GROUP A IMPACT EVALUATION

PY2020 HVAC Fuel Substitution

California Public Utilities Commission

Date: May 20, 2022


CALMAC Study ID: CPU0338.01

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1 EXECUTIVE SUMMARY

This report presents the electric and natural gas energy savings evaluation of heating, ventilation, and air conditioning (HVAC) fuel substitution equipment in ratepayer-funded energy-efficiency programs in program year (PY) 2020. Fuel substitution in the context of energy efficiency programs involves converting all or a portion of the existing energy use from one fuel to another, such as natural gas to electricity or vice versa. DNV evaluated energy savings for two selected HVAC fuel substitution technology groups, central and ductless systems. Only one program administrator (PA), Southern California Edison (SCE), offered a midstream-designed program that reported natural gas savings from HVAC fuel substitution although Southern California Gas Company (SCG) is the predominant gas service provider for these utility customers. We conducted this evaluation as part of the California Public Utilities Commission (CPUC) Energy Division (ED) Evaluation, Measurement & Verification contract.

The primary goals of this PY2020 evaluation are to:

- Assess the gas (therms) and electric (kWh) energy consumption changes realized by the selected HVAC technologies.
- Determine the savings that occur as a result of the program with respect to end users, decision-makers, and participating market actors.
- Provide insights into conditions in which evaluated HVAC technologies are producing energy savings cost-effectively and what improvements can be made to move towards strategic statewide energy-efficiency goals.

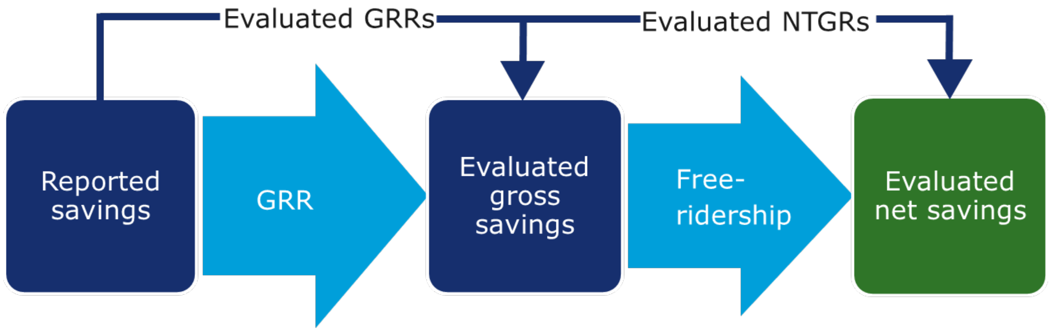
This evaluation collected critical data from participating end-user utility customers and decision-makers (those who make the decision to implement an energy efficiency project) to adjust key technical parameters that affect the calculation of energy savings.

The first major step was to evaluate the gross savings for each of the two selected technologies. Gross savings are the changes in energy use that resulted from energy efficiency activities, regardless of what factors may have motivated the program participants to take actions. We develop ratios of the evaluated savings to the PA-reported savings values, referred to as gross realization rates (GRRs), to express the evaluation results as a percent relative to the reported value.

We also evaluated the amount of savings that is attributable to the ratepayer-funded energy efficiency program. This savings is developed by first estimating the amount of free-ridership, which represents the savings that would have occurred without the PA incentive being provided (e.g., because the utility customer indicates s/he would have purchased the equipment at full cost if the incentive had not been offered). From this, net-to-gross ratios (NTGRs) can be estimated for each of the evaluated technologies by subtracting the free-ridership savings from the gross savings and then dividing it by gross savings. An evaluated NTGR of 100% would indicate that the energy and gas savings were completely due to the influence of the incentive offered by the program. A score less than 100% means that other factors were also responsible for the energy savings. Attributable net savings is the gross savings minus the free-ridership savings, calculated as the product of gross savings and the net-to-gross ratios.

NTGR values are used to calculate the evaluated technologies' net savings, which tell us how much impact the program had on the evaluated technologies' electricity and gas savings. Figure 1-1 illustrates how the GRRs and NTRGs are applied.

