in the year following the specified program year. The final sites were selected by stratified sampling using deciles of annual energy consumption.

Future Participant Site Locations

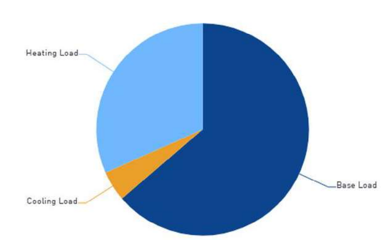


2.3 miles

Distance between treatment and future participant group centroids

3,755	18,420
Meters	Mean Baseline Consumption (Electricity)

Load Disaggregation



2. Data Preparation

Consumption data preparation and cleaning followed best practices defined in the CalTRACK 2.0 billing methods. Some key aspects of the data cleaning process are highlighted here; please see the resources section for links to more detailed documentation. The initial and final sample sizes are shown below along with the percent of the treatment population that is represented by the sample. The sample attrition table shows the impact of each filtering criterion on sample size.

7,398	3,187	43%
Meters in Treatment Population	Final Sample Size	Percent of Treatment Population Represented by Sample

Sample Attrition Table

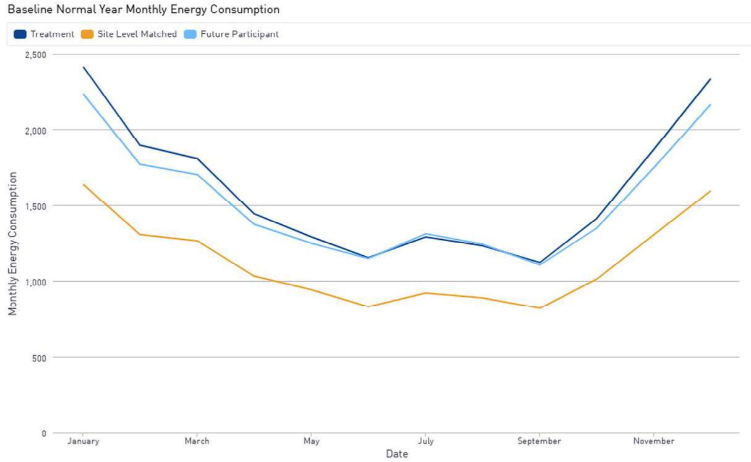
	FILTER NAME	FILTER VALUE	TREATMENT METERS DROPPED	TREATMENT METERS REMAINING
1	Initial treatment population			116150
2	Measure	DUCTEDHEATPUMP-SITE-BUILT	108901	7249
3	Year	2013, 2014, 2015, 2016, 2017, 2018	0	7249
4	Fuel	Electricity	0	7249
5	Valid consumption data in baseline and reporting periods	valid data	0	7249
6	MultiMeasure_Filter: Meters with single/multiple measure installations in baseline and/or reporting periods	--	0	7249
7	HeatingFuel: Meters with a valid heating fuel that corresponds to the selected filter value.	='ELE'	91	7158
8	HeatingZone: Meters in selected heating climate zone.	--	0	7158
9	CoolingZone: Meters in selected cooling climate zone.	--		7158
10	PeriodLength_Threshold: Meters meeting a threshold number of months of valid consumption data.	>=11	1742	5416
11	Meters with at least 5 site-level matched meters from the comparison group pool		0	5416
12	DNAC_Threshold: Meters with normalized change in annual energy consumption under a specified threshold	<1	104	5312
13	DNACPercentile_Threshold: Meters within specified percentile bands of normalized change in annual consumption	Between 0.5 and 99.5	26	5286
14	ConsumptionPercentile_Threshold: Meters within specified percentile bounds of annual energy consumption.	Between 0.5 and 99.5	20	5266
15	R2_Threshold: Meters with valid model R-squared for the baseline and reporting periods that meet a specified threshold. ...	> 0.5	701	4565
16	CVRMSE_Threshold: Meters with valid model CV(RMSE) for the baseline and reporting periods that meet a specified threshol...	< 1	0	4565
17	home_size: Meters with manufactured home size meeting a specific criteria (single-wide, double-wide, or triple-wide)	--	0	4565
18	complex_duct_sealing: Meters with the 'MH Complex Add-On' measure	--	0	4565
19	airduct_type: Meters that used specific measures relevant to Air and Duct Sealing programs	--	0	4565
20	likely_gas_water_heating: Metrs with more than 0.2 therms per day average gas consumption in August.	--	0	4565
21	Electricity Provider	--	0	4565
22	Home Size [Sq Ft]	--	0	4565
23	Water heating fuel type	--	0	4565
24	Heat pump type	HEATPUMPUPG	1338	3227
25	Contractor	--	0	3227
26	Thermostat name	--		3227
27	Heat pump baseline equipment	--	0	3227
28	Heat pump manufacturer	--	0	3227
29	Heat pump comissioning	--	0	3227
30	Multi-measure elec	=false	40	3187
31	Multi-measure gas	--	0	3187

3. Modeling Results

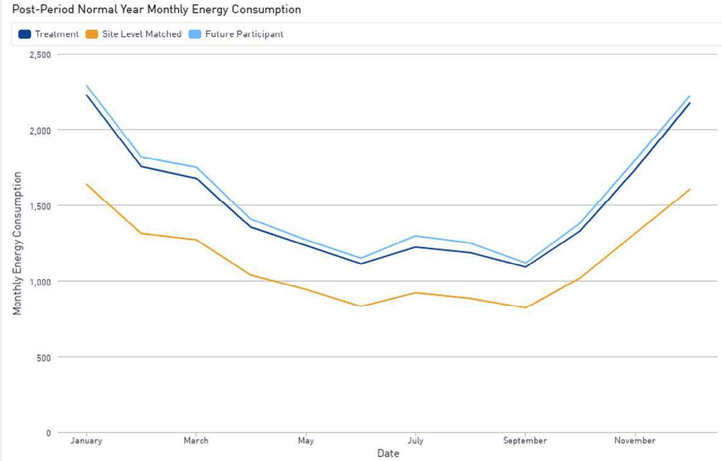
This section includes summaries of the Difference in Normalized Annual Consumption (DNAC) results for the treatment and comparison groups. The time series of monthly energy consumption illustrates the similarities and/or differences in energy consumption for the different groups in the baseline and reporting periods.

Below, you will find a breakdown of the DNAC results by group, showing the histograms of DNAC as well as the mean value expressed in raw units and as a percent of baseline annual consumption. Finally, the distribution of model types in the baseline and reporting periods are also provided as an additional layer of analysis.

