SINGLE FAMILY RETROFIT

Final Report
2019-2020 Impact and Process Evaluation
Final Report

Puget Sound Energy

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1 EXECUTIVE SUMMARY

This report summarizes the results of the impact and process evaluations of Puget Sound Energy's (PSE) 2019 and 2020 Single Family Retrofit programs.

1.1 Program Description

The Single Family Retrofit programs offer energy saving measures and services to residential customers living in existing single-family buildings. PSE's single family retrofit programs consist of two primary channels, retail programs and contractor-delivered programs. Retail programs include Appliance (Refrigerator) Decommissioning, Retail Showerheads, Retail Appliances, Web Enabled Thermostats, and Residential Lighting. Contractor-delivered programs include gas and electric Single Family Space Heating, gas and electric Single Family Water Heating, Single Family Weatherization, and Residential Windows.

1.2 Research Objectives

There are seven key research questions for this evaluation. Research questions 1 through 4 primarily inform the impact evaluation, while questions 5 through 7 primarily inform the process evaluation.

1. What are the evaluated electric and gas savings?
2. What percent of program measures can be verified as installed and operational?
3. What were the building conditions before program measures were installed?
4. What were the building conditions after program measures were installed?
5. What is the level of awareness that participants have about the program?
6. What is the level of satisfaction that participants and trade allies have with the program and program process?
7. What are the barriers that are preventing more customer participation in the program?

1.3 Impact Evaluation Results

DNV determined that 80% of the savings used to claim measure savings in the tracking data were deemed savings found in the PSE technical reference manual. The remaining 20% were calculated or custom unit savings based on various studies. DNV was also able to verify that 100% of program measures were installed in a remote video survey with program participants. Metered-based energy consumption data analysis indicated that electric installations delivered 85% of claimed savings and gas installations delivered 64% of claimed 2019 and 2020 savings, shown in the final "Total" rows in Table 1 and Table 2, respectively.

A comparison of the program level sum of the total evaluated savings to the claimed savings, labeled "Kit-plus programs" in Table 1, indicate an electric realization rate of 76% for single family weatherization program, 80% for the space heating programs, and 116% for the water heating program. The impact evaluation analysis yielded a savings weighted average of 81% across space heating, water heating, and weatherization program and indicates that four-fifths of the program's kit-plus claimed electricity savings were realized over the two program years of 2019 and 2020. The realization rate for kit-only programs indicate savings that greatly exceed claimed or expected savings per home (383% realization rate).

Table 1. Program level total claimed and evaluated electric savings, 2019-2020

Program Group	No. of Homes	Claimed (kWh)	Evaluated (kWh)	Realization Rate
Kit-plus programs				
Single Family Weatherization	2,349	3,259,779	2,488,060	76%
Space Heat	7,907	18,341,234	14,597,024	80%
Water Heat	967	1,252,791	1,452,955	116%
Total	11,223	22,853,804	18,538,040	81%
Kit-only installations				
All programs	6,542	284,693	1,090,752	383%
All installations				
Total	17,765	23,138,497	19,628,792	85%

The impact evaluation analysis for gas savings programs produced a realization rate of 89% for the single-family weatherization program, 37% for the space heating program, and 93% for the water heating program (Table 2). Homes with kit-only (aerator and showerhead only) installations have average savings per home that exceed the claimed amount with a realization rate of 200%. Overall, gas measures were able to deliver nearly two-thirds of the claimed savings over the two program years.

The realization rate for the gas space heat program is much lower than reported in past evaluations and merits further investigation. We discuss possible explanations for the lower realization rate and research activities to support an investigation into the lower realization rate in Table 4 below.

Table 2. Program level total claimed and evaluated gas savings, 2019-20

Program Group	No. of Homes	Claimed (therms)	Evaluated (therms)	Realization Rate
Kit-plus programs				
Single Family Weatherization	6,887	594,691	529,602	89%
Space Heat	11,683	1,187,383	438,130	37%
Water Heat	2,855	132,104	122,560	93%
Total	21,425	1,914,178	1,090,292	57%
Kit-only installations				
All programs	9,876	102,124	205,934	202%
All installations				
Total	31,301	2,016,302	1,296,226	64%

These evaluation results are based on meter-based energy consumption data analysis, commonly referred to as a billing analysis. A billing analysis assesses changes in consumption for a large subset of program participants controlling for changes in weather and other non-program, exogenous change. Consistent billing analysis methods were applied in all of the analyses in this report. A billing analysis has the potential to be particularly sensitive to the anomalies of household energy consumption that could have been present in the dataset due to the effects of the COVID-19 pandemic. As a result, there is an increased risk that the realization rate results presented in Table 1 and Table 2 are not an accurate representation of energy savings in an average year. In addition to pandemic effects, there are other challenges inherent to billing analysis that could explain anomalous results. We summarize possible reasons for the lower-than-expected realization rate for the Space Heating program in Table 3. The table also contains suggestions for further investigation and monitoring.

Table 3. Possible causes of low realization rates within gas Space Heating program

Possible Cause	Further Investigation
Methodological Unknowns	
COVID-19. The pandemic has created a dramatic non-routine event that has a potential to disrupt the pre-post difference-in-differences methodology.	**Literature review** investigating peer gas heating retrofit program evaluations and pandemic impact on home energy consumption and consumption analyses **Early EM&V** for 2021 and 2022 Single Family Retrofit program to monitor trend
Poorly Matched Comparison Group. The pre-post billing analysis methodology depends on a well-matched comparison group to remove exogenous effects. It is possible that there are unknown differences (e.g., demographics and propensity to participate in efficiency programs) that we were unable to identify.	**Customer surveys** to gather additional data on representative set of comparison group **Customer profile analysis** to explore details of participants and comparison group
Real World Conditions	
Decreasing pre-period participant heating load. It may be that historical participation captures those customers with higher heating loads first. As time goes on, the remaining customers may have lower heating loads. Should this trend continue, lower pre-period heating load will yield a lower magnitude of savings.	**Customer profile analysis** to provide a brief analysis on historic program participation trends that can be easily updated on a recurring basis
Equipment Baseline. Claimed savings assume an 80% AFUE, which is the minimum efficiency required by code, but it is possible that the actual replaced furnaces have a higher efficiency on average, which would reduce measured savings.	**Contractor survey** to better understand the efficiency of the replaced equipment. **Contractor ride-alongs** to track a representative sample of pre-existing heating systems
Unknown Use of Equipment. The gas furnace may be used as backup heat source (where primary may be a heat pump) or the gas furnace may be used as a primary heat source but is significantly supplemented by electric or wood heat.	**Customer survey** to establish self-reported use of heating equipment **Contractor ride-alongs** to track a representative sample of heating system use type
Increased Takeback. It is possible that participants are turning up thermostat setpoints or that smart thermostats may encourage improving comfort over energy savings following the installation of the new furnace (takeback), resulting in an increase in heating consumption.	**Customer surveys** to identify intentional increases in temperature setpoint **Consumption analysis** to identify setpoint

1.4 Process Evaluation Results

We conducted a process evaluation for the purpose of identifying program successes and opportunities for program improvement. Key research questions for the process evaluation focused on sources of program awareness among participating customers, levels of satisfaction among customers and the trade allies who implement the program, and barriers to program participation. The research activities that helped inform the process evaluation included the following:

- Program staff interview
- Online survey with program participants
- Telephone surveys with contractors participating in the program

We asked program respondents how they learned about the program in the online survey. Respondents reported learning about the program most commonly through the PSE website (20%) and through a contractor (20%).

Respondents to the online survey were asked about their satisfaction with various aspects of the program using a 5-point scale, where 5 means “very satisfied” and 1 means “very dissatisfied.” Seven distinct aspects were covered with the intention of capturing key steps of the rebate and installation process, from eligibility requirements to energy savings since receiving upgrades. Respondents were also asked about their satisfaction of the program overall. All categories yielded moderate to high average satisfaction scores, ranging from 4.1 to 4.5. Only one aspect (energy savings since receiving these upgrades) received a 4.1 average satisfaction rating while the other six aspects had high average satisfaction ratings of either 4.4 or 4.5. This suggests that participants are generally satisfied with most aspects of the program.

Participating contractors were asked in the telephone survey to rate their level of satisfaction with multiple aspects of the program, ranging from the website and application process all the way through rebate delivery. The ratings given for all categories were generally high, with the online application process, incentive amounts, and overall satisfaction having the highest average satisfaction score (4.5). Marketing efforts had the lowest average score of 4.2. These results suggest the Single Family Retrofit programs are working well, but there are opportunities to improve certain aspects of the program, such as messaging around energy savings to participants and marketing to contractors.

Participating customers who installed space heating, water heating, and/or weatherization measures were asked if they experienced any non-energy savings benefits, including improved comfort, air quality, safety, or a quieter home. The vast majority of participants (86%) experienced at least one of these benefits.

Contractors were asked about barriers preventing customers from adopting heat pump space and water heaters, both of which represented a high share of the electric savings in the Single Family Retrofit programs in 2019 and 2020. The top barriers to more widespread adoption of these technologies were:

1. Financial barriers, including high up-front cost of the equipment; and
2. Resource barriers, particularly the lack of availability of heat pump equipment due to supply-chain issues caused by the COVID-19 pandemic.

Lastly, contractors were asked about the growth potential for heat pump space and water heating technologies. The contractors generally agreed that the heat pump market is growing and cited recent heat waves in the Pacific Northwest as one of the main drivers of this growth.

1.5 Key Findings and Recommendations

Key findings from this study include the following:

- Electric space heating measures deliver 80% of claimed savings with significant variation of savings in measures delivered midstream versus downstream and between ducted and ductless heat pump systems. The midstream programs appear to have installed a sufficient share of heat pumps that converted gas heating to electric heat to undermine some portion of efficiency savings that were present for electric replacements.
- Gas space heating measures provide 37% of claimed savings, dominated by low realization rates for furnace replacements. Possible reasons for the low realization rate are discussed in Table 3 and Table 22.
- Both electric and gas water heating measures deliver over 90% of claimed savings.
- Electric and gas weatherization measures deliver 76% and 89% of claimed savings, respectively. These results are unlikely to be affected by baseline issues.
- Kit-only electric and gas installations (consisting of aerators and LEDs in the case of the former and aerators and showerheads in the latter) provide savings well in excess of the savings claimed for them. Given the weather-dependent nature of the savings, the installation of more efficient heating equipment that was not claimed through the program is a likely explanation and is supported by the program practice of sending kits to customers who did not qualify for a rebate.
- Results from the participant online survey and contractor phone survey suggest the Single Family Retrofit programs are working well, but there are opportunities to improve certain aspects of the program, such as messaging around energy savings to participants and marketing to contractors. This provides PSE with an opportunity to integrate non-energy benefits more explicitly into marketing material while also explaining that increasing setpoints to improve comfort could lead to higher energy bills.
- While participating contractors see cost as a barrier to adoption of space and water heating heat pump technologies, they generally agreed that the heat pump market is growing and cited recent heat waves in the Pacific Northwest as one of the main drivers of this growth.
- Clarifying measure names will make it easier to understand and analyze the data. Though the tracking data measure names gave some indication of the baseline condition (“from FAF”), the use of the words “from” and “with” can be clearer. For instance, “ductless HP from zonal” would seem to indicate that the zonal electric baseboard heat was removed, as opposed to “ductless HP with EFAF,” which would seem to indicate that the electric forced air furnace was not removed when the new ductless heat pump was added. However, the consumption loadshapes indicated likely supplemental electric heating after the installation of both of those ductless heat pump measure types.

Recommendations based on the key findings are as follows:

- Conduct further research to shed light on the lower-than expected gas heating savings, potentially including:
    - Literature review – establish summary of known and remaining unknown impacts of COVID-19 on consumption and whether it has disrupted savings for other gas heating programs
    - Customer and program profile – Establish trends in program participation and identify whether there are underlying discrepancies between program participants and the general PSE population
    - Customer Survey – Continue to identify whether there are discrepancies between program participants and general PSE population; identify self-reported baseline equipment type and efficiency; identify use of equipment (primary/secondary); identify takeback (increases in post-period thermostat setpoint)

    - Contractor Survey – Identify general equipment baseline and program equipment use (primary or secondary) observations
    - Program Ride-Alongs – Identify sample of equipment baseline and program equipment use (primary or secondary)
    - Updated billing analysis for 2021-2022 single family retrofit gas program – Establish early (and potentially iterative) indication of 2021 and 2022 gas program savings to monitor program performance and determine if low savings trend continues.

- Program staff should coordinate with participating contractors to make sure that they are not overpromising on bill savings that participants see as a result of their program upgrades. Online survey suggest that a segment of program participants may be somewhat disappointed in the energy savings they receive from their upgrades. Contractors should emphasize the non-energy benefits of the program, such as improved comfort, air quality, and reduction in greenhouse gas emissions for electric measures while also explaining that increasing thermostat set points for improved comfort could result in higher energy bills.
- Consider tracking additional detail related to baseline and installation conditions for space heating equipment to support a more nuanced evaluation and provide the program with appropriate attribution. Additional tracking details could include:
    - Existing equipment capacity and efficiency ratings as well as baseline period operations (e.g., typical, broken – unused, broken- used but less efficient).
    - Installation is a like-for-like replacement versus a supplement to existing electric heating system and/or full substitution

2 INTRODUCTION

In this section, we provide an overview of Puget Sound Energy's (PSE) Single Family Retrofit programs, research objectives, impact evaluation methods, and process evaluation methods.

2.1 Program Overview

The Single Family Retrofit programs offer energy saving measures and services to residential customers living in existing single-family dwellings.[1] PSE's single family retrofit program consists of two primary channels, retail programs and contractor-delivered programs.[2] Retail programs include Appliance (Refrigerator) Decommissioning, Retail Showerheads, Retail Appliances, Web Enabled Thermostats, and Residential Lighting. Contractor-delivered programs include gas and electric Single Family Space Heating, gas and electric Single Family Water Heating, Single Family Weatherization, and Residential Windows.

Table 4 summarizes the electricity savings PSE expected from the programs delivering measures to existing single family buildings in 2019 and 2020. Programs that offered measures targeting similar end-uses, provided in the second column, are grouped together. DNV evaluated the electric savings of programs that delivered space heating, water heating, and weatherization measures in both years, which are in light blue highlights. Savings from retail programs were passed through because the programs are well established with consistent savings over time (Appliance Decommissioning, Retail Appliances, Retail Appliance Kits, And Retail Showerheads), have been scaled back dramatically and will likely be discontinued in the coming years (Retail Lighting), or were recently evaluated (Web Enabled Thermostats). Home Energy Assessments were not evaluated because the program was discontinued in the second quarter of 2020.

Table 4. PSE existing single-family electric programs and claimed savings, 2019 - 2020

Program Group	Programs	MWh	
		2019	2020
Space heat	Electric Home Heating, Residential Home Heating Kits, Residential Midstream Home Heating*	9,293	9,214
Water heat	Electric Water Heating, Residential Water Heating Kits, Residential Midstream Water Heating*	534	753
Weatherization	Single Family Weatherization, Residential Windows, Residential Weatherization Kits	1,890	1,454
Residential Lighting	Retail Lighting	73,457	24,551
Home Energy Assessments	Home Energy Assessments	5,651	998
Home Appliances	Appliance Decommissioning, Retail Appliances, Retail Appliance Kits	2,481	1,270
Web-Enabled Thermostats	Web Enabled Thermostats, Web Enabled Thermostat Kits	959	476
Showerheads	Retail Showerheads	1,369	1,052
Total Evaluated		**11,717**	**11,421**
Total Claimed		95,633	39,768

*Offered only in 2020
Sources: 2019 and 2020 Annual Reports of Energy Conservation Accomplishments, Exhibit 1 Savings and Expenditures

Programs that offered gas savings in 2019 and 2020 are grouped similarly. Table 5 provides the gas savings expected from these programs. Like for electric savings programs, DNV evaluated programs that offered space and water heating, and weatherization measures (in light blue highlights) in the two years.

[1] PSE defines single-family buildings as less than or equal to four units on a parcel. For further details, see Puget Sound Energy's 2020-2021 Biennial Conservation Plan: https://www.pse.com/-/media/Project/PSE/Portal/Rate-documents/EES/ees_2020_2021_biennial_conservation_plan_exh_3_update_10_2020.pdf

[2] These program groupings were formerly referred to as direct-to-consumer programs and dealer channel programs, respectively.

Table 5. PSE existing single-family gas programs and claimed savings, 2019 - 2020

Program Group	Programs	Therms	
		2019	2020
Space heat	Natural Gas Home Heating, Residential Home Heating Kits	629,030	565,012
Water heat	Natural Gas Water Heating, Residential Home Heating Kits	66,093	68,362
Weatherization	Single Family Weatherization, Residential Windows, Residential Weatherization Kits	392,942	294,860
Home Appliances	Appliance Decommissioning, Retail Appliances, Retail Appliance Kits	16,950	6,207
Web-Enabled Thermostats	Web Enabled Thermostats, Web Enabled Thermostat Kits	239,865	163,259
Showerheads	Retail Showerheads	38,765	29,351
Total Evaluated		**1,088,065**	**928,234**
Total Claimed		1,383,645	1,127,051

2.2 Research Objectives

There are seven key research questions for this evaluation. Table 6 shows the key research questions and which research activities and data sources served as inputs to help answer each question. Research questions 1 through 4 primarily inform the impact evaluation, while questions 5 through 7 primarily inform the process evaluation. We describe the data sources and research activities in more detail in Section 3 below.

Table 6. Key Research Questions and Associated Research Activities and Data Sources

Research Question	Data Source					
	Consumption Data Analysis	Remote Verification Telephone Surveys	Participant Online Surveys	Trade Ally Telephone Surveys	Program Staff Interviews	Program Tracking Data
1. What are the evaluated electric and gas savings?	■					■
2. What percent of program measures can be verified as installed and operational?		■	■			
3. What were the building conditions before program measures were installed?			■			■
4. What were the building conditions after program measures were installed?		■	■			■
5. What is the level of awareness that participants have about the program?			■	■		
6. What is the level of satisfaction that participants and trade allies have with the program and program process?			■	■		
7. What are the barriers that are preventing more customer participation in the program?				■	■	

2.3 Impact Evaluation Overview

We used data from participants in PSE's 2019 and 2020 Single Family programs to model change in both electric and gas consumption and quantify energy savings. Our analysis was based on a two-stage modeling approach that estimates the effect of program measures on energy consumption. The approach uses variable degree-day PRISM-inspired site-level models combined with a matched comparison group to estimate program-level effects in a difference-in-difference (DID) framework.

The two-stage billing analysis approach has a long track record in energy program evaluation and is attractive for a variety of reasons including:

- Site-level focus
- Full use of weather information at the daily level
- Separation of the weather-normalization process from savings estimation
- Use of a comparison group as a proxy for non-program-related change

This methodology is consistent with the approach laid out in the Uniform Methods Project (UMP) Chapter 8 modeling approach, which provides whole-house savings estimation protocols for energy efficiency interventions that have whole-home impacts like smart thermostats.[3] It is also closely related to all other forms of program analysis that use energy consumption data including time-series and cross-section approaches. Details of the comparison group development, and first stage and second-stage models are described in Appendix C.

Billing analysis' use of historical meter-based energy consumption values makes it an essential empirical analysis approach. Billing analysis assesses changes in consumption for a large subset of program participants controlling for changes in weather and other non-program, exogenous changes. If program activity materially changes the consumption of energy, a billing analysis will quantify that change. A billing analysis has the potential to be particularly sensitive to changes unrelated to the program if those changes are correlated with program activity. The comparison group is developed to address these kinds of issues, but because information on customers is limited, it may not always be fully successful. The anomalies of household energy consumption due to the effects of the COVID-19 pandemic, for example, may not be fully addressed by the inclusion of a comparison group. Furthermore, billing analysis faithfully represents changes from pre-to-post program consumption, whether they fit program assumptions or not. If a replaced furnace is primarily used as a back-up, then the estimated savings for that installation will show relatively low consumption. On the other hand, a billing analysis may pick up measure-related changes in consumption that are not relevant to the claimed measure savings. For example, a heat pump replacement of electric heat will save on heating consumption but is likely to increase cooling consumption. Finally, the billing analysis assumption that the existing unit efficiency is the appropriate baseline against which to estimate savings is not always appropriate.

Despite these complexities and challenges, billing analysis can provide a cost-effective, rigorous test of program assumptions. In fact, during the pandemic, billing analysis has frequently been the only available evaluation option. In this report, the discussion of results includes commentary on possible implications of billing analysis limitations. This includes discussion of how the billing analysis evaluation approach could be responsible for lower or higher than expected results. In the context of the pandemic, it is also possible that the implications for billing analysis are more elusive and confounding. While there are generally many possible explanations for anomalous results, such as the uncharacteristically low realization rate for gas furnaces in the Space Heating program, the presence of COVID-19 disruptions makes it challenging to confidently attribute the low realization rate to program shortcomings.

[3] Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. The Uniform Methods Project. https://www.nrel.gov/docs/fy17osti/68564.pdf

2.4 Process Evaluation Overview

We conducted a process evaluation for the purpose of identifying program successes and opportunities for program improvement. DNV based its process evaluation findings on the perspectives of a range of program sources, including assessing the quality and completeness of program tracking data, interviewing PSE program staff and trade allies, and by examining the program participant experience through an online survey.

2.5 Report Overview

We have organized the remainder of this report as follows:

- Section 3 describes the evaluation's data sources.
- Section 4 details the results of the impact evaluation.
- Section 5 provides the results of the process evaluation.
- Section 6 includes the evaluation's key findings and recommendations.
- Appendix A details the sample design used for the remote verification surveys and participant online surveys.
- Appendix B provides the data collection instruments used for the participant online surveys and trade ally telephone surveys.
- Appendix C details the methods used for the consumption data analysis.
- Appendix D provides additional details on the impact evaluation results.
- Appendix E includes additional tables of demographic results from the participant online survey.

3 DATA SOURCES

This section provides the data sources used to evaluate PSE's single family retrofit programs. These include tracking data, energy consumption data, weather data, program staff interviews, telephone interviews with program contractors, online surveys of participating homes, and virtual site visits to verify program installations. We discuss each source in the sections below.

3.1 Program Tracking Data

PSE's 2019 and 2020 tracking data provided information on the measures installed for the Single Family Retrofit programs and the expected (claimed) savings from these installations. Additionally, the tracking data also provided the names of programs, program participant IDs, and installation dates that DNV used for the evaluation.

Table 7 provides a summary of electric measures installed through the various programs grouped under the Single Family Weatherization, Space, and Water Heating programs. Single Family Weatherization programs offered shell measures to improve the energy efficiency of building envelopes, and the Space and Water heating programs offered efficient heat pumps to improve the HVAC and water heating efficiency of the homes receiving them. Each program group also offered kits consisting of aerators and LEDs; more homes seem to have received these kits than any other measure group, indicating that there were homes that only received kits and nothing else.

Table 7. Summary of SFR installed electric measures by program year, 2019-2020

Program Group	Measure Group	2019			2020		
		Total Savings	No. of Homes	Savings per home	Total Savings	No. of Homes	Savings per home
Single Family Weatherization	Aerator	45,356	2,126	21	13,284	609	22
	Air Sealing	75,038	337	223	67,412	325	207
	Duct Sealing	31,358	34	922	26,942	33	816
	Duct Sealing and Insulation	271,414	146	1,859	156,256	116	1,347
	LED	48,472	2,126	23	13,946	609	23
	Shell Insulation	594,441	403	1,475	494,404	401	1,233
	Ventilation	1,296	14	93	262	2	131
	Windows	822,852	600	1,371	681,623	538	1,267
Space Heat	Aerator	113,264	5,167	22	30,452	1,367	22
	Heat Pump (HP)	4,031,018	1,809	2,228	4,674,773	1,600	2,922
	Heat Pump - Ductless	4,637,929	1,667	2,782	4,473,879	1,998	2,239
	Heat Pump Conversion	313,992	85	3,694	3,528	1	3,528
	HP Sizing and Lock Out	78,750	120	656			
	LED	117,705	5,167	23	31,221	1,367	23
Water Heat	Aerator	18,704	882	21	4,752	224	21
	LED	20,036	882	23	5,071	224	23
	Water Heater - Heat Pump	495,417	377	1,314	690,252	509	1,356

Table 8 summarizes the gas saving measures offered by the Single Family Retrofit programs. The programs provided shell, home heating, and water heating measures. As with electric programs, the gas programs also offered kits that delivered aerators and showerheads to participating homes. Additionally, more homes received aerators and showerheads than any other measures aimed at reducing gas consumption. The programs also installed a large number of efficient furnaces, which were the next most commonly installed gas savings measures through the programs in 2019 and 2020.

Table 8. Summary of SFR installed gas measures by program year, 2019-2020

Measure Group	Measure Group	2019			2020		
		Total Savings	No. of Homes	Savings per home	Total Savings	No. of Homes	Savings per home
Single Family Weatherization	Aerator	14,208	6,342	2	3,103	1,346	2
	Air Sealing	17,937	1,332	13	16,907	1,220	14
	Duct Sealing	6,624	156	42	5,910	122	48
	Duct Sealing & Insulation	77,625	1,035	75	60,747	802	76
	Shell Insulation	97,149	1,411	69	90,884	1,291	70
	Showerhead	78,926	6,888	11	17,074	1,384	12
	Thermostat ESS				8,976	272	33
	Windows	100,474	1,006	100	91,260	932	98
Space Heat	Aerator	10,857	5,414	2	2,617	1,281	2
	Boiler	6,902	58	119	6,783	57	119
	Fireplace	31,824	415	77			
	Furnace	551,540	4,995	110	534,600	4,843	110
	Showerhead	12,510	2,552	5	3,082	628	5
	Space and Water Heater	15,397	89	173	17,930	99	181
Water Heat	Aerator	2,614	1,271	2	657	318	2
	Showerhead	3,131	639	5	794	162	5
	Water Heater - Storage	3,400	123	28	3,416	121	28
	Water Heater - Tankless	56,949	1,115	51	63,495	1,241	51

3.2 Deemed Savings Documentation

The deemed savings are documented in the PSE technical reference manual (TRM) and associated detail files. We obtained a copy of the PSE technical reference manual dated November 20, 2020. We obtained detailed files only for measures listed in the PY2019-2020 tracking data that did not have a value in the PSE TRM unit savings field.