Baseline Normal Year Monthly Energy Consumption

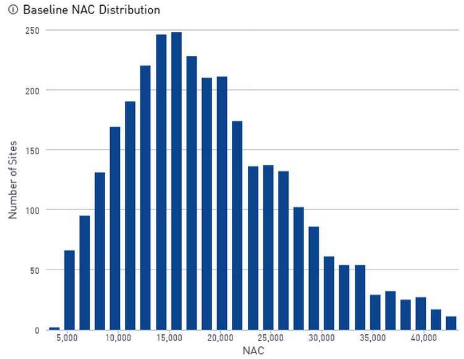


Post-Period Normal Year Monthly Energy Consumption



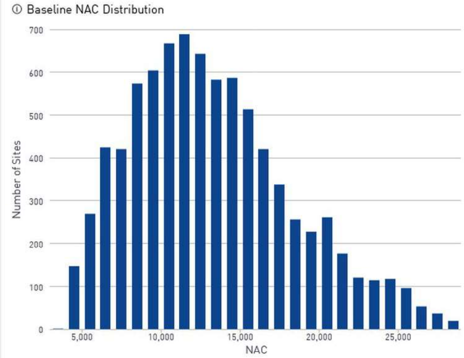
Treatment Group

Baseline NAC Distribution



Site-level Matched Comparison Group

Baseline NAC Distribution

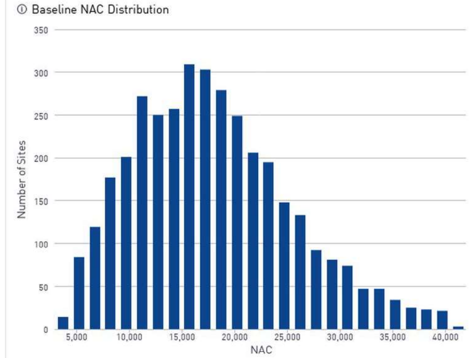


0.0533

Annual Consumption p-value

Future Participant Group

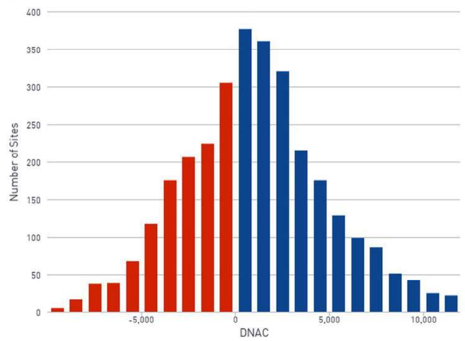
Baseline NAC Distribution



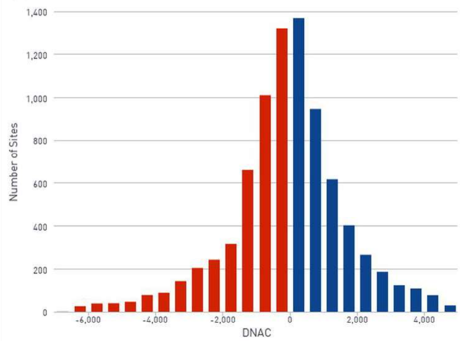
0.00689

Annual Consumption p-value

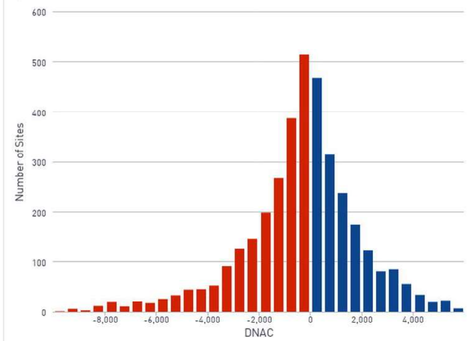
DNAC Distribution



DNAC Distribution

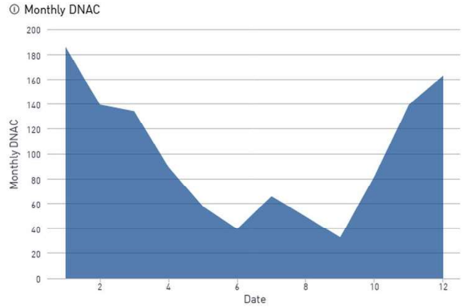


DNAC Distribution

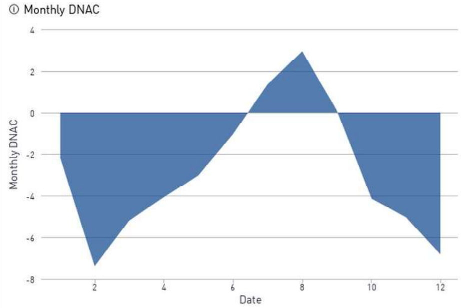


1180 +/- 93 kWh	6 +/- 0 %	-34 +/- 40 kWh	-0 +/- 0 %	-338 +/- 83 kWh	-2 +/- 0 %
Average Difference in Normalized Annual Consumption per Participant	Difference in Normalized Annual Consumption as a Percent of Baseline	Average Difference in Normalized Annual Consumption per Participant	Difference in Normalized Annual Consumption as a Percent of Baseline	Average Difference in Normalized Annual Consumption per Participant	Difference in Normalized Annual Consumption as a Percent of Baseline

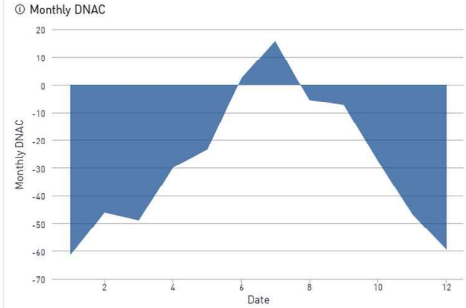
Monthly DNAC



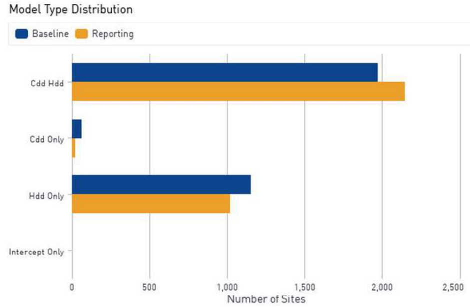
Monthly DNAC



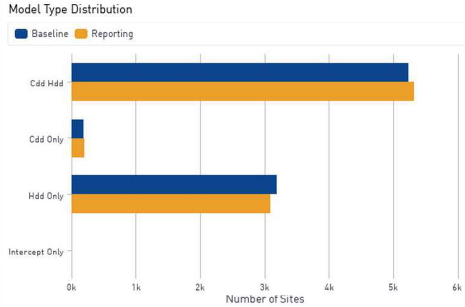
Monthly DNAC



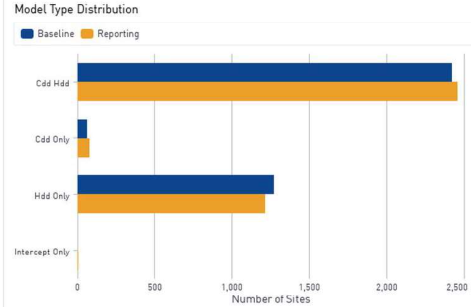
Model Type Distribution



Model Type Distribution

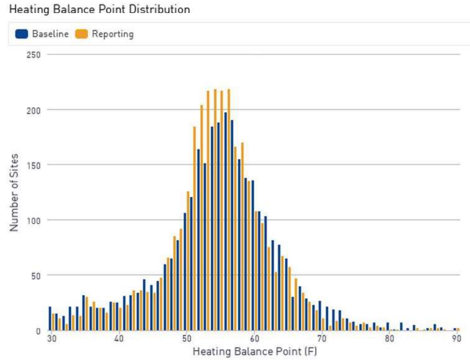


Model Type Distribution

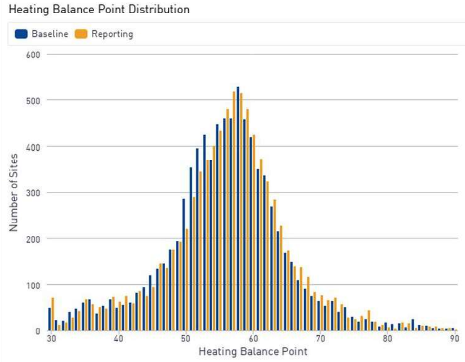


Treatment Group | **Site-level Matched Comparison Group** | **Future Participant Group**

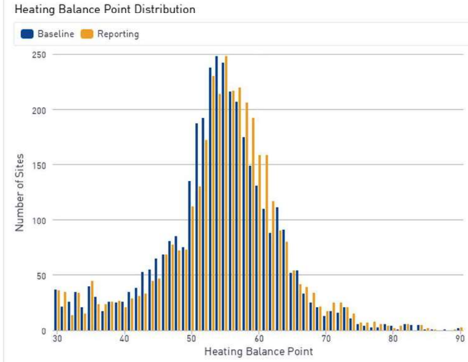
Heating Balance Point Distribution



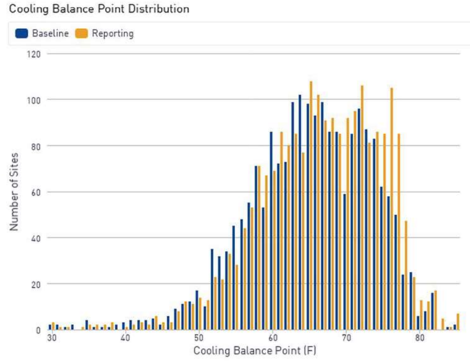
Heating Balance Point Distribution



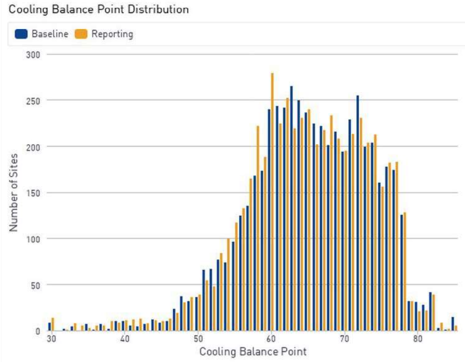
Heating Balance Point Distribution



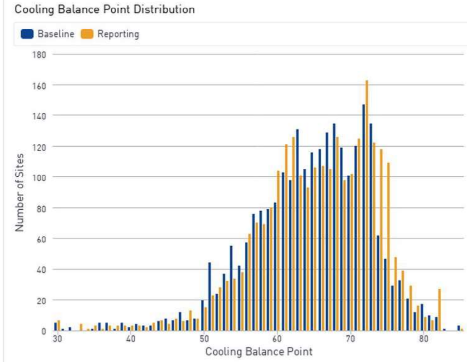
Cooling Balance Point Distribution



Cooling Balance Point Distribution



Cooling Balance Point Distribution



4. Methodology

CalTRACK and Comparison Group Methods
Documentation: docs.caltrack.org
Code: https://github.com/energy-market-methods/caltrack

Data Preparation

Baseline period: Since the predicted baseline may be unstable with different baseline period lengths, which may, in turn, affect calculated savings, the consensus of the CalTRACK 2.0 working group was to set the maximum baseline period at 12 months, since the year leading to the energy efficiency intervention is the most indicative of recent energy use trends and prolonging the baseline period increases the chance of other unmeasured factors affecting the baseline. In addition, CalTRACK uses a minimum 12-month baseline by default.

Blackout period: The blackout period refers to the time period between the end of the baseline period and the beginning of the reporting period. In this analysis, it is specified to coincide with the project installation time period, meaning that the billing period that contains the project installation date is dropped from the analysis.

Analysis periods: Different portions of the analysis used different time periods of consumption data, therefore, it is useful to clearly define these time periods and where they were used. Consider a project with an installation date on a particular day d in a particular month m in a particular program year y. The year before the program year is labelled as y-1, the year prior to that as y-2 and so on, while the years following the program year are labelled y+1, y+2 etc. In all cases, the billing period that contains the project installation was dropped from the analysis. Other sections of the analysis use the following time periods:
- *Treatment and site-level matched groups:* Baseline period includes the 12 months preceding the installation billing period. Reporting period includes the 12 months following the installation billing period.
- *Future participant group:* Baseline period is the calendar year preceding the program year (Year *y-1*). Reporting period is the program year itself (Year *y*).
- Site-level consumption matching was performed using the 12 months of data immediately prior to the project installation date.
- Equivalence tests were performed using data from the previous calendar year (y-1).

Modeling

Weather Normalization: Weather normalization of billing data in CalTRACK follows certain model foundations in literature (PRISM, ASHRAE Guideline 14, IPMVP Option C and the Uniform Methods Project for Whole Home Building Analysis). Building energy use is modeled as a combination of base load, heating load, and cooling load. Heating load and cooling load are assumed to have a linear relationship with heating and cooling demand, as approximated by heating and cooling degree days, beyond particular heating and cooling balance points. A number of candidate OLS models are fit to the consumption data using different combinations of heating and cooling balance points (ranging from 30 to 90 F) and different sets of independent variables. The model with the highest adjusted R-squared that contains strictly positive coefficients is selected as the final model and used to calculate normalized energy usage.

Model Types: CalTRACK specifies a linear relationship between energy use and temperature as reflected in the building consumption profile. In the most generic case, a model would include an intercept term, a heating balance point and heating slope coefficient, and a cooling balance point and a cooling slope coefficient. Depending on the fuel a building uses for heating or cooling or its consumption patterns, models with a single temperature coefficient and balance point (i.e., heating or cooling) may be more appropriate.