3.3 Consumption and Weather Data

DNV used energy consumption data obtained from PSE to analyze energy use patterns and changes related to the installation of the measures installed by the SF Retrofit program. The consumption data included daily electricity and gas consumption for all of PSE's residential customers from January 2018 through June 2021. DNV also received supplementary information, primarily account open dates and dwelling types, on residential customers used in the study.

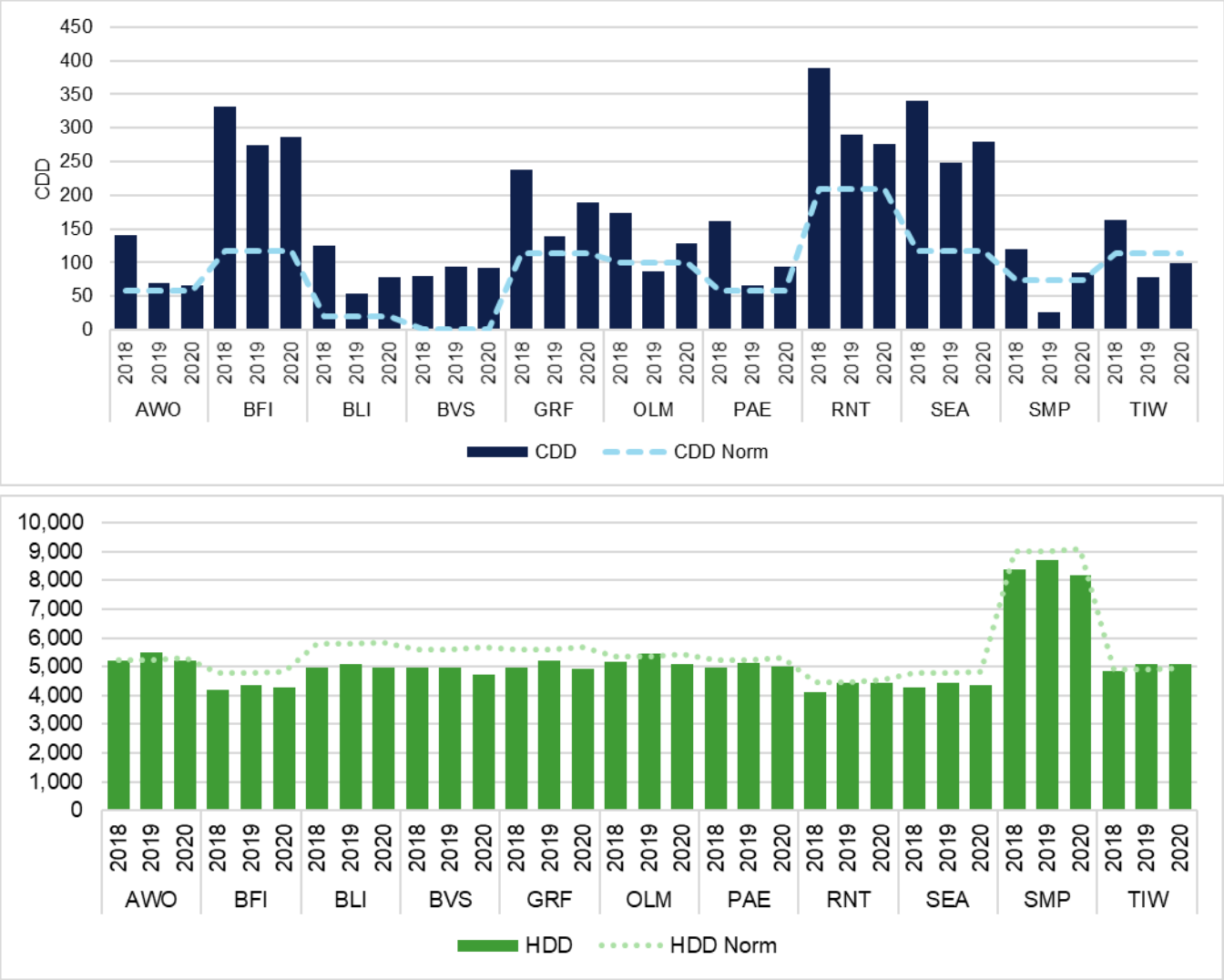
The energy consumption data DNV received served three primary purposes. First, they were used to identify customers who did not get program-provided measures (non-participants) and whose energy use patterns can help inform baseline energy consumption. Second, they served as the basis for site-level modeling used to weather normalize energy consumption. Finally, daily data were included in models used to estimate the effect of the program/measure on energy use. Additional information on data preparation and modeling is provided in Appendix C.

We used weather data to put energy consumption on the same weather basis to facilitate the comparison of energy consumption pre-and post-installation. We sourced weather data for 11 weather stations within PSE's service territory from Automated Surface Observing Systems (ASOS), joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD).[4] We obtained average daily typical meteorological year (TMY) weather data for the selected weather stations that are useful for long-term weather normalization from the National Oceanic

[4] https://www.weather.gov/asos/asostech

and Atmospheric Administration (NOAA). Figure 1 provides a summary of cooling degree days (CDD) and heating degree days (HDD) based on these data.[5] Both the CDD and HDD panels indicate that all years had more cooling and fewer heating degrees than normal.[6] The CDD panel indicates that pre-program periods, spanning part of 2018 and 2019, were slightly hotter than post-installation periods, though CDD levels are low throughout. The HDD panel indicates much higher levels of degree days with less obvious variation in heating weather pre- to post-installation periods.

Figure 1. Summary of weather data degree days calculated from a base of 65 degrees, 2018-2020



3.4 Program Staff Interview

The program staff interview took place in July of 2021 and included the Single Family Space Heating, Water Heating, Weatherization, Windows, and Web Enabled Thermostats program managers. The primary goals of the program staff interview were to understand any recent and planned program changes, barriers to program participation, marketing and

[5] HDD and CDD are daily degrees below and above a base temperature, respectively. In this case both HDD and CDD are calculated with average daily temperatures relative to 65 degrees and then summed across the year. Norm CDD and HDD are calculated using the TMY data. TMY data are historical and are not always reflective of recent weather trends. For example, the BVS station TMY data indicate that typical average daily temperatures did not exceed the base temperature for the full year.

[6] For further details on the locations of the weather stations presented in this figure, please see: https://www.faa.gov/air_traffic/weather/asos/?state=WA

outreach efforts of the program, and PSE's interactions with the Trade Ally Network (TAN). Evaluators also asked PSE program staff to characterize the quality control processes they use with respect to the installation of program measures.

3.5 Contractor Telephone Survey

PSE provided DNV with the list of 78 HVAC and water heater contractors that are currently part of PSE's Trade Ally Network (TAN). These contractors are independent recommended energy professionals who help residential customers find and apply for rebates or incentives and are trained to assist with a variety of heat pump-related services and installations.

This survey was conducted via telephone and included 40 questions that supported the process evaluation research objectives. Survey questions aimed to provide insight into program satisfaction, barriers to program participation, and market trends surrounding space and water heat pump technologies. PSE sent an advanced notification email on September 22th, 2021 to contractors requesting their participation in this telephone survey.

DNV attempted a census of the 78 HVAC and water heater contractors, with a target of 25 completed surveys. The telephone survey was effort was launched on September 29th, 2021 and remained open until November 2nd 2021. DNV made initial outreach to contractors in a randomized order, and then followed up with non-respondents at least two times throughout the course of the survey period. DNV completed surveys with 22 of the 78 contractors in the population, resulting in a response rate of 28%.

3.6 Virtual Verification

The virtual site verification process was conducted by DNV engineers with the use of the Blitzz application. The Blitzz application provides a secure live video feed between the cell phone of the program participants and a DNV engineer. Each virtual call made using the Blitzz platform produces a call summary report which details the time, date, photos captured during the call, and any notes captured by the DNV interviewer. This approach enabled DNV to safely and conveniently verify whether individual program measures are still present and operating at the claimed residential locations.

With the assistance of the resident, DNV engineers captured photos of both the program measures and equipment nameplate data during the virtual site visits. The make and model number from the nameplate photos taken at the virtual visit were compared to the program tracking data for each home. The installation address and date were verified along with general questions to ensure the measure is still operational and the correct quantity was installed. Home building characteristics were also collected to verify claim details about year built, dwelling type, heating fuel type, and primarily heating equipment type. Measures targeted for the virtual verification effort included:

- Natural Gas Home Heating
- Electric Home Heating
- Electric Water Heating
- Residential Midstream Home
- Residential Windows
- Single Family Weatherization

For measures like residential windows and weatherization, DNV engineers asked residents to show them examples of the installed measure that they could safely access.

In designing the sample for the verification effort, the program electric measures were categorized into five measure groups: electric home heating, electric water heating, residential midstream home, residential windows, and single-family

weatherization. Table 9 shows the targeted number of completes alongside the number of completed virtual site inspections by stratum. The electric home heating group consists of three strata due to the large quantity of savings attributed to this group. The electric water heating, residential midstream home, residential windows, and single-family weatherization groups each have one stratum.

Table 9. Program Electric Measures: Targeted and Actual Completed Surveys by Stratum

Program Electric Measures	Strata	Sample Target	Completed
Electric Home Heating	Eheat-1	10	7
	Eheat-2	10	8
	Eheat-3	10	9
Electric Water Heating	EDHW-1	5	4
Residential Midstream Home	ResMidH-1	5	3
Residential Windows	EResWin-1	5	2
Single Family Weatherization	ESFWth-1	5	3
Total		50	36

The program gas measures were broken out into three measure groups: natural gas home heating, residential windows, and single family weatherization. Table 10 shows the targeted number of remote verification completed surveys alongside the quantity of completed remote site inspections by stratum. The natural gas home heating group consists of three strata due to the large quantity of savings attributed to this group. The residential windows and single family weatherization groups each have one stratum. For further details on the sampling approach for the remote verification surveys, please see Section 7.1.1 in Appendix A.

Table 10. Program Gas Measures: Targeted and Actual Completed Surveys by Stratum

Program Gas Measures	Strata	Sample Target	Completed Surveys
Natural Gas Home Heating	NGHHeat-1	5	1
	NGHHeat-2	5	3
	NGDHW-1	5	4
Residential Windows	ResWind-1	5	4
Single Family Weatherization	SFWeath-1	5	3
Total		25	15

We stopped the virtual verification effort before the sample target was reached for both electric and gas measures due to the low number of remaining sample points and because our virtual verifications showed 100% installation rate, higher than what was assumed when the sample was drawn.

3.7 Participant Online Surveys

PSE provided DNV with the 2019 and 2020 population of Single Family Retrofit program participants. Prior to launching the survey, evaluators cleaned the participant tracking data. Following this, we wrote and programmed the online participant survey.

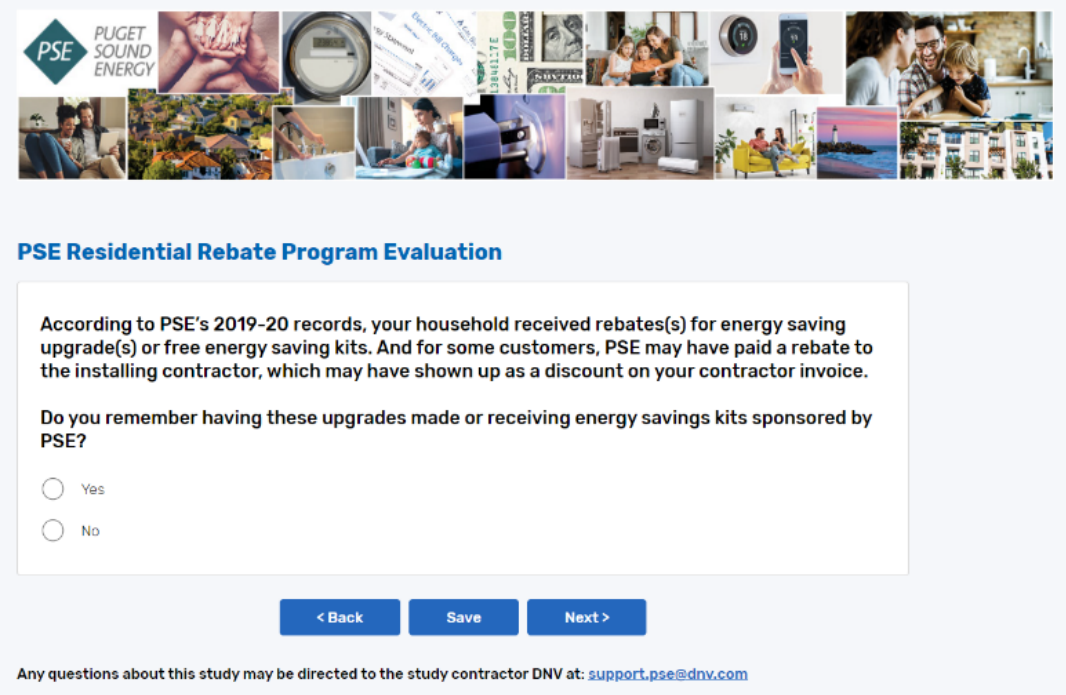
The survey included questions to support both the impact and process evaluation research objectives. For the process evaluation we aimed to find out reasons for participation, satisfaction with program delivery, and improvements in level of comfort.

The survey invitation was delivered to participant's email and included the following features:

- Branded with a PSE logo in both the email and landing page
- Contained an authorized contact within PSE to verify the authenticity of the request
- Included a PSE email/domain name Re: "PSE Residential Energy Study" pseresidentialstudy@pse.com
- Included a unique traceable hyperlink with custom information for each respondent including the participant service address and key measures of interest for impact/verification purposes.
- To motivate respondents to participate in the online survey, we offered two lottery e-gift card incentives of $300 and $200. If respondents completed the survey within the first week of the survey launching, they would qualify for the larger of the two incentives.
- All respondents were provided the option to opt-out of the survey and opt-out of the incentive.

Figure 2 shows the landing page participants view upon accessing the survey.

Figure 2. Participant Survey Landing Page



The survey was launched on September 9th, 2021 and remained open until October 3rd 2021. Non-respondents received up to two reminder emails to complete the survey. Table 11 shows the number of completed and partially completed surveys and response rate. The overall reponse rate was 21%.

Table 11. Participant Surveys Completed and Response Rate

Online Survey Results	Overall
Completed	2,140
In Progress	296
Not Started	7,926
Total Sent	10,362
Response Rate	**21%**

4 IMPACT EVALUATION RESULTS

We provide the results of our impact evaluation including a review of deemed savings, verification of installed measures, and energy consumption changes from installed measures in this section.

4.1 Results Overview

DNV was able to determine 80% of the ex-ante savings used to claim measure savings in the tracking data were deemed savings found in the PSE TRM. The remaining 20% were calculated or custom unit savings based on various studies. Evaluators were also able to verify that 100% of the measures in the remote verification survey were installed. Metered-based energy consumption data analysis indicated that electric installations delivered 85% of claimed savings and gas installations delivered 64% of claimed savings.

4.2 Reported Savings

We performed a review of the reported savings in the tracking data by comparing claimed savings to the deemed savings documented in the PSE technical reference manual (TRM). On a savings basis, 80% of the claims in the tracking data easily matched deemed measure savings in the PSE TRM. DNV and PSE are identifying ways to streamline verification efforts in the future for the remaining 20% of claims. These include:

1. Tracking data can report savings units per ton or per Btu/h
2. When kWh and/or therms savings were missing from the TRM, we noted that the “UnitType” was listed as “custom” or “calculated.” For this set of measures, we obtained detailed “measure case” files from PSE to perform further investigation.

For measures with calculated or custom unit types, the savings were generally taken from Regional Technical Forum (RTF) workbooks, whitepapers, or previous evaluations, and then adjusted to be more specific to PSE’s service area and individual projects. Thus, not all measures with claimed savings are strictly deemed, but instead have reported savings that account for variation in climate zone and building type and are based on a lookup table or simple formula.

4.3 Verification Results

Evaluators completed a total of 51 gas and electric measure remote verification surveys and were able to verify that all 51 of these primary measures were installed and operational (100% of measures were verified). For further details on the sampling approach for the remote verification surveys, please see Section 7.1.1 in Appendix A or Section 3.6.

Table 12 shows the number of completed surveys, number of primary electric measures verified, and the percent of electric measures verified by stratum. A total of 36 primary measures were verified resulting in 100% verification rate for the program electric measures.

Table 12. Electric Measures Verification Results

Program Electric Measures	Strata	Completed Surveys	Primary Measures Verified	% Verified
Electric Home Heating	Eheat-1	7	7	100%
	Eheat-2	8	8	100%
	Eheat-3	9	9	100%
Electric Water Heating	EDHW-1	4	4	100%
Residential Midstream Home	ResMidH-1	3	3	100%
Residential Windows	EResWin-1	2	2	100%
Single Family Weatherization	ESFWth-1	3	3	100%
Total		36	36	100%

Table 13 shows the number of completed surveys, number of primary gas measures verified, and the percent of gas measures verified by stratum. A total of 15 primary measures were verified resulting in 100% verification rate for the program gas measures.

Table 13. Gas Measure Verification Results

Program Gas Measures	Stratum	Completed Surveys	Primary Measures Verified	% Verified
Natural Gas Home Heating	NGHHeat-1	1	1	100%
	NGHHeat-2	3	3	100%
	NGDHW-1	4	4	100%
Residential Windows	ResWind-1	4	4	100%
Single Family Weatherization	SFWeath-1	3	3	100%
Total		15	15	100%

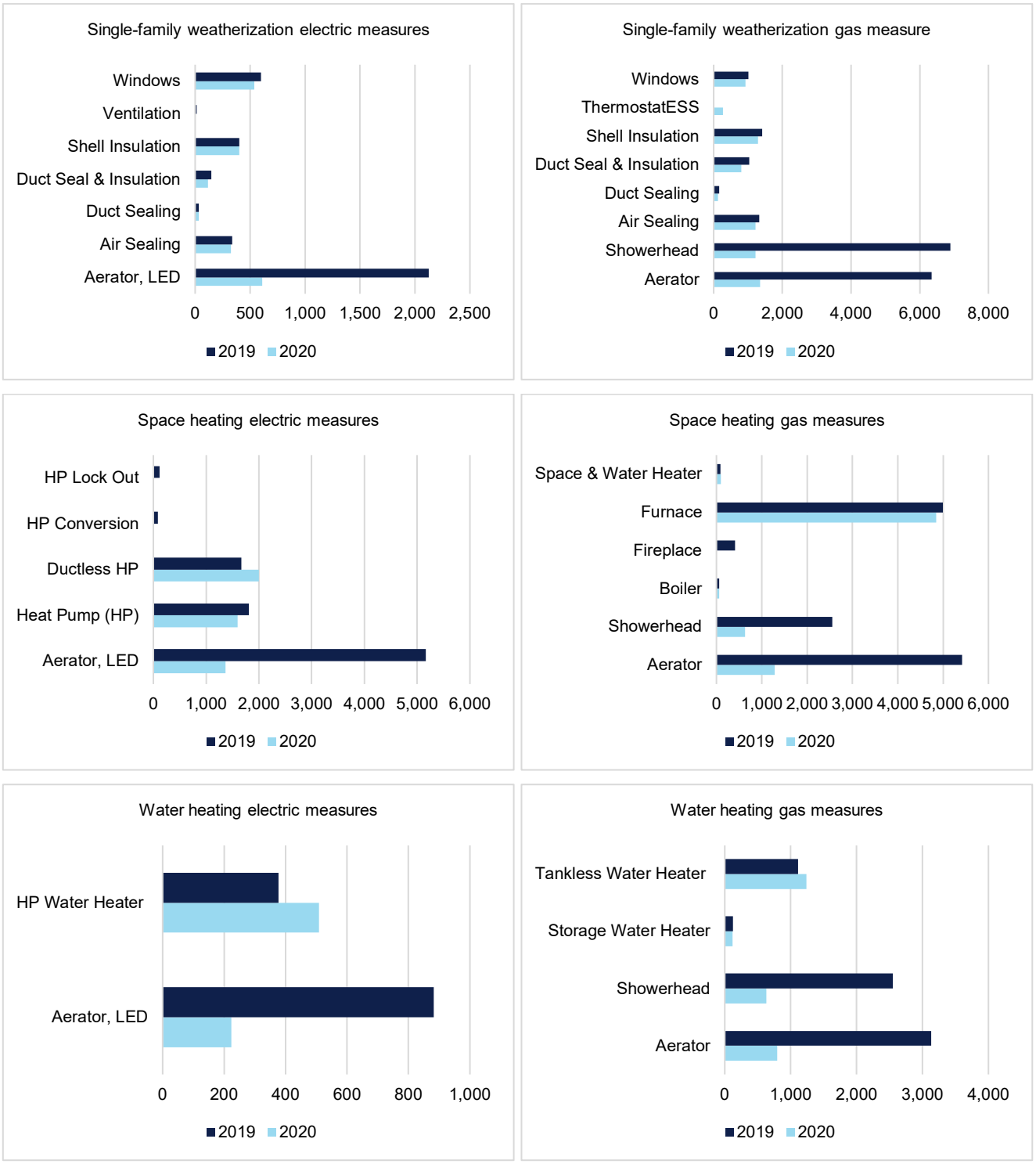
4.4 Evaluated Savings Results

We evaluated the energy consumption impact of measures installed through PSE's Single Family Retrofit programs using consumption data analysis. We used two primary models for this purpose. First, we used site-level models to control for the effect of weather on energy consumption. Second, we used difference-in-difference (DID) models to model change in weather normalized energy consumption post-program intervention. These models were based on data from participants and matched non-participants. We provide details on modeling and data preparation in Appendix C.

PSE's SFR programs installed electric and gas savings measures through three program groups: Single Family Weatherization, Space Heating, and Water Heating programs. The first program group offered measures to improve building envelope, and the second and third offered space and water heating measures. Each program group also offered kits consisting of aerators and LEDs (electric programs) or aerators and showerheads (gas programs).

Figure 3 provides the list of measures and the number of homes receiving the measures in each program group by fuel. As the panels in the figure indicate, a large number of homes that received aerators and LEDs, and aerators and showerheads did not install other shell, space, and water heating related program measures.

Figure 3. SFR programs electric and gas measures, 2019 – 2020



Due to the presence of a large number of homes that installed kit-only measures, we evaluated the energy saving impact of kit-only installations separately from homes that installed kits along with other measures (kit-plus). We examined the energy savings impact of kit-plus single family weatherization, kit-plus space heating, and kit-plus weather heating programs for

each fuel separately from kit-only programs. Since the kit-plus programs involved the installation of different mixes of measures, we estimate savings per home for each kit-plus program separately, while we estimate a single electric and gas savings per home for kit-only installations. Thus, we use data from all homes that received kit-only installations from the three different programs to estimate a single electric and gas savings per home.

Table 14 presents the number of participating households whose consumption data were included in the analysis. The table tracks the attrition of available data based on analysis requirements as described in the table.

Table 14. Household data attrition used in the analysis, 2019-2020

Single family retrofit analysis data attrition	Electric	Gas
Number of customers with savings claims	16,354	28,137
Number of customers not participating in other programs	15,229	25,621
Number of customers with any usable energy use data*	10,669	12,464
Number of customers with sufficient pre-and post-data used in kit-only analysis	1,670	875
Number of customers with sufficient pre-and post-data used in kit-plus analysis	4,969	7,795

*Customers without multiple meters, negative reads, zero reads (for electric), and zero annual reads

We detail the results below, but our analysis indicates that:

- Electric and gas weatherization measures deliver 76% and 89% of claimed savings, respectively
- Electric space heating measures deliver 80% of claimed savings while gas space heating measure provide 37% of claimed savings
- Both electric and gas water heating measures deliver over 90% of claimed savings
- Kit-only electric and gas installations (consisting of aerators and LEDs in the case of the former and aerators and showerheads in the latter) provide savings well in excess of the savings claimed for them

Table 15 provides estimates of electric savings per home for homes that participated in programs that delivered shell, space heating, and water heating measures. It provides the savings from kit-plus programs that delivered measures along with kits and from kit-only installations from all the programs. We should note that kits were retired in 2020, so not all rebated projects received a kit in the 2020 program year. Average estimated electric savings per home for kit-plus programs, which includes the savings of the different mix of measures including kits (aerators and LEDs), are 1,059 kWh for the Single Family Weatherization program, 1,846 kWh for the Space Heating program, and 1,503 kWh for the Water Heating program. These savings are 6% to 10% of total annual electricity use. The average savings per home for participants that received kits-only, which consisted mostly of 2 aerators and 2 LEDs, is 167 kWh or 1.4% of annual electricity consumption.