Difference in Normalized Annual Consumption (DNAC): The DNAC is calculated by using two CalTRACK regression models in conjunction with Typical Meteorological Year (TMY3) weather data, as follows:
- Two models are fit to the consumption data - one model for the baseline (pre-intervention) period and one for the reporting (post-intervention) period.
- Long-term heating and cooling degree days based on TMY3 data are substituted in both regression equations to calculate the Normalized Annual Consumption (NAC) for each period. TMY3 data is maintained by NREL and includes weather averages for 1020 locations in the US between 1991-2005.
- DNAC is determined by subtracting the two NACs (DNAC = Baseline NAC - Reporting NAC).

Disaggregation: Disaggregated loads are calculated from the different components of the statistical model fit. The weather sensitive components (heating and cooling load) are calculated by multiplying the relevant model coefficients (beta_hdd or beta_cdd) by the total degree days in a normal weather year (total HDD or CDD). For each site, the total HDD or CDD can be calculated using that site's estimated degree day balance points (also an output of the model) and the temperature for its closest weather station. The base load is estimated by multiplying the intercept of the statistical model by the number of days (365 for a full year).

Savings calculation: Savings are calculated by subtracting the DNAC for either comparison group from the DNAC for the treatment group.

Savings Uncertainty: Uncertainty presented in this analysis is calculated using the ASHRAE Guideline 14 formulation for aggregating the prediction uncertainty of point estimates in a time series. It is calculated at a 90% confidence level. The total uncertainty at the site-level is calculated using the sum of squares of the baseline and reporting models. Other aggregate uncertainty values (e.g. for a portfolio or for a difference-in-differences estimate) are also aggregated using the square root of the sum of squares.

Comparison Group Generation

Site-level Matching: In monthly consumption matching, a comparison group is constructed by selecting 20 matches from the comparison group pool with the shortest distance d to the treatment group customer under consideration. After applying the selected filters on the comparison group, the comparison group is filtered down to the closest 5 matches to each treatment group member. The pool is limited to non-participants within the same zipcode as the treatment group customer. The distance d is, in essence, a way to reduce 12 monthly consumption differences between any two customers to one metric (see Figure). In the present analysis, we selected twenty nearest neighbors for each treatment site based on the Euclidean distance of monthly consumption.

Future Participant Groups: Comparison groups comprising future participants are considered to be representative of participants in most aspects (observable and non-observable). For example, future participants are known to be eligible to receive the measure, and for some measures, they may have the same baseline equipment as the participants. Future participants have the same propensity to participate in the program as participants, thus reducing or eliminating self-selection bias, something that is otherwise difficult to control for in a quasi-experimental study. More comprehensive data is typically collected for future participants, allowing for potentially better matching and more insightful analysis. From a practical perspective, future participant groups may be difficult to construct for all measures, unless a program has been running for multiple years and is considered stable with sufficient data collection over the analysis period. Sample sizes for the comparison group may also be constrained if using future participants.

Stratified sampling is applied to future participant groups to attempt to replicate the distributions of the underlying variable (annual consumption) in the comparison group. Annual consumption of all treatment sites is first split into deciles, then a random sample is selected from within each corresponding bin in the comparison group pool of future participants.

Sampling method: In all cases where sampling was required from the comparison group, sampling was performed without replacement.

Impact Evaluation Report

Electricity Impact of Ductedheatpump-Manufactured in Program Year 2013, 2014, 2015, 2016, 2017, 2018

Result Summary

Measure: Ductedheatpump-Manufactured	Program Year: 2013, 2014, 2015, 2016, 2017, 2018		Fuel: Electricity	*Last Consumption Data Update:* Q1 2020 *Last Participation Data Update:* Q1 2020 *CalTRACK Version:* 2.0
Meter Data Filters:	DNAC: <100%	DNAC Percentile: Remove Top and Bottom 0.5%	Annual Consumption Percentile: Remove Top and Bottom 0.5%	
Model Filters:	Period Length: 11 Months or Longer	R-Squared: >0.5	CV(RMSE): < 1	
Metadata Filters:	Cooling Zone(s): All	Heating Zone(s): All	Heating Fuel: Electricity	Heat Pump Manufacturer: All
	Thermostat Name: All	Heat Pump Baseline: All	Multi Measure Filter: Single Measure Only	Heat Pump Adv. Controls or Commissioning: All
	Air / Duct type: All	Home size: All	Complex Duct Sealing: All	LikelyGasWaterHeating: All
Electric Provider: All	Contractor: All	Water Heating Fuel: All	Home Size (SqFt): All	Ducted heat pump type: Heatpumpupg

193 Treatment Meters	1943 +/- 266 kWh Average Normal Year Pre-Post Difference in Consumption per Participant	13 +/- 2 % Percent Normal Year Pre-Post Difference in Consumption per Participant	15,530 Mean Baseline Consumption (Electricity)	153% Realization Rate
343 Site-level Matched Meters	1801 +/- 326 kWh Average Savings Relative to Site-level Matched Comparison Group	12 +/- 2% Percent Savings Relative to Site-level Matched Comparison Group	13,501 Mean Baseline Consumption (Electricity)	142% Realization Rate
279 Future Participant Meters	2153 +/- 350 kWh Average Savings Relative to Future Participant Group	14 +/- 2% Savings Relative to Future Participant Group	14,649 Mean Baseline Consumption (Electricity)	170% Realization Rate

1. Introduction

This report contains the results of applying the two-stage approach (informed by the DOE's uniform methods chapter on whole building analysis) for calculating claimable savings to the selected portfolio of energy efficiency projects (see Figure). This approach begins with identification of two comparison groups for the treatment sample: (a) a site-level matched comparison group and (b) a future participant group. These groups are described below along with summary statistics (site locations, sample size, baseline consumption and baseline load disaggregation).

The CalTRACK methods are then applied to arrive at site-level savings, normalized for weather, and reflective of energy consumption changes for customers at the meter. Using a difference of differences for the treatment group with each comparison group accounts for population-level consumption changes (e.g. economic changes, rate changes, natural energy efficiency adoption etc.). The methods contained within this report are the outcome of a recent peer-reviewed study completed by Energy Trust of Oregon and Open Energy Efficiency (see "Methodology" section for more details).