Table 15. Claimed and estimated electric savings per home, 2019-2020

Program Group	Claimed (kWh)	Evaluated (kWh)	Average Annual Consumption (kWh)	% Consumption Savings
Kit-plus installations				
Single Family Weatherization	1,388	1,059	16,510	6%
Space Heat	2,320	1,846	17,612	10%
Water Heat	1,296	1,503	19,112	8%
Kit-only installations				
All programs	44	167	11,600	1.4%

To calculate total evaluated savings, we multiplied the estimated savings per home by the number of participating homes for each program. A comparison of the sum of the total evaluated savings to the claimed savings indicate an electric realization

rate of 76% for Single Family Weatherization program, 80% for the Space Heating programs, and 116% for the Water Heating program (Table 16). The electric realization rate for kit-plus programs is 81% and indicates that four-fifths of the program's kit-plus claimed electricity savings were realized over the two program years of 2019 and 2020. The realization rate for kit-only programs indicate savings that exceed claimed or expected savings per home. Taken together, the overall realization rate for Single Family Retrofit electric programs is 85%.

Table 16. Program level total claimed and evaluated electric savings, 2019-2020

Program Group	No. of Homes	Claimed (kWh)	Evaluated (kWh)	Realization Rate
Kit-plus programs				
Single Family Weatherization	2,349	3,259,779	2,488,060	76%
Space Heat	7,907	18,341,234	14,597,024	80%
Water Heat	967	1,252,791	1,452,955	116%
Total	11,223	22,853,804	18,538,040	81%
Kit-only installations				
All programs	6,542	284,693	1,090,752	383%
All installations				
Total	17,765	23,138,497	19,628,792	85%

We provide analogous estimated savings per home for gas installations in Table 17. As the table indicates, gas savings per home were 77 therms for homes in the Single Family Weatherization program, 38 therms for homes in the space heating program, and 43 therms for homes in the water heating program. These savings reflect installations that include aerators and showerheads delivered through kit programs and, in the case of single-family weatherization programs, also delivered through the Home Energy Assessment (HEA) program. Average savings per home for participants receiving kit-only or aerators and/or showerheads were 21 therms. The estimated savings per home represented 10% of annual whole-home consumption for Single Family Weatherization participants, 5% for Space Heating program participants, and 6% for Water Heating participating homes. For homes installing only aerators and showerheads delivered through kit-only programs or the HEA program, the savings per home amounted to 3% whole-home consumption.

Table 17. Claimed and estimated gas savings per home, 2019-2020

Program Group	Claimed (therms)	Evaluated (therms)	Average Annual Consumption (therms)	% Consumption Savings
Kit-plus installations				
Single Family Weatherization	86	77	771	10%
Space Heat	102	38	775	5%
Water Heat	46	43	760	6%
Kit-only installations				
All programs	10	21	693	3%

We calculated total evaluated savings for each SFR gas program by multiplying the estimated savings per home by the total number of participating homes. When compared to the claimed savings, these evaluated total savings indicate a realization rate of 89% for the Single Family Weatherization program, 37% for the Space Heating program, and 93% for the Water Heating program (Table 18). As seen in the electric results above, homes with kit-only (aerator and showerhead only) installations have average savings per home that exceeds the claimed amount with a realization rate of 200%. Overall, the realization rate for Single Family Retrofit gas programs and installations is 64% for program years 2019 and 2020. Gas measures were able to deliver nearly two-thirds of the claimed savings over the two program years.

Table 18. Program level total claimed and evaluated gas savings, 2019-20

Program Group	No. of Homes	Claimed (therms)	Evaluated (therms)	Realization Rate
Kit-plus programs				
Single Family Weatherization	6,887	594,691	529,602	89%
Space Heat	11,683	1,187,383	438,130	37%
Water Heat	2,855	132,104	122,560	93%
Total	21,425	1,914,178	1,090,292	57%
Kit-only installations				
All programs	9,876	102,124	205,934	202%
All installations				
Total	31,301	2,016,302	1,296,226	64%

4.5 Discussion

Consumption or billing data analysis provides the difference between pre-and post-installation period energy consumption following an energy efficiency intervention. This offers an important empirical snapshot of the impacts of a program while also potentially being sensitive to certain conditions that may obscure the signal a billing analysis offers. First, any billing analysis covering recent years contends with the challenges of the COVID-19 pandemic and its variable effects on consumption. The methods used are specifically designed to address these kinds of changes over time, but the pandemic represents a kind of exogenous, non-program related change that pushes the methods to the limit. At the simplest level, more customers working from home increases consumption in the post period of this analysis and has the potential to produce higher savings estimates reflecting this new level of consumption. More generally, there is a clear possibility for greater variability in savings estimates due to the increased possibility of mismatched comparison groups. With regards to the pandemic, though, there are limited opportunities to learn from the findings.

In contrast, there are conditions specific to the programs evaluated here that may affect estimated savings levels that, with exploration, can help us better understand the program, provide input for improved future implementation and support more accurate evaluations in the future. The next three sections summarize findings in three areas with important implications for program savings and implementation:

- Heat pump savings are sensitive to baseline assumptions for both heating and cooling consumption and the implications of fuel conversion. These conditions will complicate any form of evaluation and are embedded in the billing analysis. Some of these conditions indicate that actual savings could be higher than indicated by the billing analysis.
- Gas furnace savings are lower than expected, but these savings are unlikely to be explained by baseline issues alone.
- Energy efficiency kits that were installed without other rebated measures have accompanied installations of non-rebated measures in many, or all instances. PSE mails kits to customers who applied for a rebate but were not eligible. The modest savings associated with these un-rebated energy efficient installations is picked up in the kit energy savings estimates.

In general, if pre-installation period consumption does not represent the appropriate baseline, then estimated energy consumption changes based on this method may not fully reflect the level of savings achieved from program installations. A malfunctioning furnace that sits idle for half a winter, heating replaced by a non-gas secondary source, may appear in the gas consumption data as an increase in consumption after installation. Similarly, in cases of fuel conversion where gas

heating is replaced by efficient electric heating in the form of heat pumps, using pre-installation level of electric consumption as a baseline will result in erroneous levels of electric savings estimates.

In this evaluation, some of the analysis we conducted should avoid such complication. For example, DID models should provide robust estimates of energy consumption changes from weatherization measures installed to improve the building envelopes. Weatherization changes buildings in ways that should be reflected clearly in the consumption data, in the absence of other confounding factors. On the other hand, consumption data analysis used to determine the impact of heat pump installations became complicated because the measures contained a mixture of in-situ baseline conditions. For example, our analysis revealed that some heat pump installations in the categories “Air Source Heat Pump”, “Split Tier 1 and 2 Heat Pump” and “Ductless Tier 1 and 2 Heat Pump” involved fuel substitution where participants switched their gas heating equipment with electric heat pumps while others did not.

Program staff indicated fuel switching was allowed in midstream programs and that it was accounted for in the baseline assumptions for those programs. Because of the very different consumption profiles in fuel switching and non-fuel switching homes, the two groups should be segmented for a consumption analysis, and subsequently weighted together to determine overall measure savings. However, instances of fuel substitution installations were noted in the tracking data. Another baseline factor that strongly affects savings, and should be segmented in a consumption analysis, include installations of ductless heat pumps with participants retaining their existing electric heating equipment since this implies a likelihood of increased comfort from added heating load. Installations with added air conditioning load constitute another change to comfort with added load where the analysis could be improved by segmenting those homes for the DID model.

4.5.1 Heat Pump Discussion

The space heat program electric results include some instances of billing analysis challenges. Heat pumps represent 98% of the electric savings in the Space Heating program and the overall realization rate for this program is 80%, but some of the specific heat pump measures within the program have much lower realization rates which lower the overall number. In some instances, there are reasonable explanations for the lower savings that could ultimately support higher savings estimates, if additional information were available to understand appropriate baseline or installation conditions.

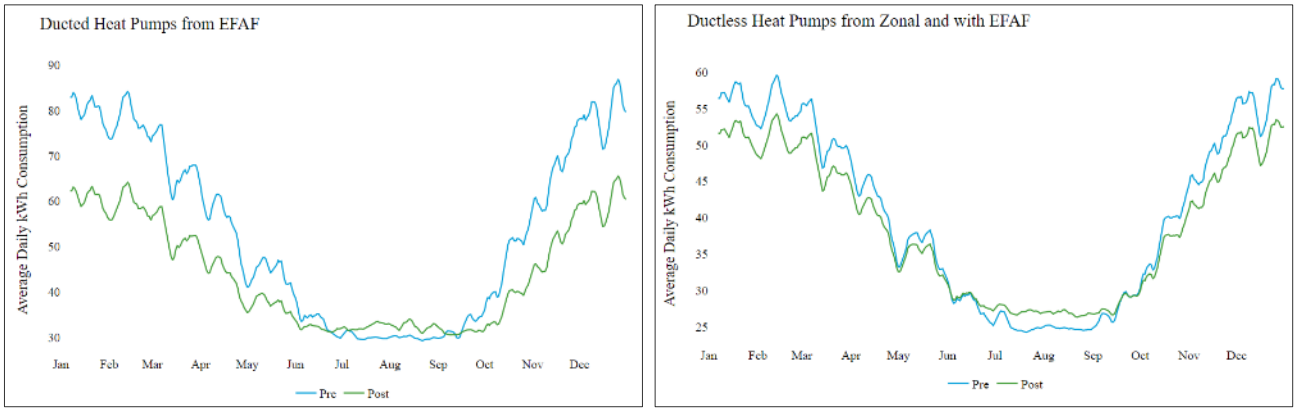
Table 19 provides average claimed and estimated electric savings per home, along with the number of installations for the different classes of heat pumps installed. The top five are contractor-delivered heat pumps, while the latter two were installed through midstream programs. Of the top five, two were ducted and two ductless heat pump installations, each of which could have been either conversions of existing equipment or supplemental to existing equipment. The expected existing equipment includes electric forced air furnaces (EFAF) and zonal or electric baseboard heating systems, though in some cases there is evidence that some form of gas heating equipment may have also been present. The first four heat pumps in the list saved from 60% to 100% of the savings expected for them. These systems were expected to save 11% to 24% of annual electricity use and provided 7% to 24% of such savings. The last three heat pumps, which included air source and Tier 1 and 2 ducted and ductless heat pumps, on the other hand, delivered less than 20% of claimed savings and, in one case, were associated with increased electricity consumption.

Table 19. Heat pump claimed and estimated electric savings per home, 2019-2020

Heat Pump Type	Claimed savings		Evaluated savings		Realization Rate	Number of installations
	kWh	% of annual consumption	kWh	% of annual consumption		
Ductless Heat Pump from Zonal	1,991	11%	1,314	7%	66%	1,912
Ductless Heat Pump with EFAF	4,203	24%	2,625	15%	62%	770
Heat Pump with AC from EFAF	3,609	20%	2,931	17%	81%	129
Heat Pump from EFAC	3,994	23%	4,209	24%	105%	1,331
Air Source Heat Pump	939	5%	174	1%	18%	1,668
Split Tier 1 and 2 Heat Pump	4,944	28%	812	5%	16%	247
Ductless Tier 1 and 2 Heat Pump	1,379	8%	-89	-1%	-6%	857

Figure 4 provides weather normalized average pre- and post-installation household daily electricity consumption for customers who installed the four heat pump types that delivered savings at least 60% of claimed levels. Both panels in the figure indicate lower electricity use in the heating seasons post-installation, while there are increases in the cooling seasons. The panels also make it evident that the higher realization rates for the ducted systems at 81% and 105% compared to 62% and 66% for the ductless systems are probably due the greater heating related savings for the former and not due to differences in cooling related savings; both sets of heat pumps indicate modest increases in summer electricity use post-installation. While ducted systems replace existing electric forced air furnaces, ductless systems have a greater probability of being supplemental to existing electric heating systems. Survey data and program staff corroborate this usage case. The continued use of existing electric resistance heating systems, though expected and accounted for in the deemed savings estimates for the homes that installed ductless heat pumps may not be fully accounted for given the lower savings and realization rates for homes that installed these systems. Savings will reflect the amount of less efficient resistance heat that was replaced by the more efficient heat pumps. Furthermore, to the extent the ductless heat pumps are associated with any increase in the overall provision of heating to the house, 100% of that increase will quickly erode the 10-15% savings produced where inefficient heating was replaced.

Figure 4. Weather normalized average daily electricity use for ducted and ductless heat pumps from EFAF, zonal and with EFAF pre- and post-installation, 2019-2020



Additional heating as well as newly available cooling represent increased consumption that will count against savings in a billing analysis. In both cases, there are reasonable scenarios where the counterfactual would have been less efficient, additional resistance heat and/or a room air conditioner. The billing analysis alone is unable to distinguish between these scenarios and situations where measure savings were simply over-estimated, or units improperly installed. While survey data can provide some evidence of the presence of some scenarios, to fully account for these scenarios, the tracking data

need to capture conditions at each installation site. This improved tracking data will not only improve the ultimate evaluation of the program, but also facilitate correlating site conditions with observed changes in consumption, thus providing fine-grained tuning of program savings expectations.

We also examined average daily electricity use changes pre- and post-installation for the heat pumps that provided savings that were much lower than expected. Figure 5 provides the weather normalized average household daily electricity consumption pre- and post-installation for two classes of such heat pumps. In both cases, electricity use is higher in the post period compared to the pre-period. These pre-post plots may again point to the influence of other exogenous changes on electricity use, which in the case of air source heat pumps results in modest savings as indicated in the table above. Both plots indicate increases in consumption across the year with ductless Tier 1 and 2 heat pumps clearly providing additional cooling that was not present in pre-installation consumption patterns. Again, if either heat or cooling were supplemental, the baseline condition of the billing analysis may not represent the appropriate counterfactual for assessing savings. Additional consideration of these factors in the tracking data will support both improved claimed savings as well as the subsequent evaluation of those savings.

Figure 5. Weather normalized average daily electricity use of air source and ductless Tier 1 and 2 heat pumps, 2019-2020

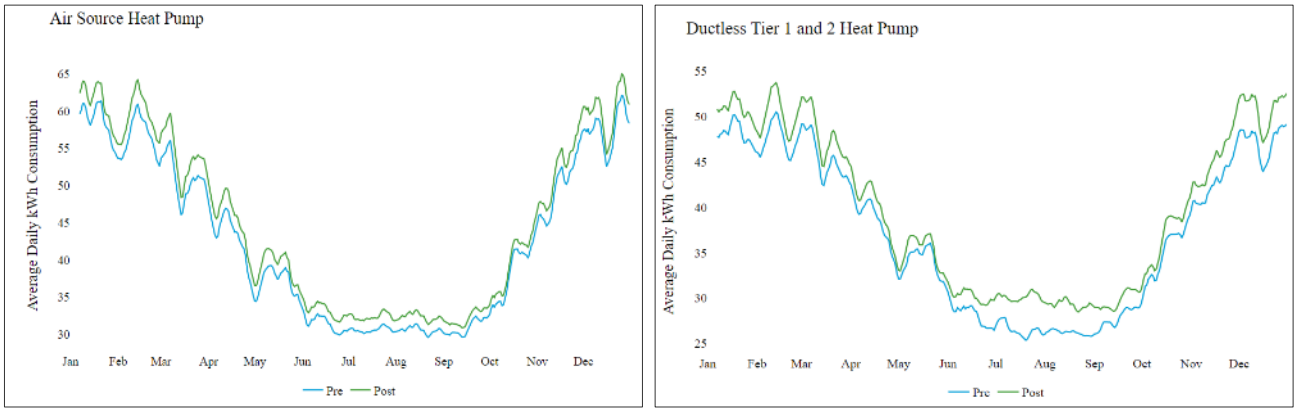
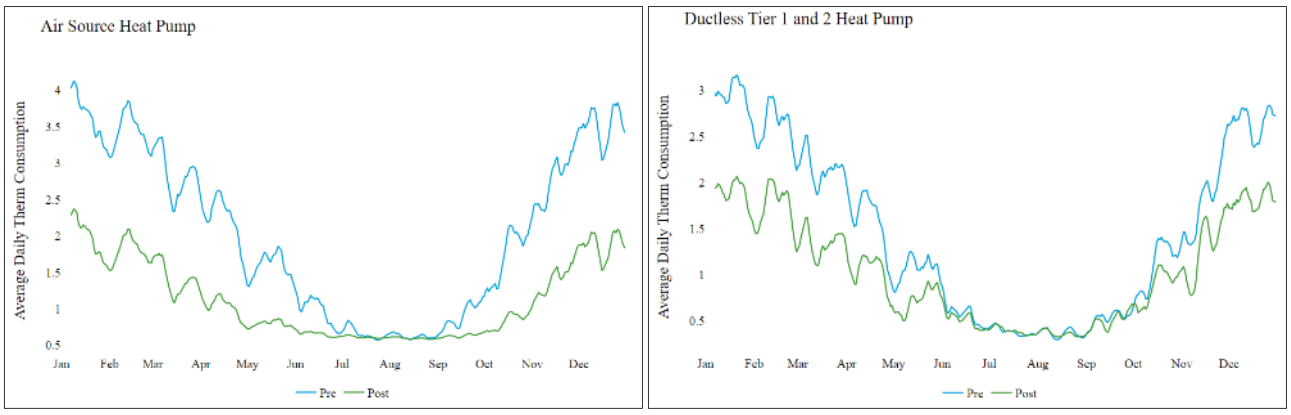


Figure 6 provides another explanation for why these heat pumps do not provide the expected level of electricity use reductions post-installation. These plots suggest the possibility that electric load building may be taking place from the substitution of existing gas-fired heating systems with the electric heat pumps. Some of the installations probably involve fuel substitution from gas to electricity rather than conversions from less efficient electric heating to heat pumps that seem to be the basis for the expected savings. To examine the possible presence of such substitution, we weather normalized the available gas consumption data for the participants that received these classes of heat pumps (216 homes) and compared the normalized daily gas use pre- and post-installation. Figure 6 provides these plots and indicates a decline in normalized gas use from about 3.5 to 4 therms per day in the pre-installation heating season to 1.5 to 2 therms per day in the post-installation heating season. This is strong evidence of the presence of fuel substitution from gas to electricity, and, based on the available data, this indicates a reduction in half of gas use during the heating season; such substitution may be happening for up to half of the participants who installed these heat pumps.

Figure 6. Weather normalized average daily gas use of air source and ductless tier 1 and 2 heat pumps, 2019-2020



Using the available daily gas and electricity data for the subset of participants who installed air source and ductless, 216 and 786 homes respectively, we estimated average annual gas reductions and electricity increases pre- to post-installation to examine the extent of load building, gas reduction, and the implied electricity reduction per home from fuel substitution. Table 20 provides a summary of these estimates. Estimated gas reductions are 160, 199 and 343 therms per home. Based on a therm to kWh conversion of 29.3 and taking into consideration the increase in electricity load building as captured by the negative pre- to post-installation average increase per home, we estimated electricity reductions of about 3,800 to 9,300 kWh per home, which would amount to about 20% to 50% of annual electricity use.

Table 20. Estimated electricity savings from fuel substitution heat pump, 2019-2020

Heat Pump Type	Electric (kWh)			Gas (therms)			Gas reduction in kWh	Total kWh reduction	Reduction as % of Annual Combined Consumption* in kWh
	pre	post	difference	pre	post	difference			
Air Source Heat Pump	15,662	16,421	-758	756	413	343	10,036	9,277	25%
Split Tier 1 and 2 Heat Pump	16,537	16,698	-161	609	411	199	5,816	5,655	16%
Ductless Tier 1 and 2 Heat Pump	13,589	14,478	-889	538	378	160	4,694	3,805	13%

*Combined annual gas and electric consumption in kWh

We provide these estimates as an indication of the extent of energy savings these SFR Space Heating program measures may be achieving. For a proper program attribution, it is necessary to have tracking data that captures baseline conditions and whether an installation involves a replacement from an existing electric heating system to a more efficient heat pump equipment or a substitution from gas to an efficient electricity (heat pump) powered heating. While a subset of electric space heating measures delivered lower savings than expected, the overall realization rate for these measures is relatively high at 80%.

4.5.2 Gas Furnace Discussion

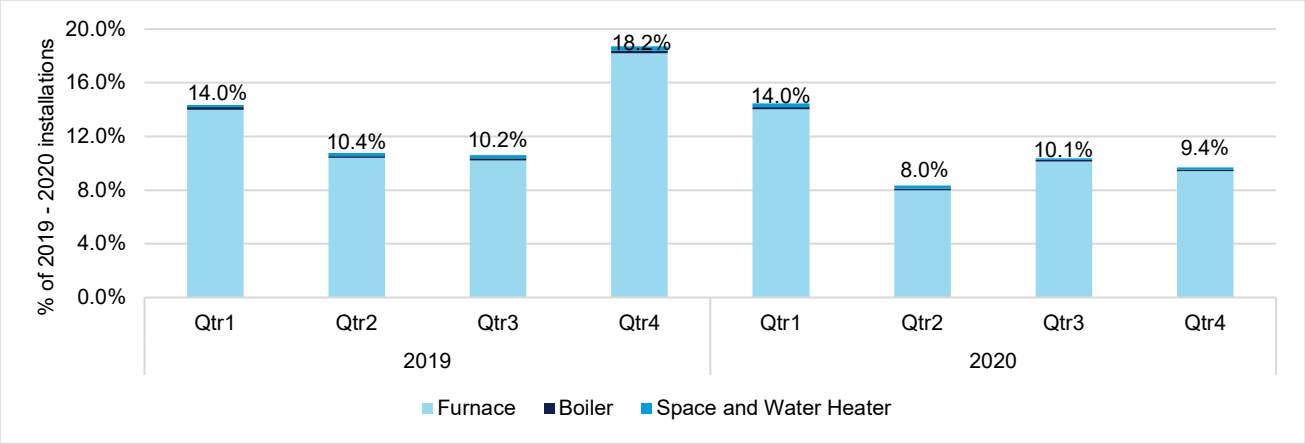
Gas space heating measures, on the other hand, delivered 37% of claimed savings. Furnaces made up over 90% of gas space heating installations and drive the realization rate estimated for this program. DNV's estimated gas savings by space heating equipment indicates that furnace savings per home were almost 70% lower than claimed (Table 21).

Table 21. Estimated gas savings by space heating equipment, 2019-2020

Space Heating Type	Claimed (therms)	Evaluated (therms)	Realization Rate
Boiler	119	63	53%
Fireplace	77	36	46%
Furnace	110	34	31%
SW Heater	177	125	71%

One possible explanation for these low savings estimate could be increased variability in gas use due to the pandemic. We were able to explore this by estimating savings for different time periods. For example, participants that installed furnaces in the first two quarters of 2019 had post-installation heating season gas consumption unaffected by the pandemic. While those that installed furnaces in the third quarter of 2019 also had post-installation heating season consumption before the pandemic began, we were conservative and did not include them in the non-covid-affected heating season analysis. Thus, we modeled the energy use of those that installed furnaces in the first two quarters of 2019 separately to examine if savings for this subset of customers is different than for the rest. As Figure 7 indicates, about 25% of installed furnaces had a heating season post-period (prior to March 2020) unaffected by COVID-related occupancy changes. Estimated savings per home from these installations were qualitatively similar at 44 therms to installations that took place in the rest of 2019 and 2020, and hence subject to the effects of the pandemic.

Figure 7. Timing of gas space heating measure installations, 2019-2020



Another baseline-related explanation for low furnace savings could be lower than expected heating loads served by the furnace. There is evidence from the survey where 40% of participants report using fireplaces to supplement heat, which could contribute to lower estimated furnace savings. Similarly, if the gas furnace now serves as back up heat for a heat pump, then the magnitude of savings will reflect this lower level of furnace consumption. PSE recognizes this concern and attempts to screen out these customers, but that requires verification which is generally not performed on a majority of applications.

We also investigated the ex-ante savings (of 110 therms per unit) used for furnace claims in the tracking data and found an evaluation study to be the source. KEMA, DNV's predecessor, conducted a billing analysis of 2005 and 2006 furnace installations for PSE and found estimated savings of 83 to 88 therms. It is likely that furnace efficiencies in the building stock (baseline) have improved in the past 15 years while high efficiency furnaces are reaching the efficiency limit (of 100%) so lower savings would be expected now. Though we were unable to review the study on which the current savings are based, it may be reasonable to question whether current estimates of gas furnace savings are too high. In this instance, while there

are possible baseline issues that could affect savings levels, it is unlikely that they can fully explain the low realization rates for this measure.

We present a summary of possible causes for the low realization rate for the gas Space Heating program and set of potential next steps in Table 22 below.

Table 22. Possible causes of low realization rates within gas Space Heating program

Possible Cause	Further Investigation
Methodological Unknowns	
COVID-19. The pandemic has created a dramatic non-routine event that has a potential to disrupt the pre-post difference-in-differences methodology.	**Literature review** investigating peer gas heating retrofit program evaluations and pandemic impact on home energy consumption and consumption analyses **Early EM&V** for 2021 and 2022 Single Family Retrofit program to monitor trend
Poorly Matched Comparison Group. The pre-post billing analysis methodology depends on a well-matched comparison group to remove exogenous effects. It is possible that there are unknown differences (e.g., demographics and propensity to participate in efficiency programs) that we were unable to identify.	**Customer surveys** to gather additional data on representative set of comparison group **Customer profile analysis** to explore details of participants and comparison group
Real World Conditions	
Decreasing pre-period participant heating load. It may be that historical participation captures those customers with higher heating loads first. As time goes on, the remaining customers may have lower heating loads. Should this trend continue, lower pre-period heating load will yield a lower magnitude of savings.	**Customer profile analysis** to provide a brief analysis on historic program participation trends that can be easily updated on a recurring basis
Equipment Baseline. Claimed savings assume an 80% AFUE, which is the minimum efficiency required by code, but it is possible that the actual replaced furnaces have a higher efficiency on average, which would reduce measured savings.	**Contractor survey** to better understand the efficiency of the replaced equipment. **Contractor ride-alongs** to track a representative sample of pre-existing heating systems
Unknown Use of Equipment. The gas furnace may be used as backup heat source (where primary may be a heat pump) or the gas furnace may be used as a primary heat source but is significantly supplemented by electric or wood heat.	**Customer survey** to establish self-reported use of heating equipment **Contractor ride-alongs** to track a representative sample of heating system use type
Increased Takeback. It is possible that participants are turning up thermostat setpoints or that smart thermostats may encourage improving comfort over energy savings following the installation of the new furnace (takeback), resulting in an increase in heating consumption.	**Customer surveys** to identify intentional increases in temperature setpoint **Consumption analysis** to identify setpoint

4.5.3 Kit Savings Discussion

While space heating-related savings constituted the bulk of claimed savings from PSE's SFR programs, these programs also delivered only kit measures to a substantial number of participants. Estimated savings per home for kit-only installations are much higher than claimed. One likely explanation for these higher-than-expected savings is that a subset of homes that received kit-only measures from PSE may have installed HVAC measures outside of PSE programs that were higher efficiency than their existing system. PSE is aware of this situation because kit households are sent to all applicants. Those applicants who are kit-only will include rejected applicants who went ahead with unit changes outside the program. These new systems may have only been standard efficiency, but still improved on the efficiency relative to existing system. The consumption analysis confirms the presence of heating related savings that we would not expect to see from kits of this kind where baseload savings are primarily expected. This is an example of a shortcoming of the billing analysis approach where other consumption-related changes are correlated with installation of a measure.

Table 23 provides estimated savings per home from kit-only installations at the whole-home level and for baseload and heating load; baseload and heating are the two components of whole-home energy consumption. Whole-home savings for electricity and gas, which we presented in the previous section, are mostly due to heating load reductions and not due to baseload reductions. This finding supports the explanation of additional energy savings activities undertaken by participants outside of PSE programs.

Table 23. Estimated savings per home by load type from kit-only installations, 2019-2020

Load Type	Evaluated electric savings			Evaluated gas savings		
	kWh	Average Annual Consumption (kWh)	% Savings	Therms	Average Annual Consumption (therms)	% Savings
Whole-home	167	11,600	1.4%	21	693	3.0%
Baseload	-93	7,883	-1.2%	1	174	0.8%
Heating load	256	3,476	7.4%	16	518	3.1%

5 PROCESS EVALUATION RESULTS

This section summarizes the findings for the Single Family Retrofit process evaluation, and includes results from the program staff interview, participant online surveys, and contractor surveys.

5.1 Overview

We conducted a process evaluation for the purpose of identifying program successes and opportunities for program improvement. Key research questions for the process evaluation focused on sources of program awareness among participating customers, levels of satisfaction among customers and the trade allies who implement the program, and barriers to program participation. The research activities that helped inform the process evaluation included the following:

- Program staff interview
- Online survey with program participants
- Telephone surveys with contractors participating in the program

We discuss the results of these research activities in the sections that follow.

5.2 Recent and Planned Program Changes

Evaluators interviewed the PSE program managers for Single Family Space Heating, Water Heating, Weatherization, Windows, and Smart Thermostats programs. The focus of the discussion was on recent and planned program changes for Space Heating, Water Heating, and Weatherization programs.

Space Heating

- The program provides incentives for installations of gas and electric space heating systems, including natural gas furnaces, boilers, integrated space and water heat systems, and electric resistance conversions to ductless and unitary heat pumps.
- PSE has provided midstream incentives for space heat pumps beginning in 2020 and through 2021. Through the midstream delivery channel, contractors can get instant rebates on qualified heat pumps at participating distributors.
- According to PSE's website "midstream rebates are not dependent on existing heating fuel or heating equipment."[7] This suggests that fuel substitution is currently allowed through the midstream delivery channel.
- According to PSE's program guide, the Space Heating program will remove existing midstream rebates and only allow downstream rebates for qualified space heating measures in 2022. The midstream program will continue as a separate program in 2022.

Water Heating

- The program provides incentives for installations of gas and electric water heating systems, including electric heat pump water heaters, natural gas water heaters, and tankless water heaters.

[7] https://www.pse.com/rebates/midstream?utm_source=direct&utm_medium=shorturl&utm_campaign=ee-dlr-midstream&sc_camp=DD3E869F161A447FFCDFC7B319EA5E48

- PSE has provided midstream incentives for electric heat pump water heaters beginning in 2020 and through 2021. Through the midstream delivery channel, contractors can get instant rebates on qualified heat pumps at participating distributors.
- As with midstream incentives for space heat pumps, PSE's website states that "midstream rebates are not dependent on existing heating fuel or heating equipment."[8]
- According to PSE's program guide, the Water Heating program will remove existing midstream rebates and continue to provide downstream rebates for water heating measures in 2022. The midstream rebates will be in a separate program rather than being combined with water heat.
- Beginning in September 2020, PSE launched a retail incentive pilot program for Tier 3 heat pump water heaters at participating Home Depot and Lowe's stores.

Weatherization

- The Weatherization program provides incentives on a variety of weatherization measures in single family existing homes, including insulation, duct sealing, and air sealing. Certified contractors from the Trade Ally Network (TAN) perform these installations.
- Beginning in 2022, PSE will offer air sealing and insulation incentives on a per square foot basis rather than as a percentage of project cost. This change was made to reflect increased energy savings from larger homes and to align PSE's programs with other regional offerings.
- For the 2022 and 2023 program years, PSE is considering the addition of new measures including triple pane/U22 windows.
- PSE will continue to offer bonus bundle incentives. Bonus incentives are available to customers who choose to implement three or more incentivized weatherization measures.

Adapting to COVID-19 Pandemic

Program managers mentioned a few programmatic changes that occurred as a result of the COVID-19 pandemic. These changes included the following:

- The Space and Water Heating programs implemented virtual verifications rather than in-person verifications. Typically, this involves video phone calls or standard audio calls with follow-up requests for photos for documentation.
- The Weatherization program required photo documentation for completed projects rather than in person documentation as of September 2020.
- Blower door testing has been temporarily suspended for any projects that require blower door testing.

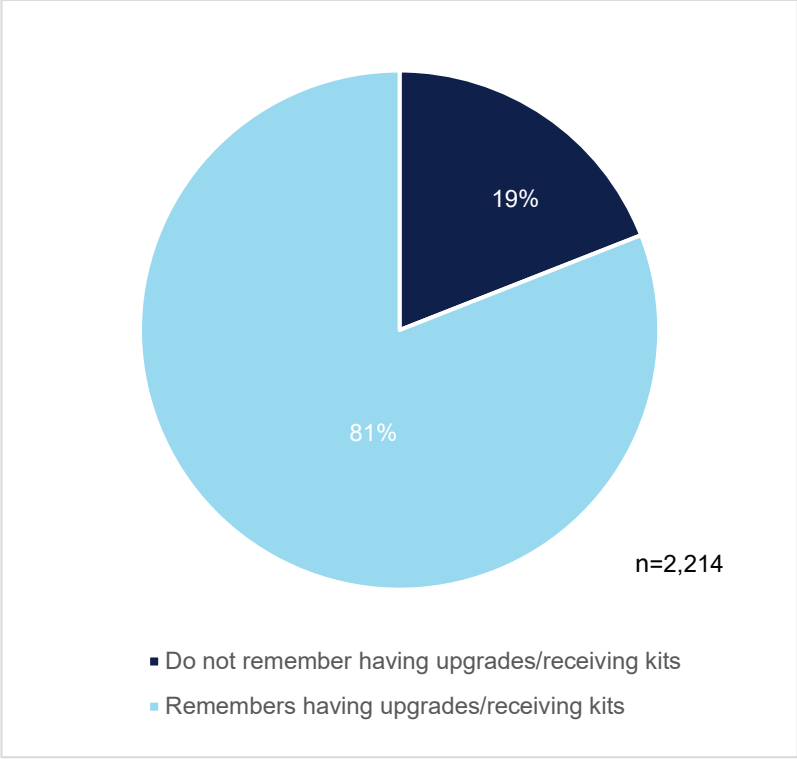
5.3 Program Awareness

This section summarizes results related to level of awareness of among Single Family Retrofit program participants.

[8] Ibid.

Evaluators asked respondents if they remember having energy saving upgrade(s) or receiving free energy savings kits. Four out of five respondents (81%) reported that they remembered participating in the program (Figure 8).[9]

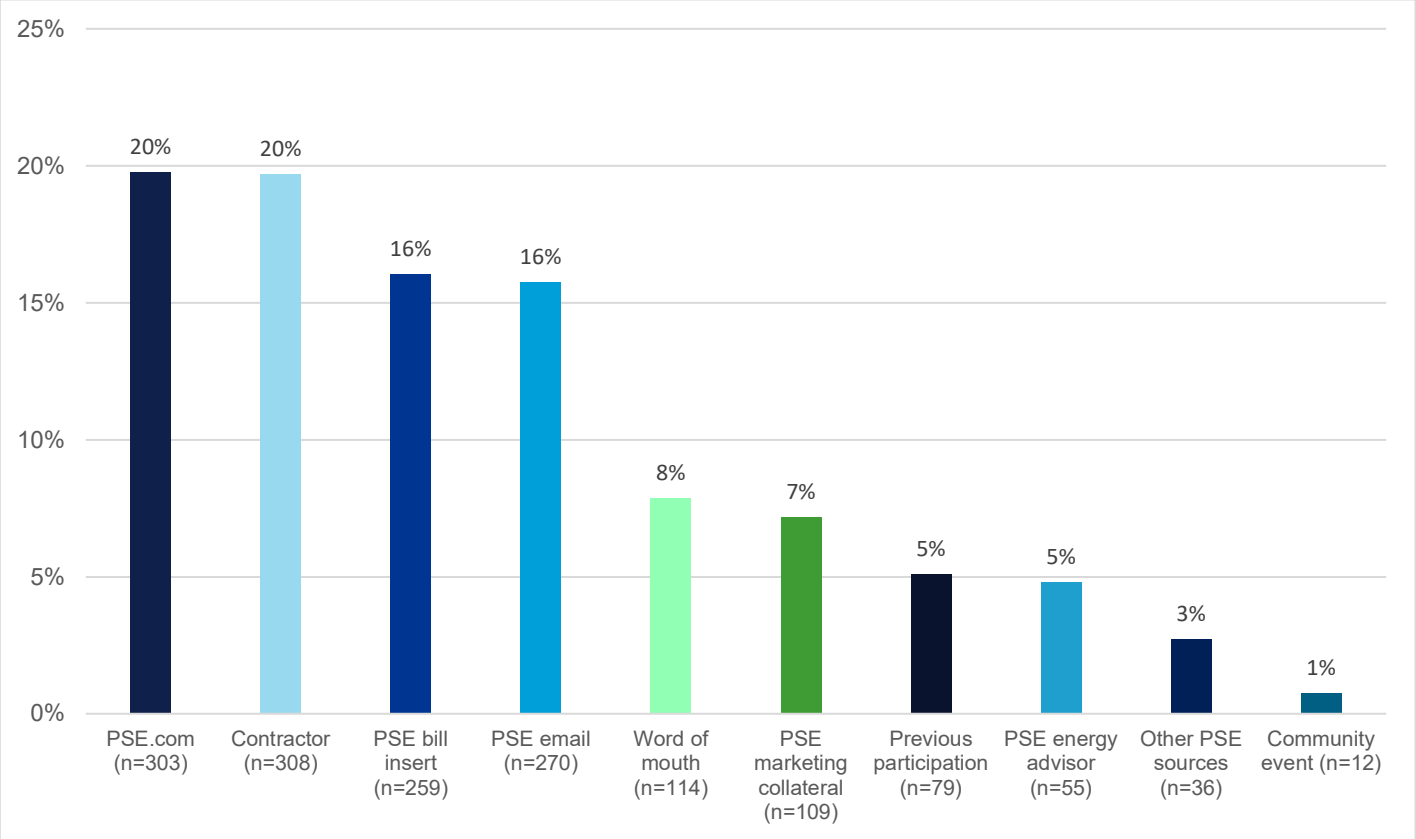
Figure 8. Recall of Program Participation



We asked program respondents how they learned about the program. Respondents reported learning about the program most commonly through the PSE website (20%) and through a contractor (20%), followed by PSE bill insert (16%) and PSE email (16%). The remaining nine sources of awareness account for only 29% (Figure 9).

[9] Note that survey respondents were not required to answer every question to advance the online survey and that some respondents chose to skip survey questions. As such, there was some attrition in the number of respondents who answered questions as the survey advanced.

Figure 9. Source of Program Awareness

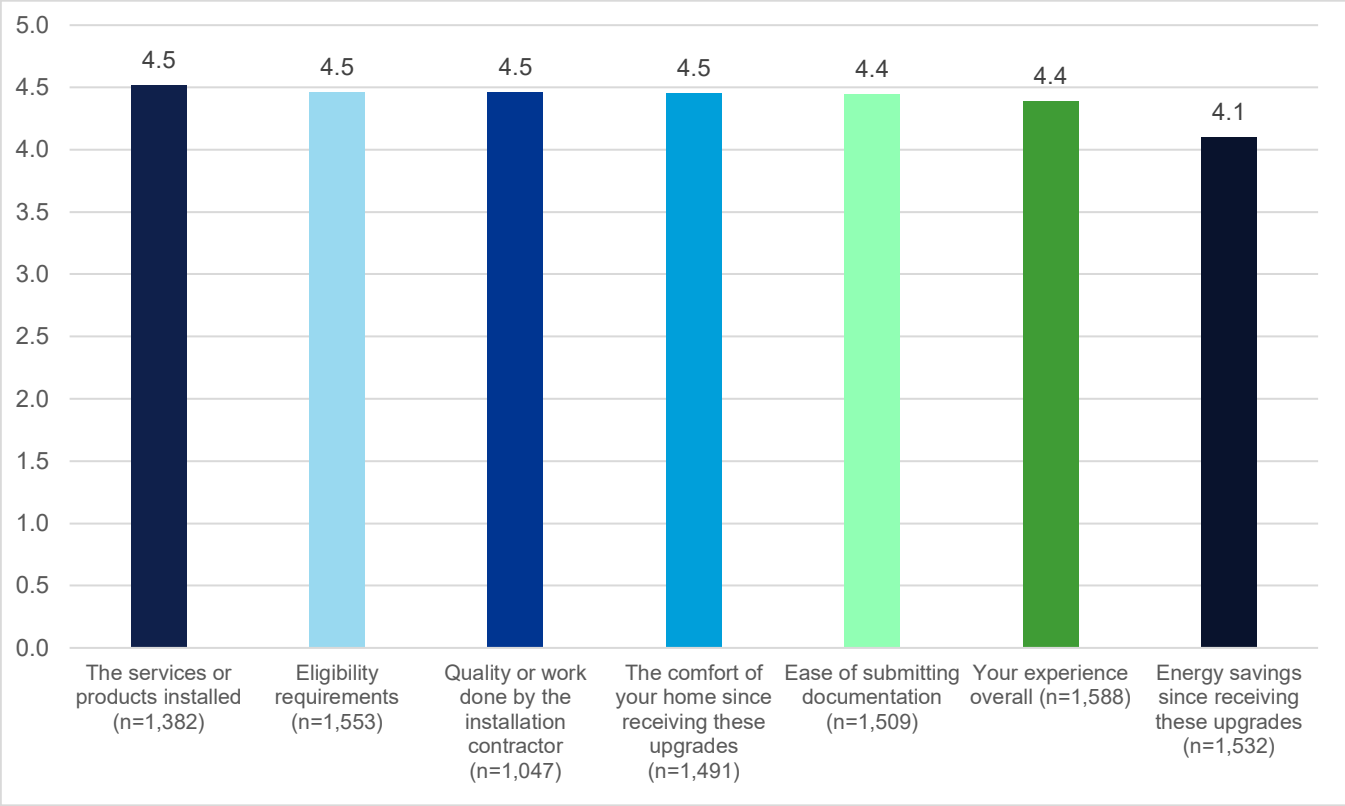


5.4 Program Satisfaction

DNV asked participants about their satisfaction with various aspects of the program using a 5-point scale, where 5 means "very satisfied" and 1 means "very dissatisfied." Seven distinct aspects were covered with the intention of capturing key steps of the rebate and installation process, from eligibility requirements to energy savings since receiving upgrades. Respondents were also asked about their satisfaction of the program overall.

Figure 10 presents satisfaction with the various aspects of the program as well as satisfaction with the overall program experience. All categories yielded moderate to high average satisfaction scores, ranging from 4.1 to 4.5. Only one aspect (energy savings since receiving these upgrades) received a 4.1 average satisfaction rating while the other 6 aspects had high average satisfaction ratings of either 4.4 or 4.5. This suggests that participants are generally satisfied with most aspects of the program. The lower average satisfaction rating (4.1) of energy savings since receiving upgrades may be due to participants expecting to see higher bill savings as a result of the upgrades they made than what they experienced on their bills.

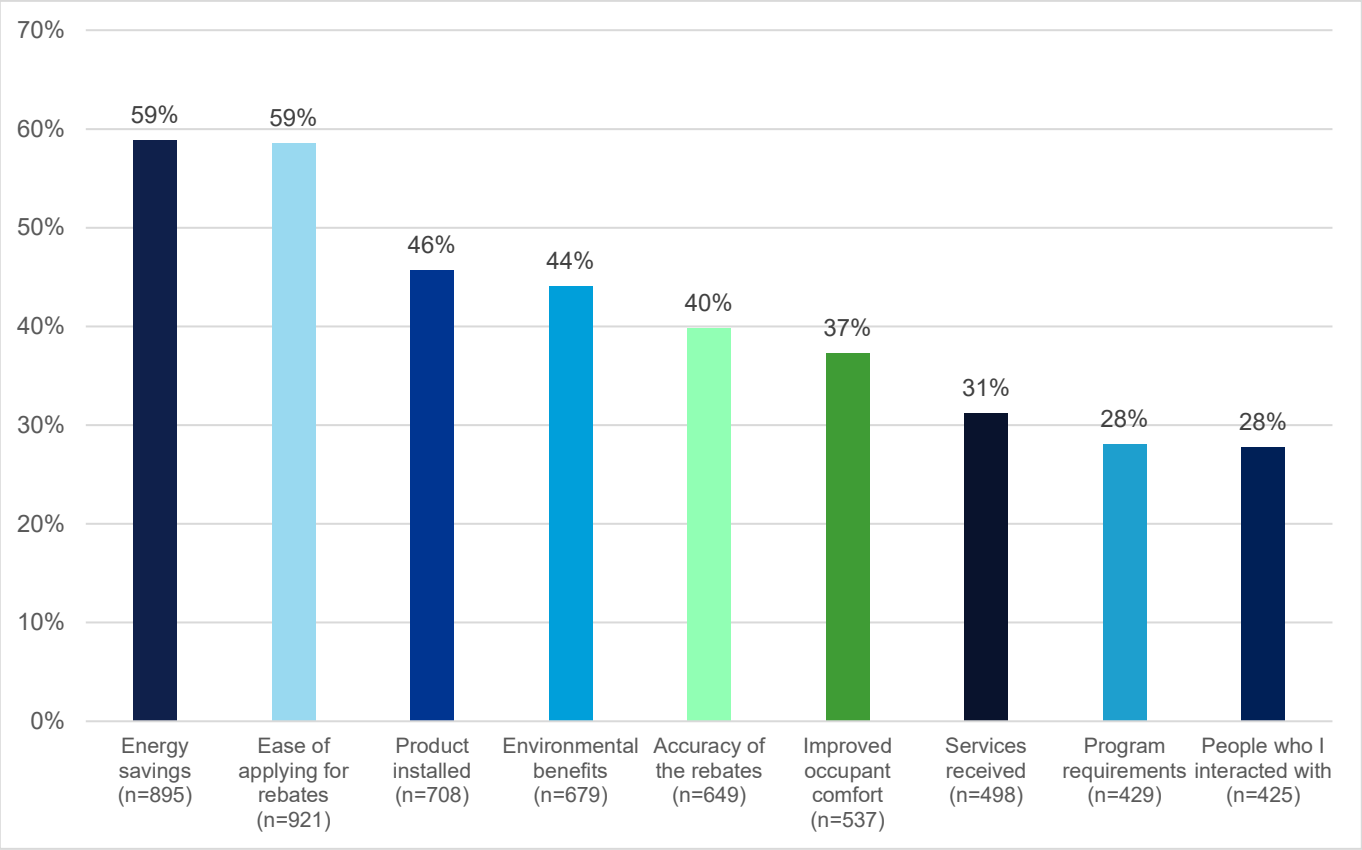
Figure 10. Participant Satisfaction with the Program



5.4.1 Participant Perspective

Respondents were asked about their perspective of various aspects of the program. First, respondents were asked which aspects of the program went well when thinking about their overall experience (Figure 11). Energy savings (59%) and ease of applying for rebates (59%) were most frequently cited as aspects of the program that went well. The third and fourth most frequently cited aspects of the program that went well were satisfaction with the product that was installed (46%) and environmental benefits associated with upgrades (44%). This suggests that most customers believe the program is doing a good job of achieving energy savings and that the application process is working well for participants.

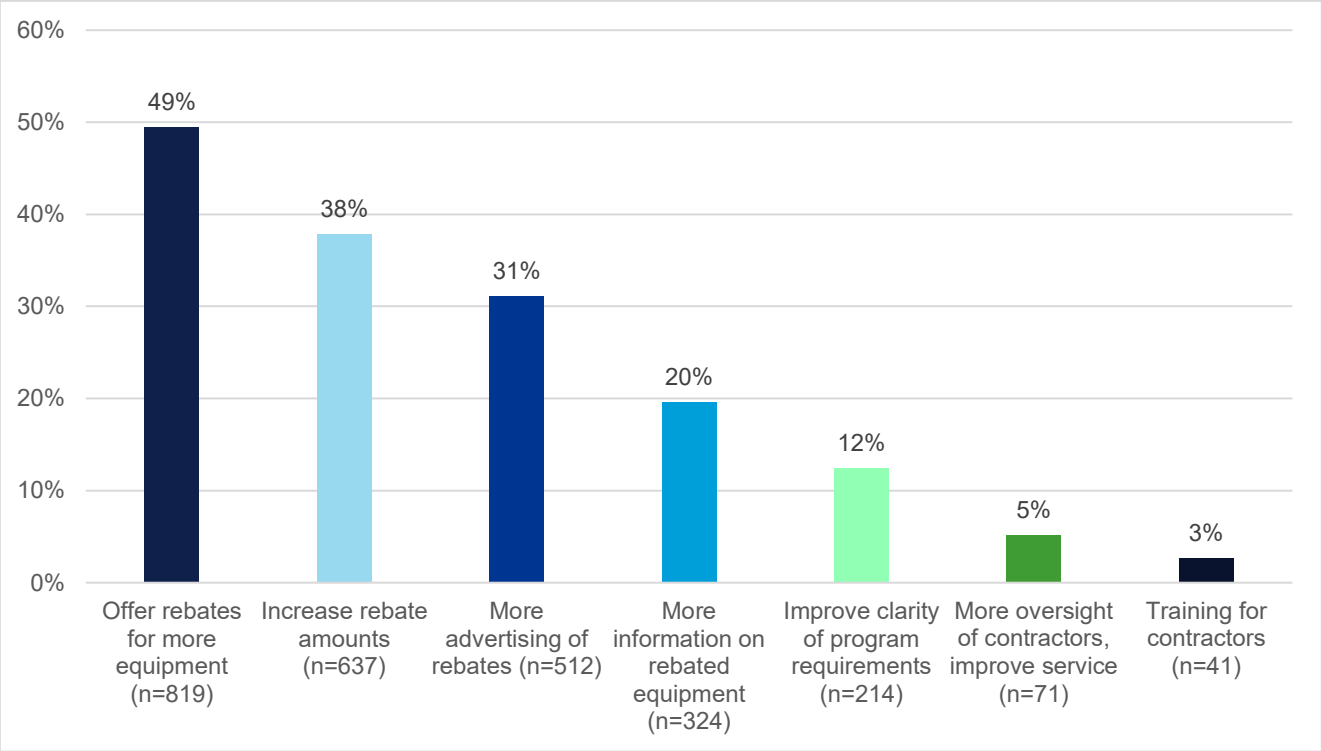
Figure 11. Respondents Report of Program Aspects That Went Well



*Number of respondents= 1,606. Respondents were allowed to cite multiple program aspects, so totals are greater than 100%.

The survey asked respondents what aspect of the program could be improved. As shown in Figure 12, the most common recommendation cited for program improvement was to offer rebates for more equipment (49%), increase rebate amounts (38%), and increase advertising of rebates (31%). The aspects of the program respondents reported needing to be improved the least were improving clarify of program requirements (12%) and increased information on rebated equipment (5%) and training for contractors (3%).