The report includes the following sections:
Result Summary - Includes the overall portfolio results
Section 1. Introduction - Overview of report and the different groups included in the analysis
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Section 3. Modeling Results - CalTRACK model outputs and Difference in Normalized Annual Consumption (DNAC) results
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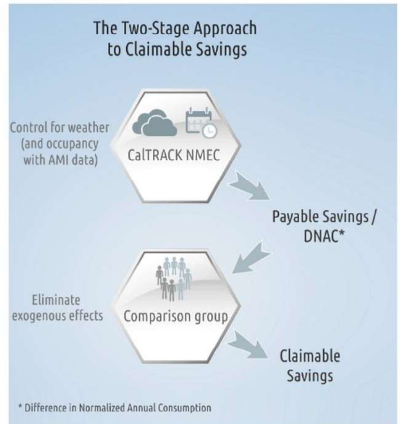
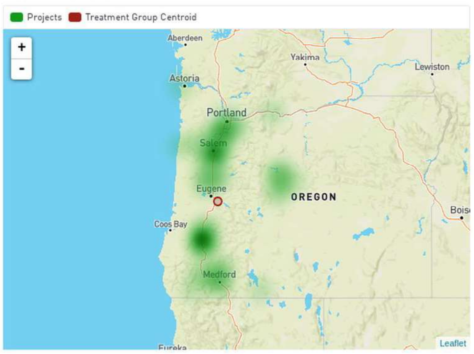
Two-Stage Approach



Treatment Group

The treatment group consists of sites that participated in the specified energy efficiency projects in the specified program year. Only sites that installed single measures are included in the treatment group. And this group includes the subset of sites that had sufficient data quality for modeling.

Treatment Site Locations

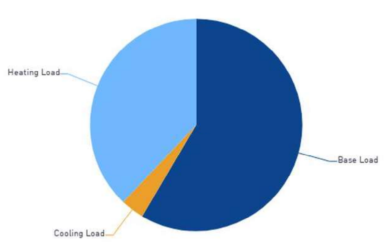


112.8 miles

80% of projects lie within this distance from treatment group centroid

193	15,530
Meters	Mean Baseline Consumption (Electricity)

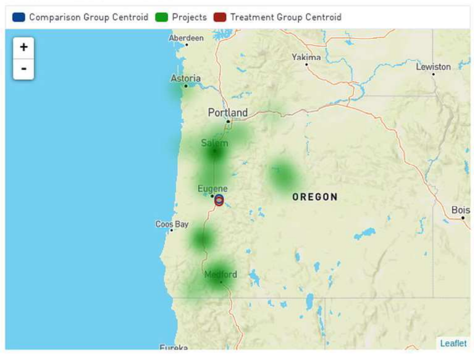
Load Disaggregation



Site-level Matched Comparison Group

This group includes comparison group sites that were matched at the site-level to treatment group sites. Each treatment group site is matched to five comparison group sites from the same zipcode, but only the sites with sufficient data quality were included in the group. Matching was performed using monthly consumption in the baseline period as detailed in the Methodology section.

Site-level Matched Site Locations

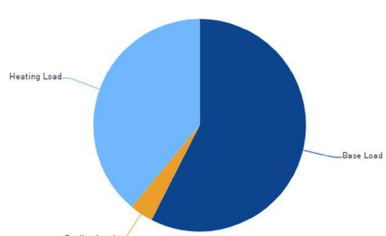


13.4 miles

Distance between treatment and comparison group centroids

343	13,501
Meters	Mean Baseline Consumption (Electricity)

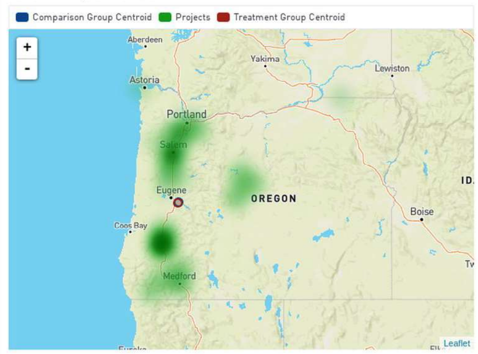
Load Disaggregation



Future Participant Group

The pool of sites that was used to create this group was composed of sites that installed the same measure in the year following the specified program year. The final sites were selected by stratified sampling using deciles of annual energy consumption.

Future Participant Site Locations

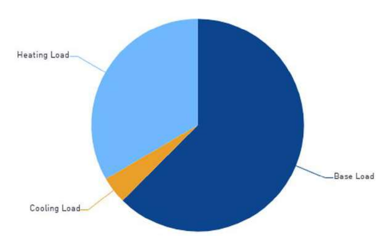


1.8 miles

Distance between treatment and future participant group centroids

279	14,649
Meters	Mean Baseline Consumption (Electricity)

Load Disaggregation



2. Data Preparation

Consumption data preparation and cleaning followed best practices defined in the CalTRACK 2.0 billing methods. Some key aspects of the data cleaning process are highlighted here; please see the resources section for links to more detailed documentation. The initial and final sample sizes are shown below along with the percent of the treatment population that is represented by the sample. The sample attrition table shows the impact of each filtering criterion on sample size.

710	193	27%
Meters in Treatment Population	Final Sample Size	Percent of Treatment Population Represented by Sample