Figure 12. Opportunities for Program Improvement



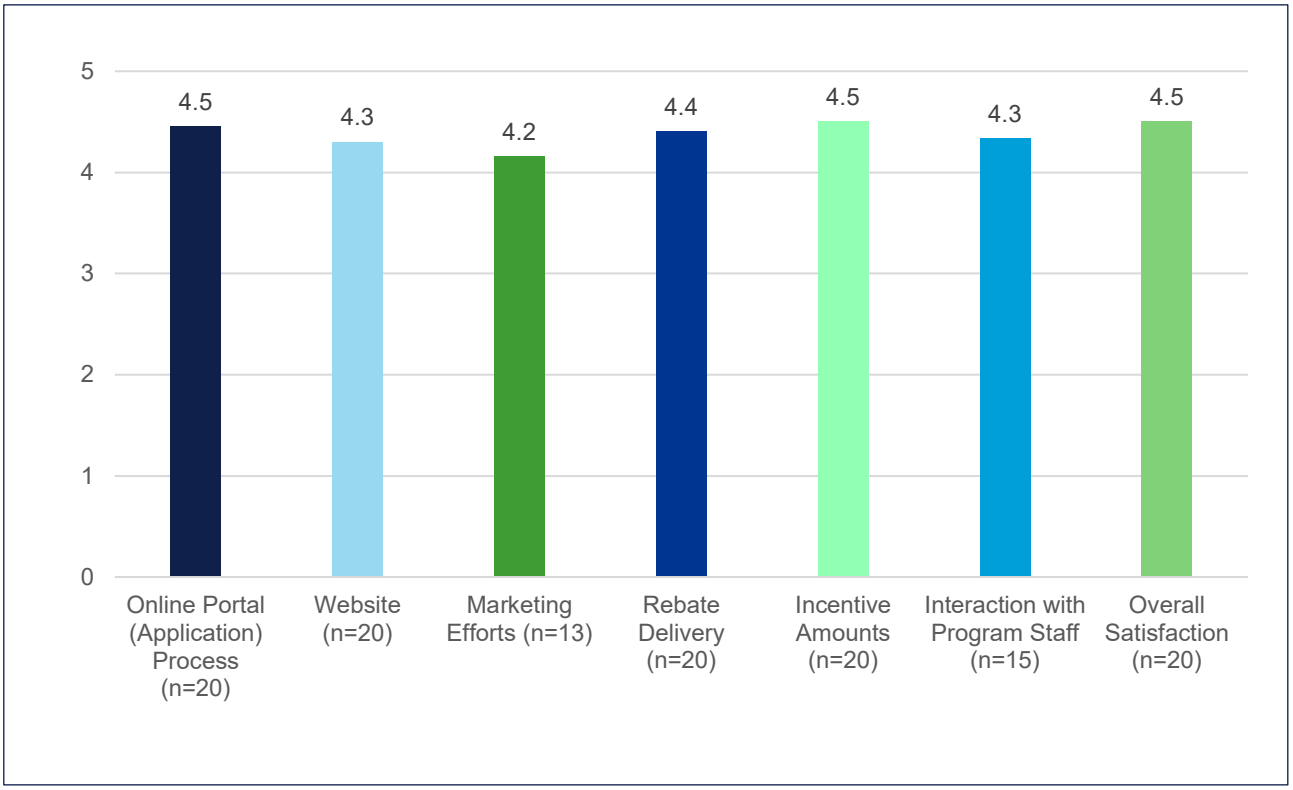
*Number of respondents= 1,591. Respondents were allowed to select multiple program improvements, so totals are greater than 100%.

5.4.2 Contractor Perspective

Evaluators asked contractors about satisfaction with various aspects of the program using a 5-point scale, where 5 means "very satisfied" and 1 means "very dissatisfied." There were seven different aspects covered, ranging from the website and application process all the way through rebate delivery.

Figure 13 presents contractor-reported satisfaction with the various aspects of the program covered in this evaluation. The ratings for all categories were high, with the online portal (application) process, incentive amounts, and overall satisfaction having the highest average satisfaction score (4.5). Marketing efforts had the lowest average score of 4.2, although interactions with program staff was the only category where any of the contractors responded with a score lower than 3 which indicates dissatisfaction (two contractors gave a rating of 2).

Figure 13. Contractor Satisfaction with the Program



Interviewers also asked respondents if they thought the rebates levels for various equipment types were adequate to move program sales, and if not, what rebates levels would be needed to move consumer demand. Table 24 shows what percent of respondents thought the existing rebate levels were sufficient to move program sales. All respondents stated the rebates were sufficient for Heat Pump Water Heaters (Tier 3) and Electric FAF to ASHP conversions, and all but two respondents reported adequate rebate levels for Air Source Heat Pumps (10 HSPF), Split System Heat Pumps (Tier 2), and Zonal electric resistance to ductless heat pump conversions. Tier 1 Ductless Heat Pumps and Split System Heat Pumps received the lowest percent of respondents citing adequate rebate levels (50% and 57%, respectively), both with an average recommend rebate level of $650.

Table 24. Program Incentive Level Adequacy

Measure	Rebate	Percent of Respondents Reporting Sufficient Rebate Level	Average Recommended Rebate
Heat Pump - Air Source - 10.0 HSPF (n=15)	$1,500	87%	-
Heat Pump - Ductless less than 65 kBtu/h – Tier 1 min HSPF 9.5 (n=16)	$400	50%	$650
Heat Pump - Ductless less than 65 kBtu/h – Tier 2 min HSPF 11 (n=17)	$600	76%	$575
Heat Pump - Split system Less than 65 kBtu/h – Tier 1 min HSPF 9 (n=14)	$300	57%	$650
Heat Pump - Split system Less than 65 kBtu/h – Tier 2 min HSPF 10 (n = 14)	$500	86%	-
Zonal electric resistance to ductless heat pump conversion (n = 14)	$800	86%	$1,500
Heat Pump Water Heater - Tier 3 (n = 7)	$500	100%	-
Electric FAF to ASHP conversion (n=14)	$1,500	100%	-

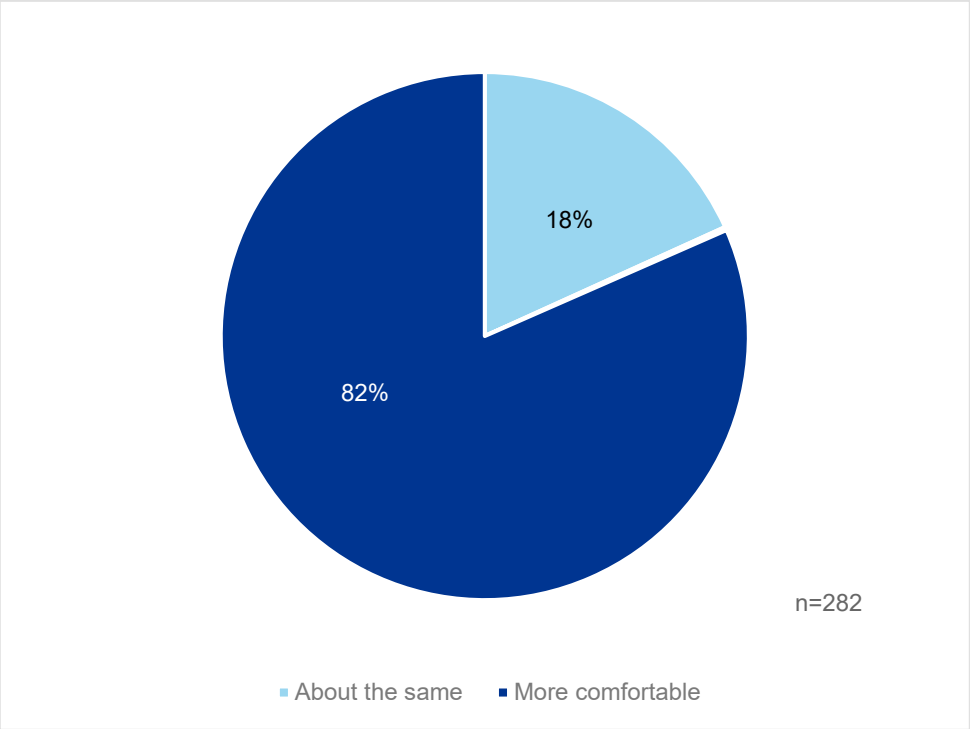
5.5 Program Benefits

One of the ancillary benefits of the measure installations is the improvement in home of comfort (along with energy savings). The survey asks participants if they are now more comfortable in their homes since the improvements were made. These findings can be one way the program motivates customers to adopt measures, appealing to their desire for improved savings and comfort. Participants were asked a series of questions on home comfort and the sources of discomfort they previously experienced.

Participants who install space heating, water heating, and/or weatherization measures were asked if they experienced any of the following benefits: improved comfort, air quality, safety or if the home is quieter. The vast majority of participants (86%) experienced at least one of these benefits.

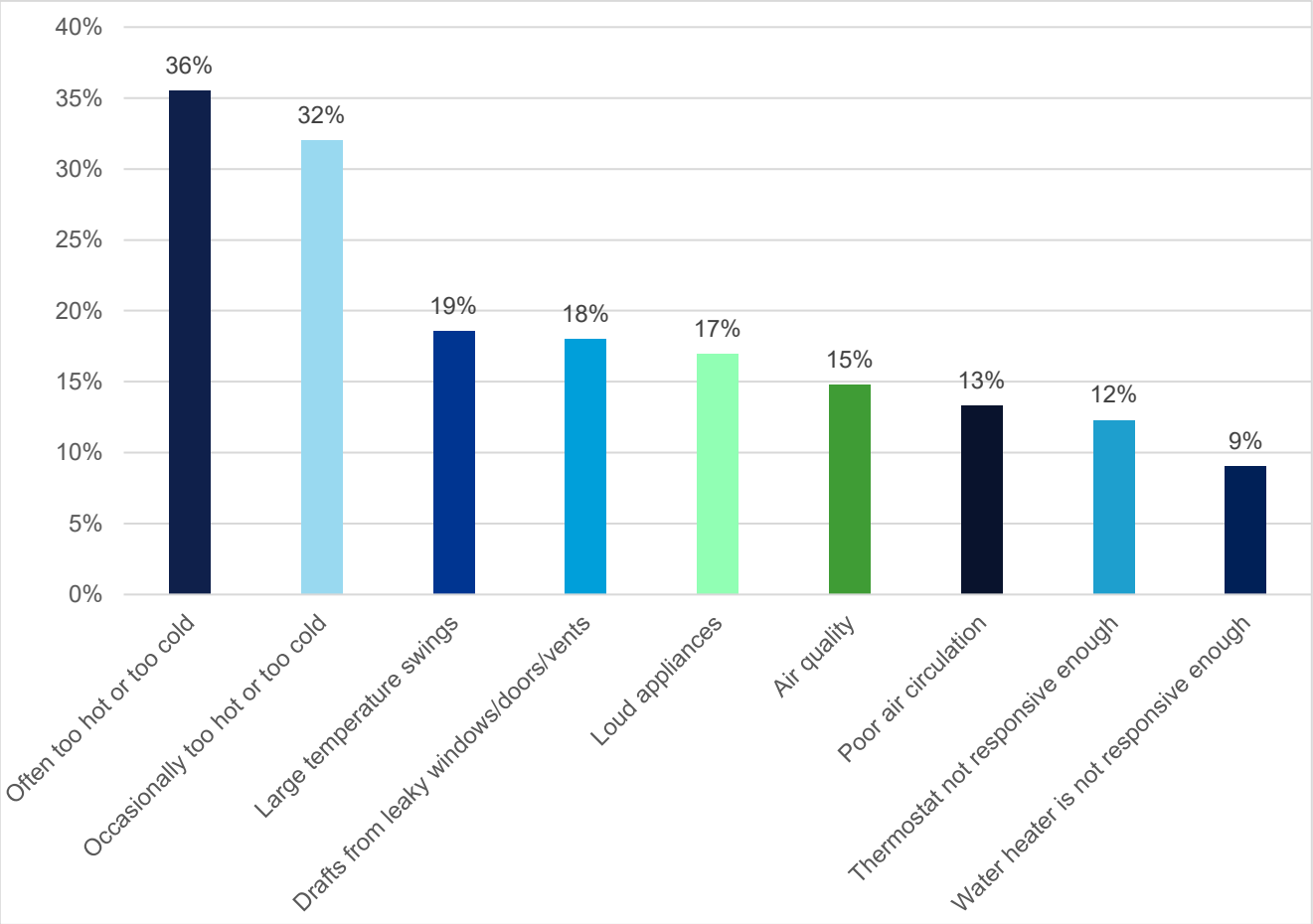
Among those who experienced these benefits, we asked whether their level of comfort was more, less, or about the same level of comfort since the improvements were made (Figure 14). More than four in five participants (82%) reported that they were more comfortable, and 18% reported that they experienced the same level of comfort, and only one respondent (less than 0.5%) reported that they were less comfortable.

Figure 14. Level of Comfort from Program Measures(s)



The survey asked participants about discomforts they experienced in the home prior to program measure installation (Figure 15). Experiencing temperature swings either often (36%) or occasionally (32%), and/or drafts (19%) were cited most frequently as previous sources of discomfort. This suggests that the program measures are helping to deliver consistent and desired level of temperature to participants.

Figure 15. Previous Sources of Discomfort



*Number of respondents= 218. Respondents were allowed to select multiple program improvements, so totals are greater than 100%.

5.6 Barriers to Program Participation

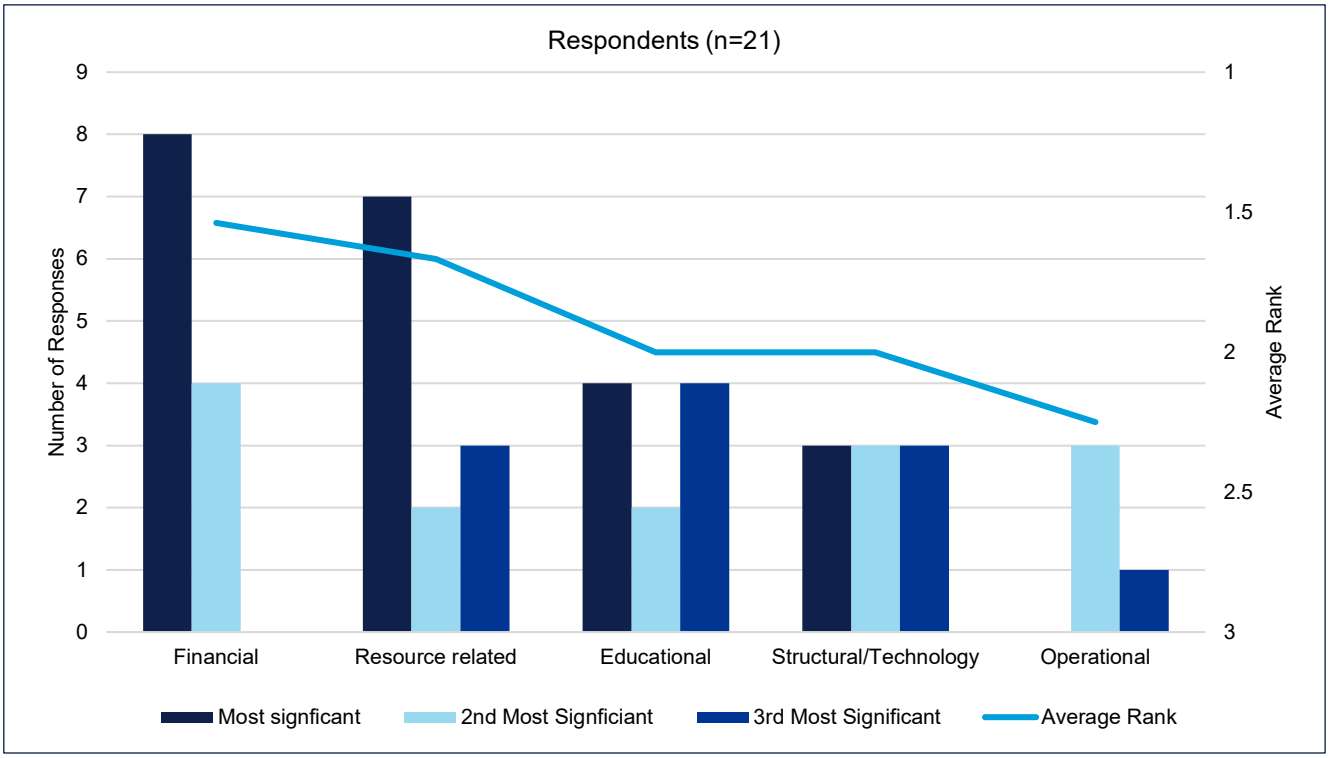
5.6.1 Contractor Perspective

Respondents from the contractor survey were asked a multi-response, 3-part question surrounding barriers that need to be addressed to improve the advancement and adoption of space and water heat pump technologies. Contractors were asked what barriers existed, which ranked as the top three barriers to heat pump adoption, and what should be done to address them. Respondents were asked to consider the following possible barriers:

- Resource-related (e.g., availability of equipment)
- Educational (e.g., unfamiliar, or inexperienced with the products)
- Structural / Technology (e.g., installation space constraints, electrical panel upgrades)
- Operational (e.g., noisy, slower to change temperature compared to gas alternative)
- Financial (e.g., higher upfront costs, insufficient payback)

As depicted in Figure 16 over half of the respondents cited financial barriers (n=8) or resource-related barriers (n=7) as the most significant barrier to space and water heat pump technologies.

Figure 16. Contractor Perceived Barriers to Heat Pump Adoption



When asked what should be done to address the financial barriers, contractors provided suggestions on offering additional rebates, more flexible financing options, and additional education about long-term savings:

- Potentially offer more rebates for more expensive equipment and lower SEER units that don't meet requirements (2 respondents)
- Educating customers on the long-term energy savings (2 respondents)
- Offer more flexible financing options (1 respondent)

When contractors were asked what could be done about the resource-related barriers resulting from COVID, all respondents stated that this issue was out of their control. For example, two contractors explained:

- *"Out of our hands. Manufacturers have material shortages that are driving this. Don't think there is anything PSE can do."*
- *"This is a barrier for all equipment types, not just heat pumps. Don't think there's much that can be done, just hope this issue goes away soon."*

Education and structural / technology-related barriers were the next most frequently cited barriers behind financial and resource barriers. Operational barriers were the least frequently cited, with no contractors reporting this as the most significant barrier. Contractors' responses when asked for suggestions on how to overcome these barriers included:

- Educational barriers:

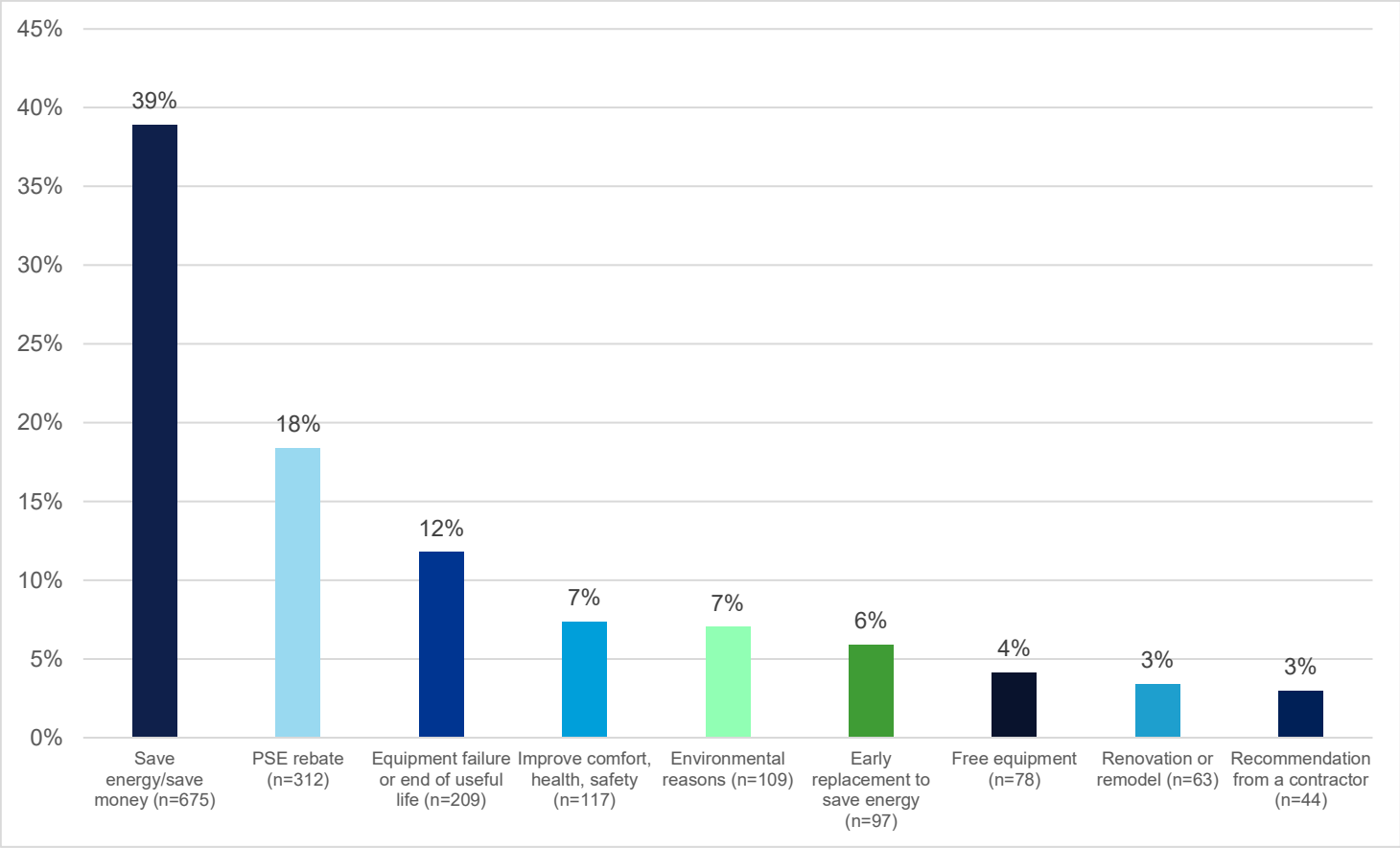
- *"Ways other than internet to reach customers. Many older, lower income individuals in the area refuse to go online. They have sent out mailers, which frustrates some to get junk mail, but was somewhat successful in educating people on rebates and encouraging them to call their utility company."*
- *"Need more education support from PSE of how heat pumps operate, how owners should be operating heat pumps, and how they're expected to work."*
- *"Promoting overall heat pump application and concept to market would help people understand non-conventional technology"*

- Structural / technology-related barriers:
  - "*Unless manufacturers can address the space / temperature constraints, then there isn't much that can be done. Lots of times it just doesn't make sense to install a heat pump for a certain customer."*
  - *"Providing the right types of brands and models. For noise and space limitations, higher quality products have smaller footprints and are very quiet."*
  - *"Cosmetic concepts that help overcome structural disadvantage should be marketed.*"
- Operational barriers:
  - "*Some electrical panel in existing homes won't support heat pump systems. You have to upgrade, and it adds to the cost of the job*"

5.7 Reasons for Program Participation

The online survey asked respondents what the main reason was for their participation in one of the Single Family Retrofit programs. Figure 17 shows the most frequently reported reason for program participation was to save energy or money (39%) and the second most cited reason for participation was being motivated by PSE rebates (18%). Twelve percent of respondents attributed their participation to their existing equipment failing or reaching end of life. These findings align well with what participants cited as aspects of the program that work well, namely achieving energy savings (see discussion in Section 5.4.1 above).

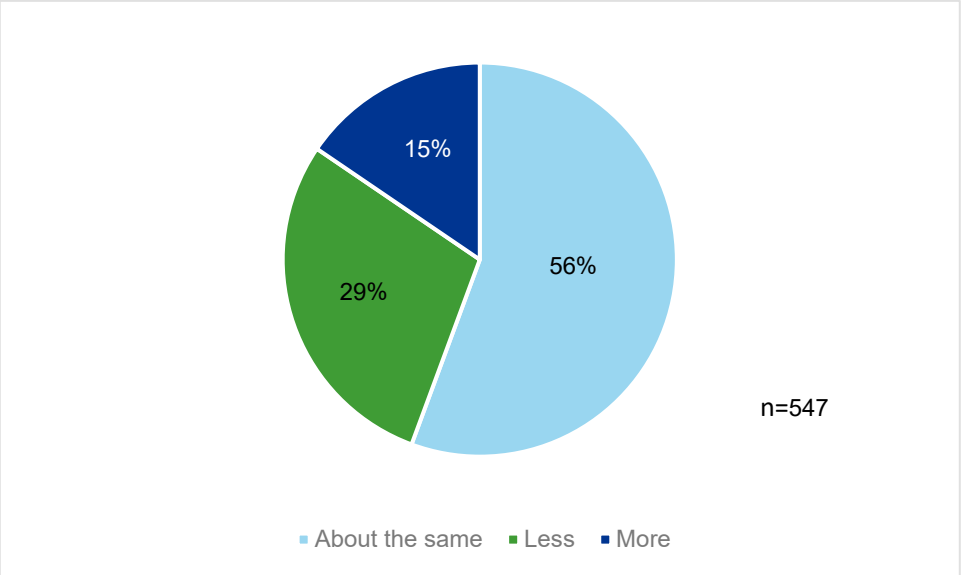
Figure 17. Reasons for Participation



5.8 Energy Use Behavior

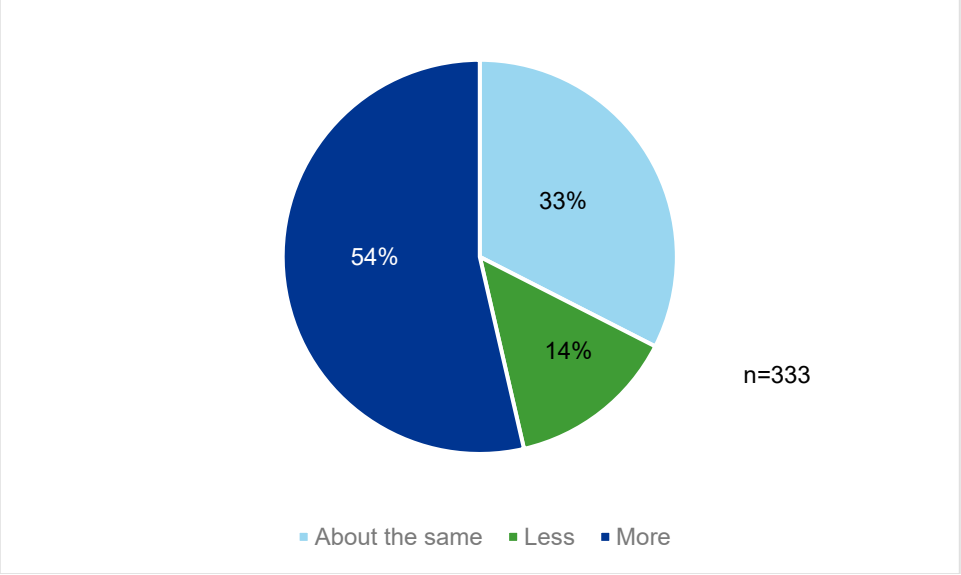
DNV asks participants how their energy use behavior has changed since receiving program upgrades. We first asked whether the use of their heating systems was more, less, or about the same since improvements were made (Figure 18). About half of respondents (56%) reported that they used their heating system about the same, and 29% reported they used their heating system less. Fifteen percent reported they were using their heating system more.

Figure 18. Use of Heating System After Program Improvements



The survey asked the same question concerning participants use of their cooling system post program improvements (Figure 19). Close to half of the respondents (54%) reported using their cooling system more, 33% reported using their cooling system about the same, and 14% reported using their cooling system less. The rise in temperatures and increase in frequency of heat waves in recent years may be a factor in participants reporting they are using their cooling systems more.

Figure 19. Use of Cooling System After Program Improvements



5.9 HVAC and Water Heater Market Trends

This section provides sales and market trend findings from contractors who report installing Heat Pump Water Heaters and Space Heaters. Contractors were first asked if they installed water heating equipment, spacing heating equipment, or both. Among the 22 contractors interviewed, the majority (n=13) reported installing both space heating and water heating equipment. The remaining nine contractors stated their company only installed space heating equipment.

5.9.1 Heat Pump Water Heater Results

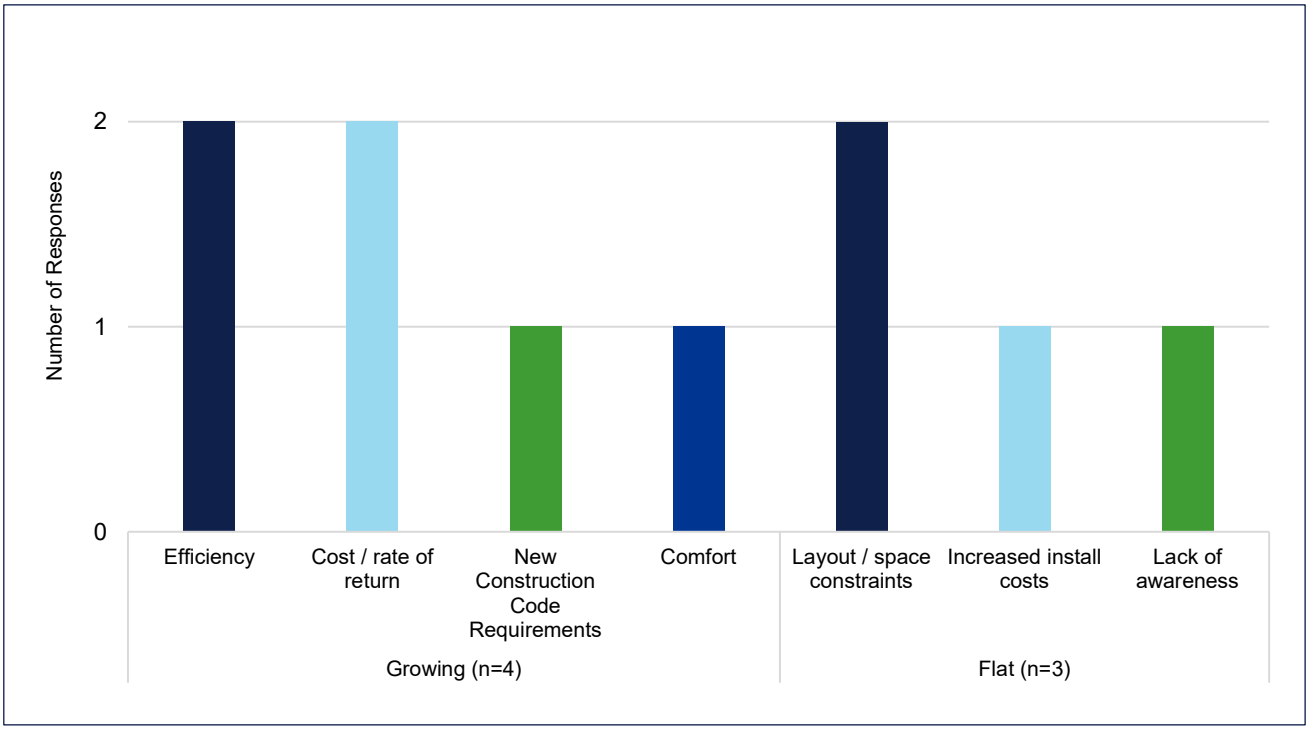
Evaluators asked all contractors who reported installing water heating equipment: a.) which of the following type of water heaters they install in the last few years, and b.) how many of each technology they install per year. As show in Table 25, all of the contractors who reported installing water heating equipment also reported installing conventional storage tank water heaters. Interestingly, respondents reported that on average they installed more tankless water heaters per year compared to conventional storage tank water heaters despite fewer contractors (10 vs. 13) installing this equipment type. A relatively smaller number of contractors reported installing hybrid heat pump water heaters (n=5) and integrated combination space and water heaters (n=4), with both also having a relatively low average number of installs per year (36 and 14, respectively).

Table 25. Contractor Reported Heat Pump Water Heater Sales

Equipment Type	Number of Installing Contractors (n=13)	Average Number of Installs per Year
Conventional storage tank	13	56
Tankless water heaters	10	60
Hybrid Heat pump water heaters	5	36
Integrated (combination) space and water heater	4	14

Next, this same subset of contractors who installed water heaters were asked if they thought the residential heat pump waters heater market is growing, declining, or relatively flat. Only 7 of the 13 contractors responded to this question, with just over half (n=4) stating the market seemed to be growing and the remaining respondents (n=3) reporting that the market appeared to be flat. Contractors were additionally asked to explain why they believed the market was trending one way or another. Figure 20 shows that the primary reason contractors believed the market was growing was due to the efficiency of the equipment and the cost / rate of return. Conversely, 'layout / space constraints' was the most commonly cited reason for why the market was believed to be flat; this sentiment is captured in the following verbatim response: "*Price is usually the driver - location factors make installs tough and more expensive with the extra cost on structural factors like relocating exhaust pipes to pump out cold air.*"

Figure 20. Reasons for Perceived Heat Pump Water Heater Market Trends



5.9.2 Heat Pump Space Heater Results

Evaluators also asked all contractors who reported installing space heating equipment: a.) which of the following type of space heating equipment they install in the last few years, and b.) how many of each technology they install per year (Table 26). Every respondent except for one stated they installed ductless heat pumps. A large portion of the contractors also installed all electric heat pumps (n=20) and split system equipment with gas heat (n=20) and electric heat (n=19), with fewer installing heat pumps with gas back up (n=14). In addition to ductless heat pumps being the most frequently installed, this equipment type also was found to have the highest volume of sales with contractors averaging 193 installs per year. Conversely, while heat pumps with gas back up were the least frequently installed equipment type, heat pumps with electric back up were found to have on average the least number of installs per year (104).

Table 26. Contractor Reported Heat Pump Space Heater Sales

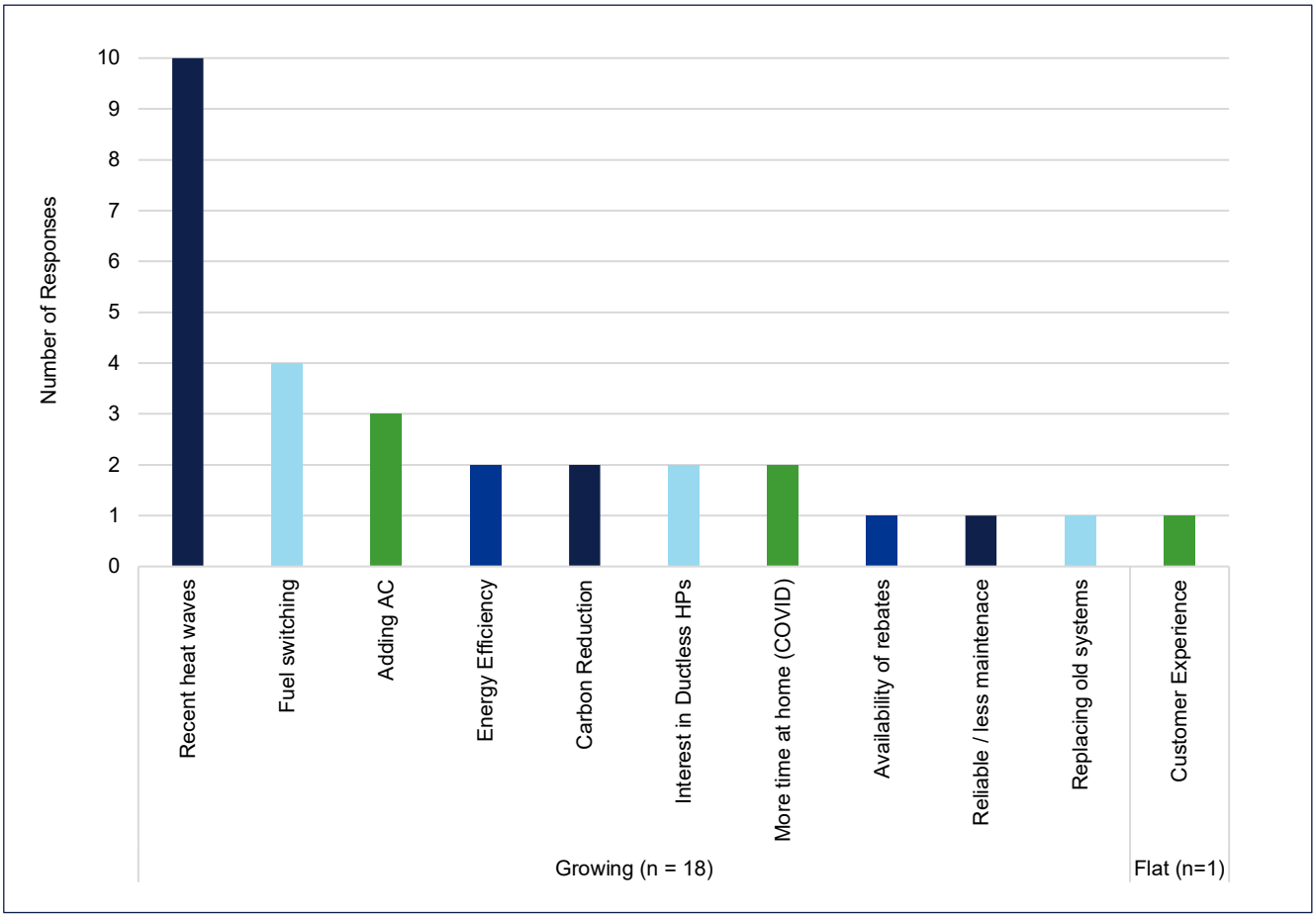
Equipment Type	Number of Installing Contractors (n=22)	Average Number of Installs per Year
Ductless heat pumps	21	193
Split system with gas heat	20	160
Split system with electric heat	19	142
Heat pump all electric	20	104
Heat pump with gas back up	14	115

Next respondents were asked if they thought the residential heat pump space heater market is growing, declining, or relatively flat. Compared to the relatively even split of contractors who though the heat pump water heating market was either growing or flat, respondents almost unanimously said they believed the heat pump space heating market to be growing. Figure 21 clearly shows the number one reason why contractors believe the heat pump space heater market is growing in PSE's territory is due to the recent summer heat waves:

- “I think it has been growing due to the weather and heat waves; people are spending more time at home due to COVID and realize the importance of a comfortable home.”
- “Summers are getting hotter and a third of homes in Seattle don't have A/C.”
- “Weather has been a big driver - folks are calling about heat pumps more often since temperatures have been on the rise.”
- “It’s getting warmer in the Pacific Northwest. People are spending more time at home and are more willing to invest.”
- “Ductless are in demand in our market. In the PSE area only 47% of the homes have A/C. The increase in demand is because the last 2-3 summers we have had very hot days compared to the last 20 years. Lots of homes do not have duct work and people want A/C, or they have central heating but no cooling and just want to add it to a place within their home. And in some cases, like multi-level homes, they just want to add more A/C to the top floors where it gets too hot. People just want part of the house to be cooled. When you have a multi-level, it is challenging to get cooling on the top floor.”

There was also a large variety of other reasons why contractors believe the market to be growing - ranging from homeowners wanting to switch fuel sources (gas to electric) to others believing the equipment is more reliable than alternatives - although these reasons were cited much less frequently compared to “recent heat waves.”

Figure 21. Reasons for Perceived Heat Pump Space Heater Market Trends



6 FINDINGS AND RECOMMENDATIONS

PSE's SFR program delivered 85% of its claimed electric savings and 64% of its gas claimed savings. DNV was able to verify that that 100% of the measures surveyed remotely were installed. In this section, we summarize overall findings from the evaluation and recommendations based on these findings.

6.1 Findings

Key findings from this study include the following:

- Electric space heating measures deliver 80% of claimed savings with significant variation of savings in measures delivered midstream versus downstream and between ducted and ductless heat pump systems. The midstream programs appear to have installed a sufficient share of heat pumps that converted gas heating to electric heat to undermine some portion of efficiency savings that were present for electric replacements.
- Gas space heating measures provide 37% of claimed savings, dominated by low realization rates for furnace replacements. Possible reasons for the low realization rate are discussed in Table 3 and Table 22.
- Both electric and gas water heating measures deliver over 90% of claimed savings.
- Electric and gas weatherization measures deliver 76% and 89% of claimed savings, respectively. These results are unlikely to be affected by baseline issues.
- Kit-only electric and gas installations (consisting of aerators and LEDs in the case of the former and aerators and showerheads in the latter) provide savings well in excess of the savings claimed for them. Given the weather-dependent nature of the savings, the installation of more efficient heating equipment that was not claimed through the program is a likely explanation and is supported by the program practice of sending kits to customers who did not qualify for a rebate.
- Results from the participant online survey and contractor phone survey suggest the Single Family Retrofit programs are working well, but there are opportunities to improve certain aspects of the program, such as messaging around energy savings to participants and marketing to contractors. This provides PSE with an opportunity to integrate non-energy benefits more explicitly into marketing material while also explaining that increasing setpoints to improve comfort could lead to higher energy bills.
- While participating contractors see cost as a barrier to adoption of space and water heating heat pump technologies, they generally agreed that the heat pump market is growing and cited recent heat waves in the Pacific Northwest as one of the main drivers of this growth.
- Clarifying measure names will make it easier to understand and analyze the data. Though the tracking data measure names gave some indication of the baseline condition ("from FAF"), the use of the words "from" and "with" can be clearer. For instance, "ductless HP from zonal" would seem to indicate that the zonal electric baseboard heat was removed, as opposed to "ductless HP with EFAF," which would seem to indicate that the electric forced air furnace was not removed when the new ductless heat pump was added. However, the consumption loadshapes indicated likely supplemental electric heating after the installation of both of those ductless heat pump measure types.

6.2 Recommendations

Recommendations based on the key findings are as follows:

- Conduct further research to shed light on the lower-than expected gas heating savings, potentially including:
    - Literature review – establish summary of known and remaining unknown impacts of COVID-19 on consumption and whether it has disrupted savings for other gas heating programs
    - Customer and program profile – Establish trends in program participation and identify whether there are underlying discrepancies between program participants and the general PSE population
    - Customer Survey – Continue to identify whether there are discrepancies between program participants and general PSE population; identify self-reported baseline equipment type and efficiency; identify use of equipment (primary/secondary); identify takeback (increases in post-period thermostat setpoint)
    - Contractor Survey – Identify general equipment baseline and program equipment use (primary or secondary) observations
    - Program Ride-Alongs – Identify sample of equipment baseline and program equipment use (primary or secondary)
    - Updated billing analysis for 2021-2022 single family retrofit gas program – Establish early (and potentially iterative) indication of 2021 and 2022 gas program savings to monitor program performance and determine if low savings trend continues.
- Program staff should coordinate with participating contractors to make sure that they are not overpromising on bill savings that participants see as a result of their program upgrades. Online survey suggest that a segment of program participants may be somewhat disappointed in the energy savings they receive from their upgrades. Contractors should emphasize the non-energy benefits of the program, such as improved comfort, air quality, and reduction in greenhouse gas emissions for electric measures while also explaining that increasing thermostat set points for improved comfort could result in higher energy bills.
- Consider tracking additional detail related to baseline and installation conditions for space heating equipment to support a more nuanced evaluation and provide the program with appropriate attribution. Additional tracking details could include:
    - Existing equipment capacity and efficiency ratings as well as baseline period operations (e.g., typical, broken – unused, broken- used but less efficient).
    - Installation is a like-for-like replacement versus a supplement to existing electric heating system and/or full substitution

7 APPENDICES

7.1 Appendix A: Sample Design

This section describes the applied sampling approach and sample summary for the remote verification and online surveys.

7.1.1 Single Family Retrofit Remote Verification Surveys

7.1.1.1 Sampling Approach

For this program both electric (kWh) and gas (therm) savings were claimed. In order to understand both electric and gas savings, separate samples were designed for each fuel type.

For the remote verification surveys, the sampling methodology employs a stratified ratio estimation technique. This stratified ratio estimation approach studies a subset of units, i.e., sample, drawn from the full population. We first place participants into groups of interest (fuel type and measure category) and then place them into strata by size, measured in terms of kWh and Therm savings. We then estimate appropriate sample sizes to achieve the targeted relative precision (±10%) at a desired level of confidence (90%) based on an assumed error ratio.

The first step in the sample design process was to identify a sampling frame of measures for each fuel type. Once sampling frames were defined, we stratified the population on the claimed energy savings (kWh or therms). Then we determined the target precisions and designed the sample to achieve ±10% relative precision for the program across all measures at the 90% confidence level using an assumed error ratio (ER) of 0.3 based on previous experience with similar studies.[10] In order to obtain insight into the largest measure groups, a minimum sample of 5 was established for each measure. Once sample sizes were calculated, we randomly chose sample points from the population in each stratum.

Once data for the sample had been collected and measure installation was verified, the measure group installation verification rate was calculated as:

$$b = \frac{\sum_{i=1}^{n} w_i \, y_i}{\sum_{i=1}^{n} w_i \, x_i}$$

Where b is combined ratio estimator, w_i is the stratum case weight, y_i is the measure verification status (0 or 1), and x_i is the assumed measure installation value of 1. The measure group verification rate is estimated as b times the program measure counts.

The relative precision at 90% confidence is calculated for b in three steps:

1. Calculate the sample residual $e_i = y_i - b\,x_i$ for each unit in the sample
2. Calculate the standard error $se(b) = \frac{\sqrt{\sum_{i=1}^{n} w_i \left(w_i - 1\right) e_i^2}}{\sum_{i=1}^{n} w_i \, x_i}$

[10] The error ratio is the ratio-based equivalent of a coefficient of variation (CV). The CV measures the variability (standard deviation or root-mean-square difference) of individual evaluated values around their mean value, as a fraction of that mean value. Similarly, the error ratio measures the variability (root-mean-square difference) of individual evaluated values from the ratio line Evaluated = Ratio multiplied by Reported, as a fraction of the mean evaluated value.

3. Calculate the relative precision $rp = \frac{1.645\ se(b)}{b}$ where 1.645 is the z-coefficient for the 90% confidence interval

7.1.1.2 Data Summary

The verification sampling frame was limited to the largest five electric measures and the largest four gas measures. Table 27 and Table 28 present the summaries of the measures included in the population data frame for electric and gas measures respectively.

Table 27. SF Retrofit Electric Measure Population Summary

Measure	Accounts	kWh Savings	Mean kWh Savings	Minimum kWh Savings	Maximum kWh Savings	Standard Deviation
Electric Home Heating	6,791	16,653,099	2,452	0	11,472	1,472
Electric Water Heating	772	976,342	1,265	0	2,510	128
Residential Midstream Home Heating	1,540	3,417,802	2,219	217	30,360	2,075
Residential Windows	1,354	1,662,857	1,228	2	14,777	1,197
Single Family Weatherization	1,173	1,865,335	1,590	9	13,250	1,310

Table 28. SF Retrofit Gas Measure Population Summary

Measure	Accounts	Therm Savings	Mean Therm Savings	Minimum Therm Savings	Maximum Therm Savings	Standard Deviation
Natural Gas Home Heating	11,527	1,268,110	110	0	220	12
Natural Gas Water Heating	2,845	138,457	49	15	561	12
Residential Windows	3,505	211,752	60	0	505	73
Single Family Weatherization	5,377	411,253	76	0	525	65

7.1.1.3 Sample Design and Selection

The sample was designed to achieve ±10% relative precision across all measures and fuel types for the defined sampling frame. Table 29 and Table 30 present the sample design summaries for the electric and gas measures respectively. The tables present the number of savings claims, total savings by fuel type, assumed error ratio, sample size, and the expected relative precision. The home heating measures for both electric and gas measures had the largest savings and were allocated the largest samples—30 for the electric measures and 10 for the gas measures.

Table 29. Electric Measure Sample Design

Measure	Accounts in Population	Tracking Savings (kWh)	Error Ratio	Sample	Expected Relative Precision
Electric Home Heating	6,791	16,653,099	0.3	30	9.2%
Electric Water Heating	772	976,342	0.3	5	22.1%
Residential Midstream Home Heating	1,540	3,417,802	0.3	5	26.7%
Residential Windows	1,354	1,662,857	0.3	5	27.6%
Single Family Weatherization	1,173	1,865,335	0.3	5	26.3%
Overall	**11,630**	**24,575,436**	**0.3**	**50**	**7.8%**

Table 30. Gas Measure Sample Design

Measure	Accounts in Population	Tracking Savings (Therms)	Error Ratio	Sample	Expected Relative Precision
Natural Gas Home Heating	11,527	1,268,110	0.3	10	16%
Natural Gas Water Heating	2,845	138,457	0.3	5	22%
Residential Windows	3,505	211,752	0.3	5	32%
Single Family Weatherization	5,377	411,253	0.3	5	27%
Overall	**23,254**	**2,029,572**	**0.3**	**25**	**12%**

As mentioned previously, a minimum of five sample points were allocated to all measures in the sampling frame to ensure a sufficient sample to provide statistically meaningful results (Table 31 and Table 32). Measures with more than 5 sample points were stratified by savings to efficiently allocate the sample within those measures. Measures with 5 sample points were not stratified; we drew a simple random sample from those measures.

Table 31. Electric Measure Stratification

Measure	Stratum	Maximum	Accounts	kWh Savings	Sample	Inclusion Probability
Electric Home Heating	1	1,997	3,500	4,887,286	10	0.0029
Electric Home Heating	2	3,517	1,988	5,564,950	10	0.0050
Electric Home Heating	3	11,472	1,303	6,200,863	10	0.0077
Electric Water Heating	1	2,510	772	976,342	5	0.0065
Residential Midstream Home Heating	1	30,360	1,540	3,417,802	5	0.0032
Residential Windows	1	14,777	1,354	1,662,857	5	0.0037
Single Family Weatherization	1	13,250	1,173	1,865,335	5	0.0043

Table 32. Gas Measure Stratification

Measure	Stratum	Maximum	Accounts	Therm Savings	Sample	Inclusion Probability
Natural Gas Home Heating	1	110	5,881	630,674	5	0.0009
Natural Gas Home Heating	2	220	5,646	637,436	5	0.0009
Natural Gas Water Heating	1	561	2,845	138,457	5	0.0018
Residential Windows	1	505	3,505	211,752	5	0.0014
Single Family Weatherization	1	525	5,377	411,253	5	0.0009

7.1.1.4 Results Post Stratification

Once the measure verification process was completed the data collected was post stratified to calculate the appropriate weights for the achieved sample. The achieved sample varied from the original design due to challenges in recruiting program participants for measure verification. Table 33 and Table 34 show the final achieved sample post stratification by fuel type and measure. The tables present the number of claims in the population, achieved sample, and number of customers (weight) that each customer represents in a given stratum.

Table 33. Electric Measure Post Stratification

Measure	Stratum	Maximum kWh Savings	Savings Claims	Total kWh	Sample	Weight
Electric Home Heating	1	1,997	4,103	6,091,477	10	410
Electric Home Heating	2	3,517	1,646	5,278,696	9	183
Electric Home Heating	3	11,472	1,042	5,282,926	5	208
Electric Water Heating	4	2,510	772	976,342	4	193
Residential Midstream Home Heating	5	30,360	1,540	3,417,802	3	513
Residential Windows	6	14,777	1,354	1,662,857	2	677
Single Family Weatherization	7	13,250	1,173	1,865,335	3	391

Table 34. Gas Measure Post Stratification

Measure	Stratum	Maximum	Savings Claims	Total Therms	Sample	Weight
Natural Gas Home Heating	1	220	11,527	1,268,110	4	2,882
Natural Gas Water Heating	2	561	2,845	138,457	4	711
Residential Windows	3	505	3,505	211,752	4	876
Single Family Weatherization	4	525	5,377	411,253	3	1,792

7.1.2 Single Family Retrofit Online Survey

The first step in the Single Family Retrofit email survey was to determine the number of completed surveys necessary. The team decided a sample of 1,000 customers was sufficient to answer the research questions identified. Based on prior survey efforts, DNV assumed a conservative 10% survey response rate. Given the desired sample of 1,000 respondents a total of 10,000 surveys were needed to reach this target. At the time of the sample design email addresses were not yet available to merge with the tracking data, so the sample size was increased to 14,000 to account for customers that can't be contacted for the survey due to missing email addresses.