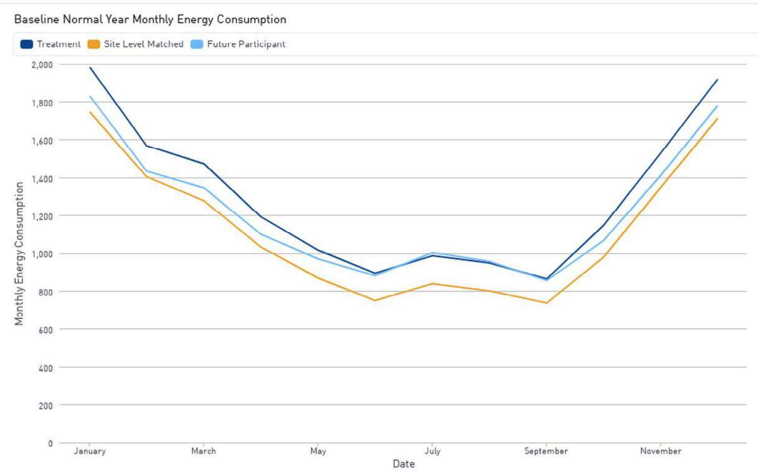
Sample Attrition Table

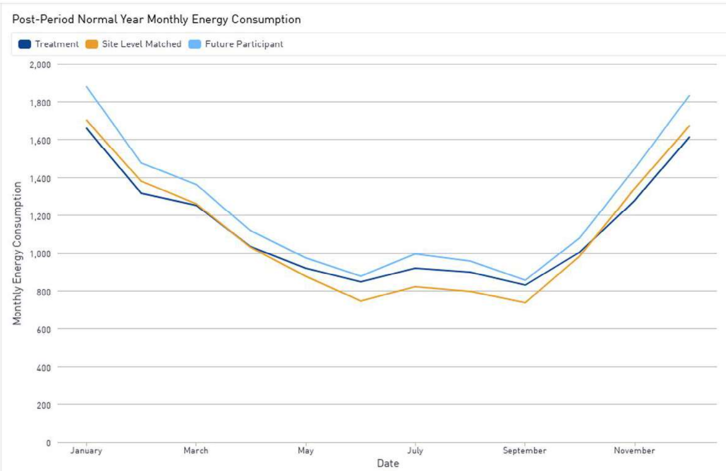
	FILTER NAME	FILTER VALUE	TREATMENT METERS DROPPED	TREATMENT METERS REMAINING
1	Initial treatment population			116150
2	Measure	DUCTEDHEATPUMP-MANUFACTURED	115472	678
3	Year	2013, 2014, 2015, 2016, 2017, 2018	0	678
4	Fuel	Electricity	0	678
5	Valid consumption data in baseline and reporting periods	valid data	0	678
6	MultiMeasure_Filter: Meters with single/multiple measure installations in baseline and/or reporting periods	--	0	678
7	HeatingFuel: Meters with a valid heating fuel that corresponds to the selected filter value.	='ELE'	2	676
8	HeatingZone: Meters in selected heating climate zone.	--	0	676
9	CoolingZone: Meters in selected cooling climate zone.	--		676
10	PeriodLength_Threshold: Meters meeting a threshold number of months of valid consumption data.	>=11	236	440
11	Meters with at least 5 site-level matched meters from the comparison group pool		0	440
12	DNAC_Threshold: Meters with normalized change in annual energy consumption under a specified threshold	<1	2	438
13	DNACPercentile_Threshold: Meters within specified percentile bands of normalized change in annual consumption	Between 0.5 and 99.5	2	436
14	ConsumptionPercentile_Threshold: Meters within specified percentile bounds of annual energy consumption.	Between 0.5 and 99.5	0	436
15	R2_Threshold: Meters with valid model R-squared for the baseline and reporting periods that meet a specified threshold. ...	> 0.5	50	386
16	CVRMSE_Threshold: Meters with valid model CV(RMSE) for the baseline and reporting periods that meet a specified threshol...	< 1	0	386
17	home_size: Meters with manufactured home size meeting a specific criteria (single-wide, double-wide, or triple-wide)	--	0	386
18	complex_duct_sealing: Meters with the 'MH Complex Add-On' measure	--	0	386
19	airduct_type: Meters that used specific measures relevant to Air and Duct Sealing programs	--	0	386
20	likely_gas_water_heating: Metrs with more than 0.2 therms per day average gas consumption in August.	--	0	386
21	Electricity Provider	--	0	386
22	Home Size [Sq Ft]	--	0	386
23	Water heating fuel type	--	0	386
24	Heat pump type	HEATPUMPUPG	189	197
25	Contractor	--	0	197
26	Thermostat name	--		197
27	Heat pump baseline equipment	--	0	197
28	Heat pump manufacturer	--	0	197
29	Heat pump comissioning	--	0	197
30	Multi-measure elec	=false	4	193
31	Multi-measure gas	--	0	193

3. Modeling Results

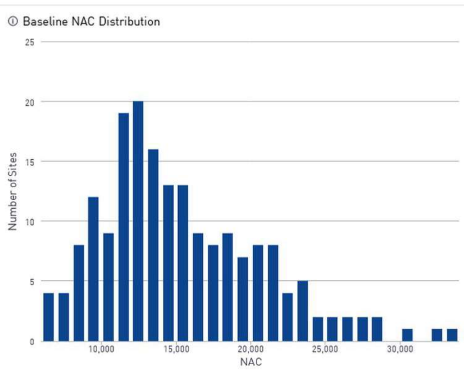
This section includes summaries of the Difference in Normalized Annual Consumption (DNAC) results for the treatment and comparison groups. The time series of monthly energy consumption illustrates the similarities and/or differences in energy consumption for the different groups in the baseline and reporting periods.

Below, you will find a breakdown of the DNAC results by group, showing the histograms of DNAC as well as the mean value expressed in raw units and as a percent of baseline annual consumption. Finally, the distribution of model types in the baseline and reporting periods are also provided as an additional layer of analysis.