The SF Retrofit program included measures with both electric and gas savings. In order to account for both of these fuel types, the survey sample was designed using annual kBtu consumption from billing data. Table 35 presents the population summary statistics and stratified sample design. A total of 67,262 customers enrolled in single family retrofit programs with an annual consumption of just over 2,708 million kBtu.

Table 35. Online Survey Sample Design

Program	Stratum	Maximum kBtu	Accounts	Annual kBtu Consumption	Sample	Inclusion Probability
SF Retrofit Participant	1	44,367,394	36,372	458,258,425,021	2,783	0.08
SF Retrofit Participant	2	57,426,272	9,971	507,839,777,278	2,783	0.28
SF Retrofit Participant	3	69,913,287	8,368	530,427,415,242	2,782	0.33
SF Retrofit Participant	4	88,022,957	7,103	552,593,582,562	2,782	0.39
SF Retrofit Participant	5	252,699,590	5,360	595,468,559,992	2,782	0.52
SF Retrofit Participant	6	23,664,373,863	88	63,604,149,574	88	1.00
Total			**67,262**	**2,708,191,909,669**	**14,000**	

7.2 Appendix B: Data Collection Instruments

PSE SINGLE FAMILY RETROFIT (SFR) PARTICIPANT SURVEY

Program Measure Categories

PSE's SFR program provides funding for the following measure categories:

Residential Space Heating: natural gas furnaces, boilers, integrated space and water heat systems, and electric resistance conversions to ductless and unitary heat pumps.

Domestic Hot Water (DHW): heat pump water heater, gas storage tank water heater, tankless water heater, integrated space/water heater

Smart Thermostats: ENERGY STAR certified smart thermostat or PSE qualified Line Voltage Connected Thermostat at participating retailers. Wi-Fi enabled smart thermostats

Weatherization/Shell: Insulation: attic, floor, wall, air sealing, duct sealing and installation, duct sealing only

CUSTOMER NOTIFICATION EMAIL

Email: From [EESEvaluations@PSE.com]

Subject: PSE Requests your feedback with the [Program Name]

Dear [CUSTOMER],

We would like to hear about your experience with the PSE [Program Name] program services performed back in [YEAR INSTALLED]. As a participant in PSE's program, your opinions are important. PSE would like your input and perspectives to understand how to best structure future energy efficiency programs designed for customers like you.

Your participation is requested in a brief [6]-minute survey about the home at: [ADDRESS]. As a thank you, your response will be entered a **drawing for a one-hundred-dollar incentive**. The information gathered will be used solely for research purposes and your individual responses will be kept completely confidential.

To get started click on this link: [ST]

DNV is the research provider retained by PSE to help administer this survey. Please contact me you'd like to validate the legitimacy of this survey

Thank you for helping to improve energy efficiency programs in Washington.

Kasey Curtis
Sr. Market Analyst
Strategic Planning, Evaluation and Research
Cell: 206-713-3052
kasey.curtis@pse.com

Any questions about this study may be directed to the study contractor DNV GL at: support.pse@dnv.com

If you would like to be removed from this survey, please click on this link [remove]

Screener

1. Do you still have an active account with PSE at this address {ADDRESS}?

   a1. Yes
   a2. No

2. According to PSE's 2019-2020 records, your household received rebates(s) for energy saving upgrade(s) or free energy saving kits. And for some customers, PSE may have paid a rebate to the installing contractor, which may have shown up as a discount on your contractor invoice. Do you remember having these upgrades made or receiving energy savings kits sponsored by PSE?

   a1. Yes
   a2. No[T&T}

SURVEY

Verification, Awareness, and Reasons for Participation

[Skip this section Q1-Q5 if measures are not of interest, e.g., "kits", LED lighting and/or aerators]

1. Just to verify, are you aware of the following upgrades associated with this program? Please check all upgrades your aware of:

[Measx]	[check all that apply]

2. Are you still using the upgrades associated with this program or have you removed/replaced them?

[Measx]	[Using Energy Saving Upgrades]	[Not Using Energy Saving Upgrades]

3. Have you made any additional upgrades to your home or installed any new equipment while these changes were made or since then?

   a1. Yes, completed additional upgrades
   a2. No additional upgrades

4. What other improvement did you make?

   a1. Lighting
   a2. Appliances
   a3. Heating
   a4. Water heating
   a5. Insulation
   a6. Windows

a7. Added spa/hot tub/pool
a8. Added electric vehicle and/or charger
a9. Added battery storage
a10. Added solar electricity
a11. Other, please specify:

5. [SHOW IF WATER HEATER REBATE] What was the condition of the old heating equipment when it was removed was it…

a1. Working but inefficient
a2. Working but in need of minor repair
a3. Working but in need of significant repair
a4. Failed was no longer working
a5. N/A new installation
a6. Don't recall

6. [SHOW IF HEATER REBATE] What was the condition of the water heating equipment when it was removed was it…

a1. Working but inefficient
a2. Working but in need of minor repair
a3. Working but in need of significant repair
a4. Failed was no longer working
a5. N/A new installation
a6. Don't recall

7. f

8. How did you learn about the PSE program? Select one response.

a1. Contractor
a2. PSE energy advisor
a3. PSE bill insert
a4. PSE.com
a5. PSE email
a6. PSE marketing collateral, signage at retail store
a7. Word of mouth
a8. Previous participation
a9. PSE energy efficiency campaigns not limited to: email, advertising earned and paid media, press releases, direct mail, PSE outreach
a10. Community events and sponsorships
a11. Other: specify
a12. Don't recall

9. Thinking back to the time when you were making the decision to participate in this program, what was the main reason you choose to participate?

a1. Save energy/save money
a2. PSE rebate
a3. Free equipment
a4. Recommendation from a contractor
a5. Equipment failure or end of useful life
a6. Early replacement to save energy
a7. Improve comfort, health, safety
a8. Reduced carbon emissions/climate change/good for the environment
a9. Renovation or remodel
a10. Don't know

Heating, Cooling, and Energy Use

[Skip this section if measures are not of interest, e.g., appliances, lighting, thermostats, aerators]

10. Which of the following natural gas appliances do you use? Select all that apply.

a1. Gas cook-top/range
a2. Gas clothes dryer
a3. Gas water heating
a4. Gas heater
a5. None of these
a6. Don't know

11. What is the main heating system used to heat this home? [Select one]

a1. Floor or wall heater
a2. Central furnace/heat pump

a3. Hot water radiator
a4. Electric baseboard
a5. Fireplace (gas/wood)
a6. Plug-in portable space heater
a7. Ductless heat pump
a8. Other [SPECIFY]
a9. Don't know

12. What other sources, if any, do you use to supplement your heat? Select all that apply.

a1. No other sources
a2. Fireplace (gas/wood)
a3. Plug-in portable space heater
a4. Floor or wall heater
a5. Central furnace/heat pump
a6. Hot water radiator
a7. Electric baseboard
a8. Ductless heat pump
a9. Other [SPECIFY]
a10. Don't know

13. Do you use air conditioning?

a1. Yes
a2. No

14. What is the main cooling system type to cool this home? Select all that apply.

a1. Central air
a2. Window or portable unit
a3. ductless
a4. Other
a5. Don't know

15. What type of thermostat is installed in your home?

a1. Non-programmable/manual thermostat
a2. Programmable thermostat that can be set to different temperatures for different times
a3. Smart thermostat, e.g., Nest, Lyric, Sensi or Ecobee
a4. Don't know

16. How do you use your programmable thermostat?

a1. Set a temperature and leave it alone [exclusive]
a2. Manually adjust temperature to meet my comfort
a3. Use a programmed schedule and rarely override
a4. Thermostat is off for most months of the year
a5. Smart thermostat automatically responds to my heating/cooling needs
a6. None of these [exclusive]
a7. Don't recall

17. Have you experienced any of the following benefits as a result of your participation in this program such as, improved comfort, air quality, safety, or the home is quieter?

a1. Yes
a2. No [Skip to Q25]

18. Would you say your home comfort since these home upgrades have been made, is more comfortable, less or about the same level of comfort?

a1. More comfortable
a2. Less comfortable
a3. About the same [exclusive]
a4. Don't recall

19. If [Q18=a1], what are some of the sources of discomfort that you previously experienced? Select all that apply.

a1. Often too hot or too cold
a2. Occasionally too hot or too cold
a3. Large temperature swings
a4. Drafts from leaky windows/doors/vents
a5. Poor air circulation
a6. Thermostat not responsive enough
a7. Water heater is not responsive enough
a8. Loud appliances
a9. Air quality
a10. None
a11. Other, specify:
a12. Don't recall

20. If [Q18=a2] What are some of the sources of discomforts that you are currently experiencing? Select all that apply.

a1. Often too hot or too cold
a2. Occasionally too hot or too cold
a3. Large temperature swings
a4. Drafts from leaky windows/doors/vents
a5. Poor air circulation
a6. Thermostat not responsive enough
a7. Water heater is not responsive enough
a8. Loud appliances
a9. Air quality
a10. None
a11. Other
a12. Don't recall

Next, I would like to know, since receiving these upgrades, what changes, if any, have you made to the way you heat or cool your home.

21. Since these improvements have been made, would you say you're using the heating system more, less or about the same?

a1. More
a2. Less
a3. About the same
a4. Not applicable (e.g., use Wood heat)

22. How about cooling, since these improvements have been made would you say you're using the cooling system more, less or about the same?

a1. More
a2. Less
a3. About the same
a4. Not applicable

Satisfaction with the Program

Thinking about your experience with the program, I'd like to ask about various aspects of satisfaction with program delivery.

23. Using a scale of 1 to 5 where 1 means very dissatisfied, 2 is somewhat dissatisfied, 3 is neither satisfied nor dissatisfied, 4 is somewhat satisfied, and 5 is very satisfied, how satisfied are you with the following program components?

Program Components	Rating	For any component of the program you are less than satisfied with (<4), please indicate what is the cause of dissatisfaction and what needs to be done to correct it
a1. Eligibility requirements	1 2 3 4 5	
a2. Ease of submitting documentation	1 2 3 4 5	
a3. Quality or work done by the installation contractor	1 2 3 4 5	
a4. The services or products installed	1 2 3 4 5	
a5. The comfort of your home since receiving these upgrades	1 2 3 4 5	
a6. Energy savings since receiving these upgrades	1 2 3 4 5	
a7. Your experience overall	1 2 3 4 5	

24. Thinking about this program and your overall experience, what aspects of the program went well? [record]

a1. Rebates
a2. People who I interacted with
a3. Ease of use
a4. Energy savings
a5. Improved occupant comfort
a6. None
a7. Other
a8. Don't know

25. What aspect of the program could be improved? [record]

a1. More advertising
a2. Training for contractors
a3. More oversight of contractors, improve service
a4. Offer more rebated equipment
a5. Increase rebate amounts
a6. Other, specify:
a7. No suggestions
a8. Don't know

About Your Home

These last questions help better understand customers who utilize these programs. This information is collected for internal purposes only and remains confidential.

26. For each of the following age groups, how many people, including yourself, live in this home at least 6-months a year? Please select one response for each age category.

Age Category:

a1. Under 5
a2. 6 to 18
a3. 19 to 65
a4. 65 and older

27. Has the number of household residents changed since [month/year]? Select all that apply.

a1. Increased
a2. Decreased
a1. Unchanged
a2. Prefer not to say

28. [If Q19= a1 or a2 then ask otherwise skip]: How many more/fewer people live in your home?

a1. Increased by qty:
a2. Decreased by qty:

29. What is the primary household language?

a1. English
a2. Spanish
a3. Chinese (including Mandarin and Cantonese)
a4. Tagalog
a5. Vietnamese
a6. Korean
a7. Prefer not to say
a8. Other (please specify)

30. What is the highest degree or level of school you have completed? If you're currently enrolled in school, please indicate the highest degree you have received.

a1. Less than a high school diploma
a2. High school degree or equivalent
a3. Vocational/trade school or associate degree
a4. Bachelor's degree (e.g., BA, BS)
a5. Master's degree (e.g., MA, MS, MEd)
a6. Doctorate (e.g., PhD, MD, EdD)
a7. Prefer not to say
a8. Other (please specify)

31. Do you own or rent?

a1. Own
a2. Rent

32. Which of the following building types best describes your home?

    a1. Single-family detached home (home not attached to another home)
    a2. Townhouse, duplex, or row house (shares exterior walls with neighboring unit, but not roof or floor)
    a3. Apartment or condominium (2–4 units)
    a4. Apartment or condominium (5 or more units)
    a5. Mobile home
    a6. Other

33. Please check the range that best describes your household's 2020 total annual income.?

    a1. Less than $10,000
    a2. $10,000 – $19,999
    a3. $20,000 – $24,999
    a4. $25,000 – $49,999
    a5. $50,000 – $74,999
    a6. $75,000 – $99,999
    a7. $100,000 – $149,999
    a8. $150,000 – $174,999
    a9. $175,000 – $199,999
    a10. $200,000 – $249,999
    a11. $250,000 or more
    a12. Prefer not to say

34. This concludes our survey. As a thank you for your participation your response will be entered into a drawing for a $300 Amazon e-gift card. If selected as the winning respondent, you will be notified by email. Would you like to be included in the incentive drawing?

    a1. Yes, include my response in the drawing
    a2. No, exclude my response in the drawing.

CONTRACTOR SINGLE-FAMILY RETROFIT SURVEY

ADVANCE LETTER

Dear Contractor,

Puget Sound Energy is currently evaluating its residential space and water heating rebate programs. You are receiving this email because our records show your company is part of PSE's Trade Ally Network (TAN) and that you may have installed rebated equipment in PSE service territory. We would like to request your participation in a brief telephone survey on how the rebate program can better collaborate with contractors to promote the installation of energy efficient equipment.

PSE has retained the energy consulting company and independent program evaluator, DNV Energy (www.dnv.com), to support this effort. This email serves to authorize their request for information.

Sometime in the next few weeks a representative from DNV may contract your company to request participation in a brief 10 minute survey. If you would like to suggest a representative from your company to participate in this effort, you may contact DNV directly at, DNV Energy: Amber Watkins, (707) 820-4400 or by emailing support.pse@dnv.com

Reward for your Participation. Upon completion of the survey, DNV will offer you a $25 e-gift card from Amazon for your participation in this research effort. Your feedback will help PSE improve its energy efficiency program offerings and help customers save energy. Your cooperation is most appreciated.

Sincerely,

Kasey Curtis
Sr. Market Analyst
Strategic Planning, Evaluation and Research

Puget Sound Energy
355 110th Ave NE
Bellevue, WA 98004

1 SURVEY

Hello ____ my name is ___ and I'm calling on behalf of Puget Sound Energy here at DNV Energy. According to PSE records, your company performed at least one installation that received a rebate from PSE's incentive program. As the sponsor of this program, PSE would like to gather some information from your company in order to improve the program.

1. Who could I speak with at your company who is familiar with the residential sales practices or installations at your company? [Record]

2. Is that person available now?

    a1. Yes – continue
    a2. No- call back/leave message

3. First can you tell me about yourself, what type of work do you do for your company? Are you a…
    a1. Sales Associate a2. Sales Manager

a3. General Manager
a4. President /Owner
a5. Technician
a6. Administrator
a7. Other Specify)
a8. [Don't Know]
a9. [Refused]

4. According to PSE records, your company installed energy saving equipment rebated in one of PSE's residential existing homes programs sometime in the last couple years. Are you familiar with PSE rebate?

a1. Yes
a2. No [probe to see if there is someone else who might know of it]

5. Has your company received a rebate or installed rebated equipment from PSE since 2019 or 2020 to your knowledge?
a1. Yes
a2. No
a3. Don't know

1.1 Equipment Sales

6. What type of equipment do you install? Water heating, space heating, or both types of equipment?
a1. Water heating
a2. Space heating
a3. Both
a4. Neither [thank and terminate]

1.2 HP Water Heater Sales

[If Q6=a1 water heating, ask Q7; else, skip to Section 1.3]

7. In the last few years which if the following type of water heaters have you installed?

8. Thinking about the water heaters you installed, can you rank them in the order that you install the most to the least?

9. About how many of each kind do you install each year?

Type	Q7. Install this type?	Q8. Rank	Q9. Num. of units sold
A1. Conventional storage tank	Yes/No/Don't know		#
A2. Tankless water heaters	Yes/No/Don't know		#
A3. Hybrid Heat pump water heaters	Yes/No/Don't know		#
A4. Integrated (combi) space and water heater	Yes/No/Don't know		#

10. Have you ever purchased a Heat Pump water heater from retail stores such as Home Depot or Lowe's or do you always buy them from a distributor?
a1. Distributors only
a2. Home Depot or Lowe's only
a3. Both distributors and Home Depot/Lowe's
a4. Other

11. [IF 10=a3, else skip to 11] What percent of you heat pump water heater purchases are through traditional distributors versus retail (Home Depot or Lowe's)? [TOTAL SHOULD EQUAL 100% BETWEEN THE 2 CATEGORIES]
    a1. Distributor purchase percentage
    a2. Home Depot/Lowe's percentage
    a3. Other sources:

12. [IF 10=a2 or a3, else skip to 11] Of the heat pump water heaters that you purchase at Home Depot or Lowe's, what percent do you install in residential versus commercial buildings?
    a1. Residential
    a2. Commercial

13. [IF 10=a2 or a3, else skip to 11] Of the residential heat pump water heaters that you purchase at Home Depot or Lowe's, what percent do you install in existing buildings versus new construction buildings?
    a1. Existing building percentage
    a2. New construction percentage

14. [IF 10=a2 or a3, else skip to 11] Why do you purchase heat pump water heaters at Home Depot or Lowe's?
    a1. Utility rebates
    a2. Cost (lower price)
    a3. Other reason (record)

15. Is purchasing heat pump water heaters at Home Depot or Lowe's common among other contractors in your industry?

    a1. Yes
    a2. No
    a3. Don't know

16. In your opinion are heat pump water heaters a growing market, declining, or relatively flat market for residential?
    a1. Growing
    a2. Declining
    a3. Flat

17. Why do you say that?

18. Thinking about all the water heaters installed in the last year, about how many customers switch their fuel type to electricity from gas or propane _____Number/ Don't know

19. Given the range of products available on the market today does your company recommend heat pump water heaters?
    a1. Yes [why?]
    a2. No [why not?]

1.3 HP Space Heaters

If they sell both water heaters and space heaters read statement: "Next, I'd like to ask you some questions about the space heating equipment you install."

20. In the last few years, which if the following type of space heating units have you installed?

21. Thinking about the water heaters you installed, can you rank them in the order that you install the most to the least?

22. About how many of each kind do you install each year?

Type	Q20. Install this type?	Q21. Rank	Q22. Num. of units sold
A1. Split system with gas heat	Yes/No/Don't know		#
A2. Split system with electric heat	Yes/No/Don't know		#
A3. Heat pump all electric	Yes/No/Don't know		#
A4. Heat pump with gas back up	Yes/No/Don't know		#
A5. Ductless heat pumps	Yes/No/Don't know		#

23. [If Q20=a2, a3, a4, or a5] Thinking about all the space heating systems installed in the last 12 months, about how many customers switch their fuel type to electricity from gas or propane _____Number/ Don't know

24. In your opinion are heat pump space heaters a growing market, declining, or relatively flat market for residential?
    - a4. Growing
    - a5. Declining
    - a6. Flat

25. Why do you say that?

26. [Skip if Q7 ≠ a3 and Q20 ≠ a3, a4, or a5] What is the main reason your customers install **HEAT PUMPS=FOR SPACE HEATING OR WATER HEATING?**

    - a1. Save money
    - a2. Save energy
    - a3. Availability of rebates
    - a4. Better use of solar electricity
    - a5. Good for the environment
    - a6. Equipment failure/end of useful life
    - a7. Equipment purchase was affordable
    - a8. Health and safety
    - a9. Recommendation from a 3rd party or contractor
    - a10. Appeal to prospective renters
    - a11. Pairs well with solar
    - a12. Don't know
    - a13. Other reasons, specify

27. Given the range of products available on the market today does your company recommend heat pump space heaters?
    - a1. Yes
    - a2. No

28. Why do you say that?

1.4 Barriers

29. To improve the advancement and adoption of the space and water heat pump technologies, we would like to know what barriers need to be addressed. We broke out the barriers into five categories of [A1-A5]. For example, if we think of the financial barriers, the barriers may be factors like higher first costs, or payback. If the barrier is educational, it could be inexperienced contractors or customers unfamiliar with the technology, or

it could be resources based, a limited supply of equipment, or is operational like maintenance that needs to be done on the system, slower heating times, or is it structural like products may not be drop in ready or electrical load/panel limitations, etc.

a1. Resource
a2. Education
a3. Structural
a4. Operational
a5. Financial
a6. All of the above
a7. None of these/no barriers
a8. Don't know

1) **Resource Barriers**
Availability of equipment

2) **Educational barriers:**
Unfamiliar or inexperienced with the products - Workforce Education and Training
Customers lack interest of benefits
Need better support from manufacturers, technical guides for design build
Service requires different contractor skill set
Insufficient information
Qualified contractors

3) **Structural/Technology**
Electrical panel upgrades
Products may not be drop-in (physical, electric, plumbing for existing natural gas equipment)
Installation space constraints
Code compliance
Home upgrade requirements
Panel upgrade requirements

4) **Operational Barriers**
Maintenance needs to be done on refrigerant
Heat pumps are slower and change temperatures slower than natural gas
Noisy

5) **Financial Barriers**
Higher upfront cost
Insufficient incentives to attract customers
Insufficient payback
Installation cost

30. After all the barriers we discussed, what do you think are the top three barriers to heat pump and heat pump water heater adoption (rank in order of significance)?

31. What do you think should be done to address these barriers? [Probe on barriers in each category]

32. How do these barriers differ by water heating and space heating?

33. Next, I'd like to ask about rebate amounts. In your opinion, are the following rebate levels adequate to move program equipment sales?

Measure Type	Incentive	Good/Bad	What incentive level would be needed to move consumer demand?
Heat Pump - Air Source - 10.0 HSPF		Good/Bad	
Heat Pump - Ductless - from Zonal - 9.0 or greater		Good/Bad	
Heat Pump - Split system Less than 65 kBtuh		Good/Bad	
Heat Pump Water Heater Tier 3		Good/Bad	
Heat Pump - with AC		Good/Bad	

1.5 Program Experience

Lastly, I would like to ask about your company's experience with the program.

34. On a scale of 1 to 5 where 5 indicates "very important" and 1 indicates "not very important," how important are the PSE rebates to selling equipment to your customers?

    a1. Very important
    a2. Important
    a3. Somewhat important
    a4. Not very important
    a5. Not at all important
    a6. Don't know

35. Can you please rate your satisfaction with the following program aspects, using the satisfaction ratings of 1 to 5 where 1 is not satisfied and 5 is very satisfied. How satisfied are you with...?

    a1. Online Portal (Application) Process: [1-2-3-4-5]
    a2. Website [1-2-3-4-5]
    a3. Marketing Efforts [1-2-3-4-5]
    a4. Rebate Delivery [1-2-3-4-5]
    a5. Incentive Amounts [1-2-3-4-5]
    a6. Interaction with Program Staff [1-2-3-4-5]
    a7. Overall Satisfaction [1-2-3-4-5]

36. On a scale of 1 to 5 where 5 indicates "very active" and 1 indicates "not very active," how actively has your company promoted rebates offered by Puget Sound Energy?

    a1. 1 Not very active
    a2. 2
    a3. 3
    a4. 4
    a5. 5 Very active
    a6. 97 [DON'T KNOW/NOT SURE]
    a7. 98 [REFUSED]

37. [<4 then ask] Why haven't you been more active in promoting these rebates? [record]

38. How, if at all, are the rebates incorporated into your company's sales pitch or marketing materials? [record]

39. Are there any other upgrades or services you recommend PSE rebate that they are not currently?

This concludes all the questions I have for you today. Do you have any questions before we finish?

1. As a thank you for your participation, we offer a $25 Amazon gift card in email form. Would you like to provide your email for this? [Record]

    Email:
    Decline:

7.3 Appendix C: Consumption Data Analysis Methodology

This section provides the details of the two-stage consumption data analysis approach DNV used to estimate the impact of single family retrofit programs.

7.3.1 First-stage models

In the first stage, we estimate individual daily regression models of energy consumption for all customers in the residential analysis population. The models estimate consumption as a function of heating and cooling degree days, using daily data. Consistent with PRISM, these models identify the heating and cooling degree day base that support the best, most informed model. This individualized, site-level approach produces models that reflect the unique heating and cooling consumption dynamics of a house and its occupants. These models are required to put pre- and post-period consumption on a consistent weather basis. They also provide useful information on heating and cooling consumption.

The first-stage regression model used to estimate the effect of weather on energy consumption is given by:

$$E_{im} = \beta_0 + \beta_h H_{im}(\tau_h) + \beta_c C_{im}(\tau_c) + \varepsilon_{im}$$

Where:

E_{im} - Average electric (or gas) consumption per day for participant i during period m.