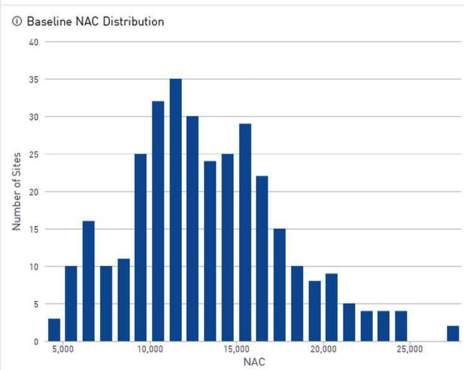




Treatment Group



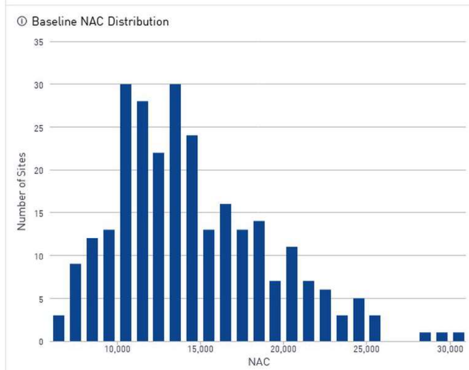
Site-level Matched Comparison Group



0.139

Annual Consumption p-value

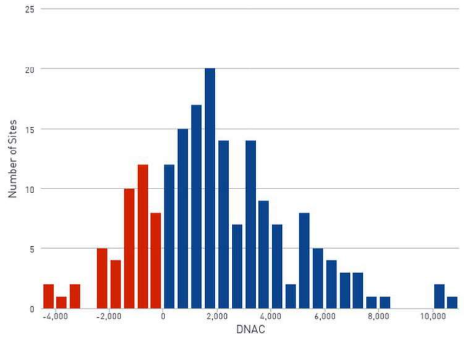
Future Participant Group



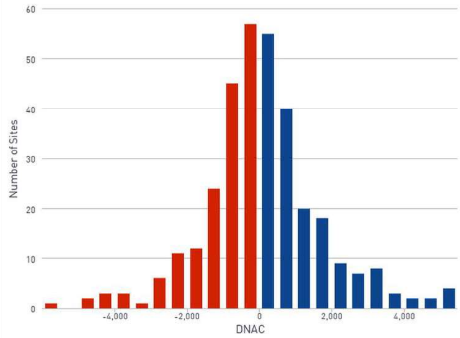
0.0549

Annual Consumption p-value

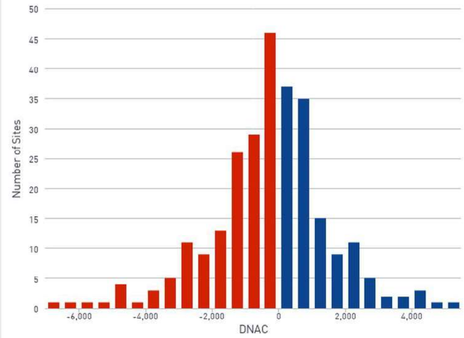
ⓘ DNAC Distribution



ⓘ DNAC Distribution

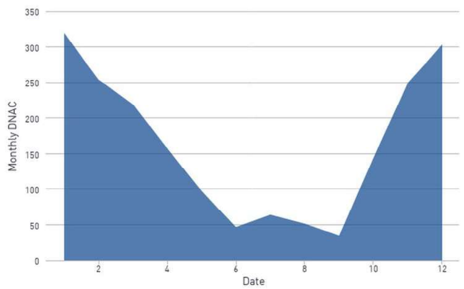


ⓘ DNAC Distribution

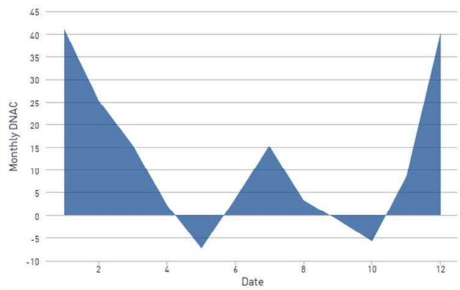


1943 +/- 266 kWh	13 +/- 2 %	142 +/- 188 kWh	1 +/- 1 %	-210 +/- 228 kWh	-1 +/- 2 %
Average Difference in Normalized Annual Consumption per Participant	Difference in Normalized Annual Consumption as a Percent of Baseline	Average Difference in Normalized Annual Consumption per Participant	Difference in Normalized Annual Consumption as a Percent of Baseline	Average Difference in Normalized Annual Consumption per Participant	Difference in Normalized Annual Consumption as a Percent of Baseline

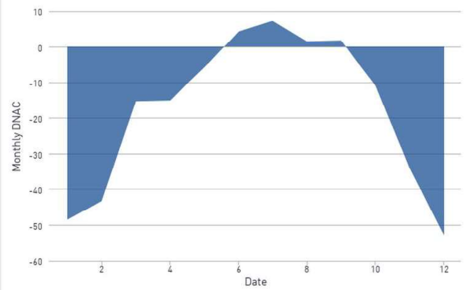
ⓘ Monthly DNAC



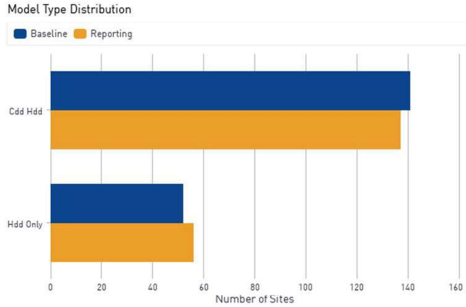
ⓘ Monthly DNAC



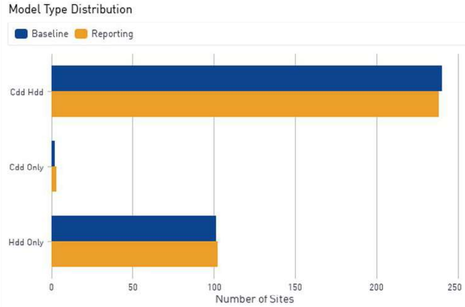
ⓘ Monthly DNAC



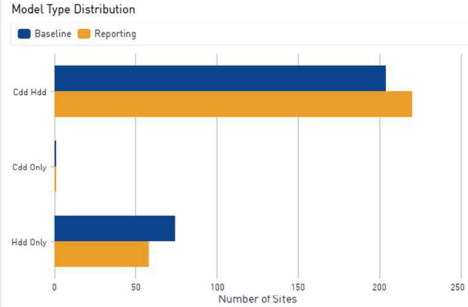
Model Type Distribution



Model Type Distribution



Model Type Distribution

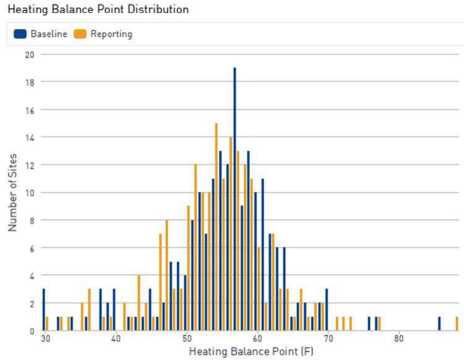


Treatment Group

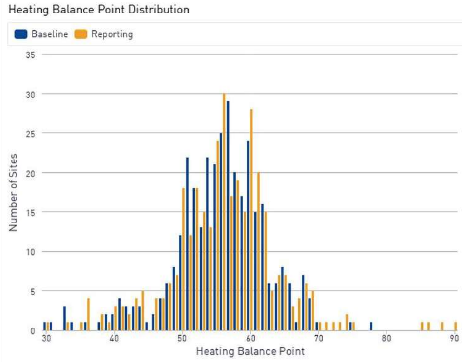
Site-level Matched Comparison Group

Future Participant Group

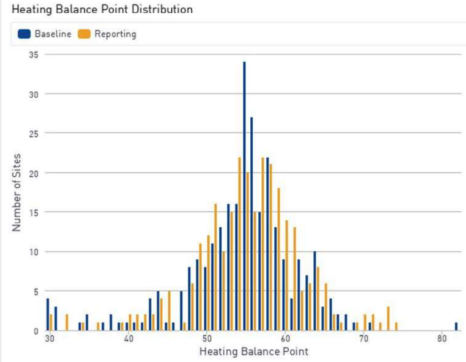
Heating Balance Point Distribution



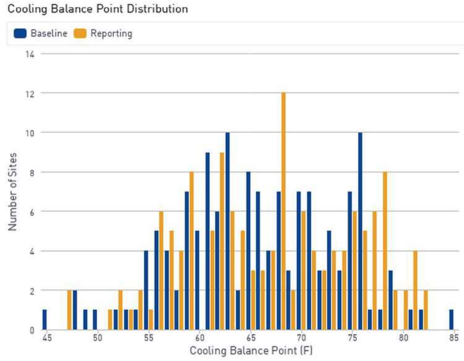
Heating Balance Point Distribution



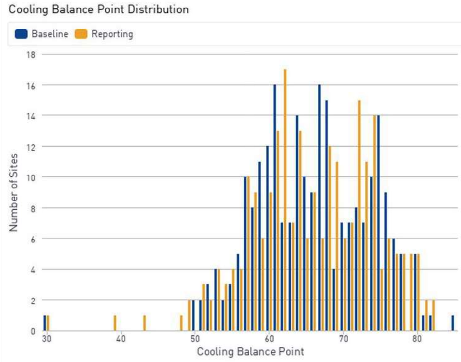
Heating Balance Point Distribution



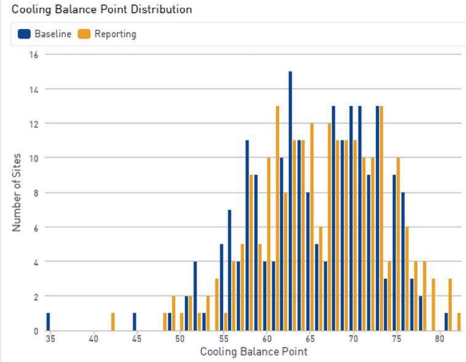
Cooling Balance Point Distribution



Cooling Balance Point Distribution



Cooling Balance Point Distribution



4. Methodology

CalTRACK and Comparison Group Methods
Documentation: docs.caltrack.org
Code: https://github.com/energy-market-methods/caltrack