$H_{im}(\tau_h)$ - Heating degree-days (HDD) at the heating base temperature reference temperature, τ_h.

$C_{im}(\tau_c)$ - Cooling degree-days (CDD) at the cooling base temperature, τ_c, (not included in gas models).

$\beta_0, \beta_h, \beta_c$ – Site-level regression coefficients measuring intercept (base load), heating load, and cooling load, on a single year's energy consumption, respectively.

τ_h - Heating base temperatures, determined by choice of the optimal regression.

τ_c - Cooling base temperatures, determined by choice of the optimal regression.

ε_{im} – Regression residual.

Consumption is estimated over a range of 64°F to 80°F for cooling and 50°F to 70°F for heating to identify the temperature base points for each site (household); statistical tests identify the optimal set of base points. The site-level models produce parameters that indicate the level of energy consumption not correlated with either HDD or CDD (baseload), and the levels of energy consumption correlated with HDD (heating load) or CDD (cooling load). We estimated site-level models using daily data. First-stage models were screened to remove estimates that had implausible (negative) cooling and heating coefficients. They were also screened to remove models with poor fit (low R squared values).

Model parameter estimates for each site allow the prediction of site-level consumption under any weather condition. For evaluation purposes, all consumption is put on a typical weather basis, using typical meteorological year (TMY) values, and produces an estimate referred to as normalized annual consumption (NAC). NAC values for the pre- and post-installation periods are calculated for each site and analysis time frame by combining the estimated coefficients $\hat{\beta}_h$ and $\hat{\beta}_c$with the annual TMY degree days H_0 and C_0 calculated at the site-specific degree-day base(s), $\hat{\tau}_c$ and $\hat{\tau}_h$. NAC is given by:

$$NAC_i = (365 \times \hat{\beta}_0) + \hat{\beta}_h H_0 + \hat{\beta}_c C_0$$

Individual household level regression models are estimated using observed weather data from Automated Surface Observing Systems (ASOS). Associated TMY data are used to weather normalize annual consumption using the estimated model parameters. The process serves two purposes; first, putting pre- and post-installation consumption on the same

weather basis so that change in weather is not conflated with program effect, and second, choosing a weather basis that represents a reasonable expectation of future weather for the ex-ante projections.

For each home in the analysis, NAC is determined separately for the pre- and post-installation years, and the pre-post difference ΔNAC_i is calculated. Pre- to post-installation changes in weather normalized energy use formed the basis of the second stage DID models.[11]

7.3.2 Comparison group

The impact evaluation follows site-level billing analysis methodologies to provide valid estimates of changes in gas and electric consumption for program participants. A key challenge for this kind of study is establishing the correct baseline from which to quantify change. The industry-accepted and recommended approach combines pre-installation data and a matched comparison group to produce a baseline that accounts for non-program-related change occurring during the evaluation timeframe.

Developing a well-matched comparison group for the participants is essential to the impact evaluation's success. It involves the identification of non-participant households that are similar to participants in relevant observable characteristics within certain strata such as dwelling type and location. Matching is an art that balances the number and complexity of matching variables with the level of stratification.

We constructed matched comparison groups from general population customers for the analysis. This effort involved identifying 1 household for every participant with similar energy use levels (constructed using daily electric and gas data) and tenure. Since PSE's residential customers are primarily located in a single climate zone, the matching did not involve stratification by geographic region.

In all cases, matching models included annual energy use, the ratio of summer-to winter energy use to account for seasonality, and measures of peak demand to construct 1-to-1 matches. For gas, we used daily gas consumption for identified 'cool wave' periods to capture winter peak demand conditions. Such periods were identified for weekdays from December through February where most customers had their maximum daily gas use. For electricity, we identified 'cool wave' period energy consumption similarly and additionally used daily electricity consumption to identify 'heat wave' periods to capture summer peak demand conditions. 'Heat wave' periods were identified for weekdays from June through September where most customers had their maximum daily kWh.

For both gas and electricity matching, we also used tenure as an additional matching variable. Tenure is the length of time, measured in years, that a customer has resided at a premise. It is based on account start dates available for every customer in PSE's records. We measure tenure as the difference, in years, from such account start dates to the beginning of the analysis period for this study, which is 2018. This measure is rounded to the nearest integer such that households residing less than half year relative to the start of 2018 are considered to have tenure of 0. While load markers such as annual energy use and peak demand identify like customers on the basis on energy use at a particular point in time, tenure helps identify like customers with similar energy use trends or changes in energy use over time.

We used Mahalanobis minimum distance matching without replacement for all matches used in the analysis. Mahalanobis distance matching is scale-invariant and considers correlations of covariates to generate matches that are well-balanced. Balance is tested using standardized mean differences, the ratio of the variance of participant to matched comparison households, and visual inspection of the distribution of covariates of participants to matched comparison households.

[11] They were also used to determine and exclude outliers based on statistical tests; DID values exceeding pre-defined DFITS or studentized residual limits were considered outliers and excluded from the second stage DID models. No more than 2-4% of observations were excluded based on such tests.

Following matching, tests of balance were conducted to test the condition of matches. The tests involved a comparison of the empirical distribution of matching variables via plots of their distribution, and the evaluation of their standardized mean differences and the ratio of their variances for the matched groups. The standardized mean difference is given by:

$$d = \left(\bar{X}_{treatment} - \bar{X}_{comparison}\right) / \sqrt{\left(S^2_{treatment} + S^2_{comparison}\right)/2}$$

A standardized mean difference value that exceeds 0.2 shows extreme imbalance, while the closer to 0 this value gets, the better the condition of matching. For the variance ratio, a value close to 1 indicates balance while values that are 0.5 or less and 2 or greater indicate extreme imbalance.[12]

7.3.3 Second-stage models

We estimated program impacts with a second-stage model that compares the pre-and post-installation site-level normalized annual consumption (NAC) between participant and comparison households. We produced the NACs with the site-level models and then captured the change in NAC between pre-and post-installation periods (∆NAC). Comparison group ∆NAC provided a proxy for the non-program change occurring between the two time-periods. This is a simple but robust model that can be estimated for geographical areas, consumption groupings or within any of the dimensions of interest.

The precision of the program-wide savings estimates is a function of the number of participants that can be incorporated into the analysis. Consumption data analyses for a program of this size estimating changes of this magnitude is expected to provide results with good relative precisions. While the analysis requires a year of pre- and post-installation data, the availability of interval data makes it possible to ease this requirement to 90% of pre- and post-period allowing the retention of data from more customers.

Pre- and post-program periods are based on a definition of a blackout period for each participant. We used installation dates from the tracking data to define a blackout period. While the majority of installations occurred within a single month for which we defined a month blackout period, we also include projects with 2-month installation periods and defined 2-month blackout periods for these installations.

The pre- to post-installation difference in NAC, which formed the basis of the DID model used to model whole-home energy changes, is given by:

$$\Delta NAC_i = \alpha_0 + \beta T_i + \varepsilon_i$$

In this model, i subscripts a household and T is a treatment indicator that is 1 for participant households and 0 for the matched comparison homes. The effect of program measures is captured by the coefficient estimate of the term associated with the treatment indicator, $\hat{\beta}$.

[12] Details of these tests are provided in http://www.iepec.org/2017-proceedings/65243-iepec-1.3717521/t001-1.3718144/f001-1.3718145/a011-1.3718175/an042-1.3718177.html

7.4 Appendix D: Impact Evaluation Details and Results

This appendix contains second-stage model results used to evaluate program installations.

7.4.1 Second-stage model results

SFR site-level, weather-normalized estimates of pre-post consumption difference are summarized in second-stage models. The intercept values from these models provide the percent change in weather normalized energy use that is not program or measure related. Negative intercept coefficients indicate, on average, increases in non-program related energy use while positive coefficients indicate decreases in non-program related energy use.

Table 36 provides coefficient estimates from kit-only electric savings per home model runs for NAC and its components. The intercept term estimates are negative for NAC and baseload indicating increasing trend in non-program related electricity use from pre- to post-retrofit periods for these two groups of electricity use; heating load has a decreasing trend. The table also provides coefficient estimates that estimate change in electricity use (kWh) associated with the kit-only installations. The standard errors, p values that capture statistical significance, and the relative precision of the estimate are also included in the table. All kit-only related load changes (reduction in cases of NAC and heating load and increases in the case of baseload) are statistically significant.

Table 36. Kit-only electric savings per home models, 2019-2020

Model	Variable	Estimate	Standard Error	Relative Precision	P-value
kit-only NAC	Intercept	-48	46	-1.6	0.2923
	treat	167	72	0.7	0.0214
kit-only baseload	Intercept	-80	38	-0.8	0.0357
	treat	-93	56	-1.0	0.0949
kit-only heating load	Intercept	23	37	2.7	0.5366
	treat	256	59	0.4	0.0001

Table 37 provides coefficient estimates from SFR kit-plus electric measure model runs for NAC. The coefficient estimates provide changes in electricity use associated with each program group. The tables also provide the p values that indicate the statistical significance associated with the estimates and their relative precisions. The results indicate savings that are statistically significant at least at the 95% confidence level and estimated with relative precision of 0.3 or 0.4.

Table 37. Kit-plus electric savings per home models, 2019-2020

Model	Variable	Estimate	Standard Error	Relative Precision	P-value
kit-plus weatherization NAC	Intercept	-120	117	-1.6	0.3071
	treat	1,059	172	0.3	0.0001
kit-plus space heat NAC	Intercept	-331	78	-0.4	0.0001
	treat	1,846	140	0.1	0.0001
kit-plus water heat NAC	Intercept	-395	265	-1.1	0.1375
	treat	1,503	388	0.4	0.0001

We also provide model results by heat pump type in Table 38. The details of the results are discussed in the impact results section of the model but indicated that contractor-installed ductless and ducted heat pumps have statistically significant savings at least at the 95% confidence levels and that are well-determined.

Table 38. Kit-plus heat pump electric savings per home models, 2019-2020

Model	Variable	Estimate	Standard Error	Relative Precision	P-value
kit-plus heat pump NAC	Intercept	-355	76	-0.4	0.0001
	Ductless Heat Pump from Zonal	1,314	187	0.2	0.0001
	Ductless Heat Pump with EFAF	2,625	323	0.2	0.0001
	Heat Pump with AC from EFAF	2,931	1,037	0.6	0.0047
	Heat Pump from EFAF	4,209	227	0.1	0.0001
	Air Source Heat Pump	174	251	2.4	0.4895
	Split Tier 1 and 2 Heat Pump	812	699	1.4	0.2455
	Ductless Tier 1 and 2 Heat Pump	-89	425	-7.8	0.8339

Table 39 provides estimates of change in gas use (therms) associated with the kit-only installations. The results indicate that kit-only related NAC and heating load reductions are statistically significant. Baseload change is not statistically significant. The estimates indicate that homes that only installed aerators and showerheads had load reduction primarily during the heating season.

Table 39. Kit-only gas savings per home models, 2019-2020

Model	Variable	Estimate	Standard Error	Relative Precision	P-value
kit-only NAC	Intercept	6.1	3.5	0.9	0.0817
	treat	20.9	5.3	0.4	0.0001
kit-only baseload	Intercept	-3.2	2.1	-1.1	0.1256
	treat	1.4	2.9	3.5	0.6389
kit-only heating load	Intercept	6.8	2.7	0.7	0.0134
	treat	16.2	4.2	0.4	0.0001

Estimates of whole-home gas consumption changes from each program type are presented in Table 40. The estimated gas use reductions from all three programs are statistically significant at least at the 95% confidence level and precisely estimated. A full discussion of model results is presented in the impact results section.

Table 40. Kit-plus gas savings per home models, 2019-2020

Model	Variable	Estimate	Standard Error	Relative Precision	P-value
kit-plus weatherization NAC	Intercept	0.5	2.3	7.4	0.8236
	treat	76.9	3.8	0.1	0.0001
kit-plus space heat NAC	Intercept	3.5	1.6	0.7	0.0253
	treat	37.5	2.6	0.1	0.0001
kit-plus water heat NAC	Intercept	4.7	3.5	1.2	0.1845
	treat	42.9	5.7	0.2	0.0001

Table 41 provides the estimates, statistical significance and precision of the gas space heating measures installed through the program. While the estimates for boilers and fireplace are not statistically significant because they were only installed in relatively fewer number of homes than the other gas space heating measures, the estimated savings for furnaces and space and water heaters are statistically significant and well-determined.

Table 41. Kit-plus heat pump gas savings per home models, 2019-2020

Model	Variable	Estimate	Standard Error	Relative Precision	P-value
kit-plus furnace NAC	Intercept	3.3	1.8	0.9	0.0693
	treat	34.4	3.0	0.1	0.0001
kit-plus fireplace NAC	Intercept	-1.7	25.2	-23.8	0.9453
	treat	35.6	37.2	1.7	0.3466
kit-plus boiler NAC	Intercept	25.6	20.5	1.3	0.2179
	treat	62.7	44.9	1.2	0.169
kit-plus space + water heater NAC	Intercept	-24.9	18.9	-1.2	0.1912
	treat	125.2	37.3	0.5	0.0012

7.5 Appendix E: Additional Online Survey Results

Below we provide demographic data for respondents to the online survey.

Table 42. Dwelling ownership or rental status

Own/Rent	Percent
Own	96%
Rent	4%
Total	**100%**

n=1,599

Table 43. Dwelling Type

Dwelling Type	Percent
Single-family detached home (home not attached to another home)	90%
Mobile home or manufactured home	4%
Townhouse, duplex, or row house (shares exterior walls with neighboring unit, but not roof or floor)	2%
Apartment or condominium (2 - 4 units)	1%
Apartment or condominium (5 or more units)	1%
An accessory dwelling unit (ADU), e.g., guest house	<0.5%
Total	**100%**

n=1,591

Table 44. Primary household language

Primary Household Language	Percent
English	96.6%
Chinese (including Mandarin and Cantonese)	1.7%
Spanish	0.7%
Tagalog	0.3%
Vietnamese	0.3%
Korean	0.2%
Russian	0.2%
Total	**100%**

n=1,513

Table 45. Highest degree or level or school completed

Level of School Completed	Percent
Bachelor's degree (e.g., B.A, B.S.)	40%
Doctorate (e.g., Ph.D., M.D., Ed.D.)	8%
High school degree or equivalent	9%
Less than a high school diploma	0%
Master's degree (e.g., M.A., M.S)	29%
Vocational/trade school or associate degree	14%
Total	**100%**

n=1,486

Table 46. Household gross annual income

Household gross annual income	Percent
Less than $49,999	9.3%
$50,000 - $99,999	28.5%
$100,000 - $149,999	25.6%
$150,000 - $199,999	15.2%
$200,000 - $249,999	8.9%
$250,000 or more	12.5%
Total	**100%**

n=1,090

About DNV

DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.

PUGET SOUND ENERGY

Evaluation Report Response

Program: Singe Family Retrofit

Program Manager: Pat Casper, Will Dixon, Holly Lloyd

Study Report Name: 2019-2020 Single Family Retrofit Impact and Process Evaluation

Draft Report Date: December 23, 2021

Evaluation Analyst: Kasey Curtis, Jesse Durst, Michelle Wildie

Date Final Report provided to Program Manager: February 17, 2022

Date of Program Manager Response: February 18, 2022

Overview:

The Single Family Retrofit programs offer energy saving measures and services to residential customers living in existing single-family buildings. PSE's Single Family Retrofit programs consist of two primary channels, retail programs and contractor-delivered programs. Retail programs include Appliance (Refrigerator) Decommissioning, Retail Showerheads, Retail Appliances, Web Enabled Thermostats, and Residential Lighting. Contractor-delivered programs include gas and electric Single Family Space Heating, gas and electric Single Family Water Heating, Single Family Weatherization, and Residential Windows.

The Single Family Retrofit program evaluation was broken into two parts: an impact and a process evaluation covering the 2019-2020 program years. There are seven key research questions for this evaluation. Research questions 1 through 4 primarily inform the impact evaluation, while questions 5 through 7 primarily inform the process evaluation.

1. What are the evaluated electric and gas savings?
2. What percent of program measures can be verified as installed and operational?
3. What were the building conditions before program measures were installed?
4. What were the building conditions after program measures were installed?
5. What is the level of awareness that participants have about the program?
6. What is the level of satisfaction that participants and trade allies have with the program and program process?
7. What are the barriers that are preventing more customer participation in the program?

The impact evaluation used data from participants in PSE's 2019 and 2020 Single Family programs to model change in both electric and gas consumption and quantify energy savings. The analysis was based on a two-stage modeling approach that estimates the effect of program measures on energy consumption. The approach uses variable degree-day PRISM-inspired

site-level models combined with a matched comparison group to estimate program-level effects in a difference-in-difference (DID) framework.

This methodology is consistent with the approach laid out in the Uniform Methods Project (UMP) Chapter 8 modeling approach, which provides whole-house savings estimation protocols for energy efficiency interventions that have whole-home impacts like smart thermostats. It is also closely related to all other forms of program analysis that use energy consumption data including time-series, cross-section approaches.

The objective of the process evaluation was to identify program successes and opportunities for program improvement. Process evaluation findings are based upon the perspectives of a range of program sources, including assessing the quality and completeness of program tracking data, interviewing PSE program staff and trade allies, and examining the program participant experience through an online survey.

High-Level Findings

Key findings from this study include the following:

- Electric space heating measures deliver 80% of claimed savings with significant variation of savings in measures delivered midstream versus downstream and between ducted and ductless heat pump systems. The midstream programs appear to have installed a sufficient share of heat pumps that converted gas heating to electric heat to undermine some portion of efficiency savings that were present for electric replacements.
- Gas space heating measure provide 37% of claimed savings, dominated by low realization rates for furnace replacements. Possible reasons for the low realization rate are discussed in the table below.

PUGET SOUND ENERGY

Possible causes of low realization rates within gas Space Heating program

Possible Cause	Further Investigation
Methodological Unknowns	
COVID-19. The pandemic has created a dramatic non-routine event that has a potential to disrupt the pre-post difference-in-differences methodology.	**Literature review** investigating peer gas heating retrofit program evaluations and pandemic impact on home energy consumption and consumption analyses **Early EM&V** for 2021 and 2022 Single Family Retrofit program to monitor trend
Poorly Matched Comparison Group. The pre-post billing analysis methodology depends on a well-matched comparison group to remove exogenous effects. It is possible that there are unknown differences (e.g., demographics and propensity to participate in efficiency programs) that we were unable to identify.	**Customer surveys** to gather additional data on representative set of comparison group **Customer profile analysis** to explore details of participants and comparison group
Real World Conditions	
Decreasing pre-period participant heating load. It may be that historical participation captures those customers with higher heating loads first. As time goes on, the remaining customers may have lower heating loads. Should this trend continue, lower pre-period heating load will yield a lower magnitude of savings.	**Customer profile analysis** to provide a brief analysis on historic program participation trends that can be easily updated on a recurring basis
Equipment Baseline. Claimed savings assume an 80% AFUE, which is the minimum efficiency required by code, but it is possible that the actual replaced furnaces have a higher efficiency on average, which would reduce measured savings.	**Contractor survey** to better understand the efficiency of the replaced equipment. **Contractor ride-alongs** to track a representative sample of pre-existing heating systems
Unknown Use of Equipment. The gas furnace may be used as backup heat source (where primary may be a heat pump) or the gas furnace may be used as a primary heat source but is significantly supplemented by electric or wood heat.	**Customer survey** to establish self-reported use of heating equipment **Contractor ride-alongs** to track a representative sample of heating system use type
Increased Takeback. It is possible that participants are turning up thermostat setpoints or that smart thermostats may encourage improving comfort over energy savings following the installation of the new furnace (takeback), resulting in an increase in heating consumption.	**Customer surveys** to identify intentional increases in temperature setpoint **Consumption analysis** to identify setpoint

PSE Comments: PSE does not dispute the realization rate DNV found through their difference-in-difference approach to evaluating the savings, and PSE appreciates their exploration of possible causes for the low realization rate. The evaluation approach taken, while an acceptable industry standard for evaluation, nevertheless contains certain weaknesses, including the fact that it cannot tell PSE the cause of the unusual result. PSE's furnace savings rates are based on testing and manufacturing data, with a baseline reflecting the Washington State code minimum, so PSE doesn't believe the rates reflect an overestimation of gas furnace performance.

- Both electric and gas water heating measures deliver over 90% of claimed savings.
- Electric and gas weatherization measures deliver 76% and 89% of claimed savings, respectively. These results are unlikely to be affected by baseline issues.
- Kit-only electric and gas installations (consisting of aerators and LEDs in the case of the former and aerators and showerheads in the latter) provide savings well in excess of the savings claimed for them. Given the weather-dependent nature of the savings, the

installation of more efficient heating equipment that was not claimed through the program is a likely explanation and is supported by the program practice of sending kits to customers who did not qualify for a rebate.

- Results from the participant online survey and contractor phone survey suggest the Single Family Retrofit programs are working well, but there are opportunities to improve certain aspects of the program, such as messaging around energy savings to participants and marketing to contractors. This provides PSE with an opportunity to integrate non-energy benefits more explicitly into marketing material while also explaining that increasing setpoints to improve comfort could lead to higher energy bills.
- While participating contractors see cost as a barrier to adoption of space and water heating heat pump technologies, they generally agreed that the heat pump market is growing and cited recent heat waves in the Pacific Northwest as one of the main drivers of this growth.
- Clarifying measure names will make it easier to understand and analyze the data. Though the tracking data measure names gave some indication of the baseline condition ("from FAF"), the use of the words "from" and "with" can be clearer. For instance, "ductless HP from zonal" would seem to indicate that the zonal electric baseboard heat was removed, as opposed to "ductless HP with EFAF," which would seem to indicate that the electric forced air furnace was not removed when the new ductless heat pump was added. However, the consumption loadshapes indicated likely supplemental electric heating after the installation of both of those ductless heat pump measure types.

  PSE Comments: PSE is continuing to retire older measure name conventions, which may still exist in our measure library. As those older measures are retired, more consistent measure names will be used. In addition, the measure description field may be utilized to further explain any baseline/existing conditions. PSE's measure case team and program staff will review these comments and consider options for improving measure names and descriptions.

Evaluation Recommendations and Program Responses

Program recommendations are found in the Single Family Retrofit Evaluation Executive Summary (Section 1), as well as the Findings and Recommendations (Section 6). The report's overall conclusions and recommendations based on the impact and process related findings and program staff responses to those recommendations, are presented below.

- Conduct further research to shed light on the lower-than expected gas heating savings, potentially including:
  - Literature review – establish summary of known and remaining unknown impacts of COVID-19 on consumption and whether it has disrupted savings for other gas heating programs
  - Customer and program profile – Establish trends in program participation and identify whether there are underlying discrepancies between program participants and the general PSE population

- Customer Survey – Continue to identify whether there are discrepancies between program participants and general PSE population; identify self-reported baseline equipment type and efficiency; identify use of equipment (primary/secondary); identify takeback (increases in post-period thermostat setpoint)
- Contractor Survey – Identify general equipment baseline and program equipment use (primary or secondary) observations
- Program Ride-Alongs – Identify sample of equipment baseline and program equipment use (primary or secondary)
- Updated billing analysis for 2021-2022 Single Family Retrofit gas program – Establish early (and potentially iterative) indication of 2021 and 2022 gas program savings to monitor program performance and determine if low savings trend continues.

Program Response: PSE will prioritize research that is most likely to explain large discrepancies in the realization rates among different fuel and technology types. Given the variety of research options, PSE believes the most likely explanations are worth exploring before investing in the full range of evaluation methods. In the next year, PSE will take several research steps to investigate possible causes of the lower realization rate, including:

- Direct billing analysis of customers that received gas furnace rebates in 2020-2021, a range that will allow for a full pre- and post- billing period within the COVID pandemic.
- Working with contractors to ensure they are correctly implementing the program as it is designed.
- Investigating whether additional customer data collection (such as baseline and program equipment information) can be done without inhibiting program uptake or contractor participation.

➢ Program staff should coordinate with participating contractors to make sure that they are not overpromising on bill savings that participants see as a result of their program upgrades. Online survey suggest that a segment of program participants may be somewhat disappointed in the energy savings they receive from their upgrades. Contractors should emphasize the non-energy benefits of the program, such as improved comfort, air quality, and reduction in greenhouse gas emissions for electric measures while also explaining that increasing thermostat set points for improved comfort could result in higher energy bills.

Program Response: PSE's program staff and Trade Ally Support team will provide communications to our contractors in 2022 and beyond to ensure non-energy benefits are properly emphasized and energy savings potential is framed realistically based on customer behavior. In fact, PSE began this effort 2020, concurrent with the evaluation. PSE began distributing collateral promoting the benefits of heat pump technology with the launch of its residential midstream space and water heat program mid-2020.

- Consider tracking additional detail related to baseline and installation conditions for space heating equipment to support a more nuanced evaluation and provide the program with appropriate attribution. Additional tracking details could include:
  - Existing equipment capacity and efficiency ratings as well as baseline period operations (e.g., typical, broken – unused, broken- used but less efficient).
  - Installation is a like-for-like replacement versus a supplement to existing electric heating system and/or full substitution

  Program Response: PSE will consider and explore tracking additional details about existing equipment where feasible. While collecting basic information such as the type of system may be trivial, certain equipment details such as capacity and efficiency ratings may be challenging depending on the age of the equipment and availability of nameplate information. It also may be prohibitive in certain program channels such as midstream where there are multiple layers between the customer and PSE (distributors, contractors).