Data Preparation

Baseline period: Since the predicted baseline may be unstable with different baseline period lengths, which may, in turn, affect calculated savings, the consensus of the CalTRACK 2.0 working group was to set the maximum baseline period at 12 months, since the year leading to the energy efficiency intervention is the most indicative of recent energy use trends and prolonging the baseline period increases the chance of other unmeasured factors affecting the baseline. In addition, CalTRACK uses a minimum 12-month baseline by default.

Blackout period: The blackout period refers to the time period between the end of the baseline period and the beginning of the reporting period. In this analysis, it is specified to coincide with the project installation time period, meaning that the billing period that contains the project installation date is dropped from the analysis.

Analysis periods: Different portions of the analysis used different time periods of consumption data, therefore, it is useful to clearly define these time periods and where they were used. Consider a project with an installation date on a particular day d in a particular month m in a particular program year y. The year before the program year is labelled as y-1, the year prior to that as y-2 and so on, while the years following the program year are labelled y+1, y+2 etc. In all cases, the billing period that contains the project installation was dropped from the analysis. Other sections of the analysis use the following time periods:
- *Treatment and site-level matched groups:* Baseline period includes the 12 months preceding the installation billing period. Reporting period includes the 12 months following the installation billing period.
- *Future participant group:* Baseline period is the calendar year preceding the program year (Year *y-1*). Reporting period is the program year itself (Year *y*).
- Site-level consumption matching was performed using the 12 months of data immediately prior to the project installation date.
- Equivalence tests were performed using data from the previous calendar year (y-1).

Modeling

Weather Normalization: Weather normalization of billing data in CalTRACK follows certain model foundations in literature (PRISM, ASHRAE Guideline 14, IPMVP Option C and the Uniform Methods Project for Whole Home Building Analysis). Building energy use is modeled as a combination of base load, heating load, and cooling load. Heating load and cooling load are assumed to have a linear relationship with heating and cooling demand, as approximated by heating and cooling degree days, beyond particular heating and cooling balance points. A number of candidate OLS models are fit to the consumption data using different combinations of heating and cooling balance points (ranging from 30 to 90 F) and different sets of independent variables. The model with the highest adjusted R-squared that contains strictly positive coefficients is selected as the final model and used to calculate normalized energy usage.

Model Types: CalTRACK specifies a linear relationship between energy use and temperature as reflected in the building consumption profile. In the most generic case, a model would include an intercept term, a heating balance point and heating slope coefficient, and a cooling balance point and a cooling slope coefficient. Depending on the fuel a building uses for heating or cooling or its consumption patterns, models with a single temperature coefficient and balance point (i.e., heating or cooling) may be more appropriate.

Difference in Normalized Annual Consumption (DNAC): The DNAC is calculated by using two CalTRACK regression models in conjunction with Typical Meteorological Year (TMY3) weather data, as follows:
- Two models are fit to the consumption data - one model for the baseline (pre-intervention) period and one for the reporting (post-intervention) period.
- Long-term heating and cooling degree days based on TMY3 data are substituted in both regression equations to calculate the Normalized Annual Consumption (NAC) for each period. TMY3 data is maintained by NREL and includes weather averages for 1020 locations in the US between 1991-2005.
- DNAC is determined by subtracting the two NACs (DNAC = Baseline NAC - Reporting NAC).

Disaggregation: Disaggregated loads are calculated from the different components of the statistical model fit. The weather sensitive components (heating and cooling load) are calculated by multiplying the relevant model coefficients (beta_hdd or beta_cdd) by the total degree days in a normal weather year (total HDD or CDD). For each site, the total HDD or CDD can be calculated using that site's estimated degree day balance points (also an output of the model) and the temperature for its closest weather station. The base load is estimated by multiplying the intercept of the statistical model by the number of days (365 for a full year).

Savings calculation: Savings are calculated by subtracting the DNAC for either comparison group from the DNAC for the treatment group.

Savings Uncertainty: Uncertainty presented in this analysis is calculated using the ASHRAE Guideline 14 formulation for aggregating the prediction uncertainty of point estimates in a time series. It is calculated at a 90% confidence level. The total uncertainty at the site-level is calculated using the sum of squares of the baseline and reporting models. Other aggregate uncertainty values (e.g. for a portfolio or for a difference-in-differences estimate) are also aggregated using the square root of the sum of squares.

Comparison Group Generation

Site-level Matching: In monthly consumption matching, a comparison group is constructed by selecting 20 matches from the comparison group pool with the shortest distance d to the treatment group customer under consideration. After applying the selected filters on the comparison group, the comparison group is filtered down to the closest 5 matches to each treatment group member. The pool is limited to non-participants within the same zipcode as the treatment group customer. The distance d is, in essence, a way to reduce 12 monthly consumption differences between any two customers to one metric (see Figure). In the present analysis, we selected twenty nearest neighbors for each treatment site based on the Euclidean distance of monthly consumption.

Future Participant Groups: Comparison groups comprising future participants are considered to be representative of participants in most aspects (observable and non-observable). For example, future participants are known to be eligible to receive the measure, and for some measures, they may have the same baseline equipment as the participants. Future participants have the same propensity to participate in the program as participants, thus reducing or eliminating self-selection bias, something that is otherwise difficult to control for in a quasi-experimental study. More comprehensive data is typically collected for future participants, allowing for potentially better matching and more insightful analysis. From a practical perspective, future participant groups may be difficult to construct for all measures, unless a program has been running for multiple years and is considered stable with sufficient data collection over the analysis period. Sample sizes for the comparison group may also be constrained if using future participants.

Stratified sampling is applied to future participant groups to attempt to replicate the distributions of the underlying variable (annual consumption) in the comparison group. Annual consumption of all treatment sites is first split into deciles, then a random sample is selected from within each corresponding bin in the comparison group pool of future participants.

Sampling method: In all cases where sampling was required from the comparison group, sampling was performed without replacement.