Figure 1-1. Energy savings evaluation process: getting from gross to net

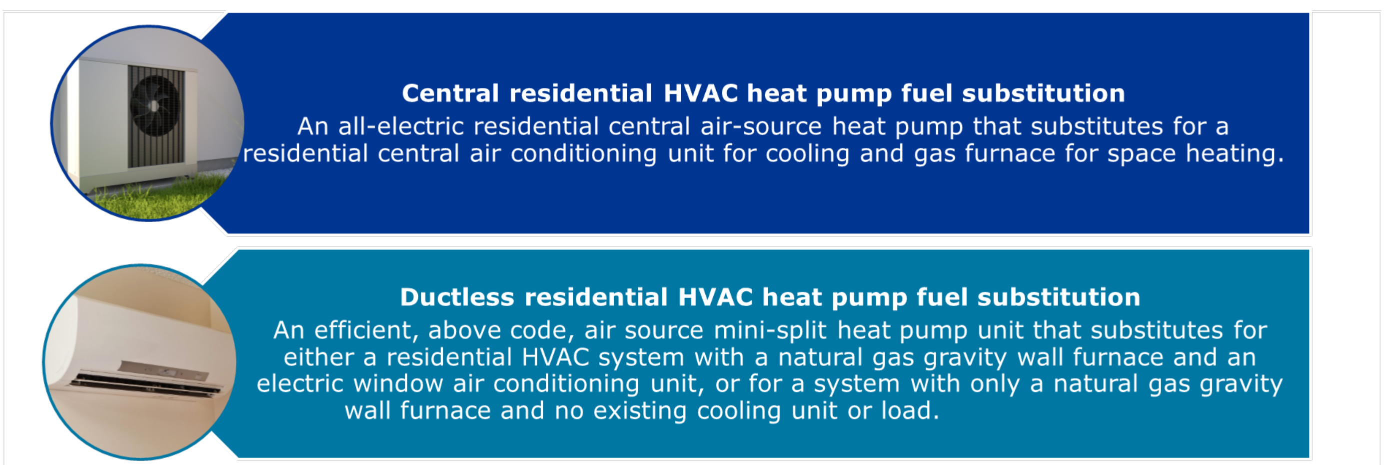


To mitigate the effects of the COVID-19 pandemic on estimated savings, we used a matched comparison group drawn from non-participating PA customers as a type of benchmark or 'control' group. Generally, a comparison group is designed to control for non-program-related, exogenous changes that might otherwise be conflated with program impacts. The disruptions from the COVID pandemic are complicated and may limit a comparison group's ability to fully assess non-program-related changes. However, using a comparison group to control for exogenous change still provides useful insights for this study.

1.1 Study background and approach

The two selected HVAC technologies evaluated in PY2020 were ductless residential HVAC heat pumps (ductless HVAC) and central ducted residential HVAC heat pumps (central HVAC), which are summarized in Figure 1-2. The two technology groups are the only two HVAC fuel substitution contributors to the prescriptive savings portfolio and represent over 52% of reported HVAC first-year gas (therm) savings for PY2020.

Figure 1-2. Summary of evaluated technologies



We evaluated the energy impact of the two fuel substitution HVAC technologies using energy consumption data analysis that is based on the approach laid out in the Uniform Methods Project[1] (UMP) Chapter 8 modeling approach. This approach provides an estimate of energy use change per household following an energy efficiency intervention such as the installation of the fuel substitution heat pumps. The method uses site-level models that control for the effect of weather on energy

[1] Li, M.; Haeri, H.; Reynolds, A. (2018). The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures. Golden, CO; National Renewable Energy Laboratory. NREL/SR-7A40-70472. http://www.nrel.gov/docs/fy18osti/70472.pdf.

consumption combined with a matched comparison group to estimate program-level effects in a difference-in-difference (DID) framework, a technique that compares the difference between the program 'treatment' group and the 'control' group.

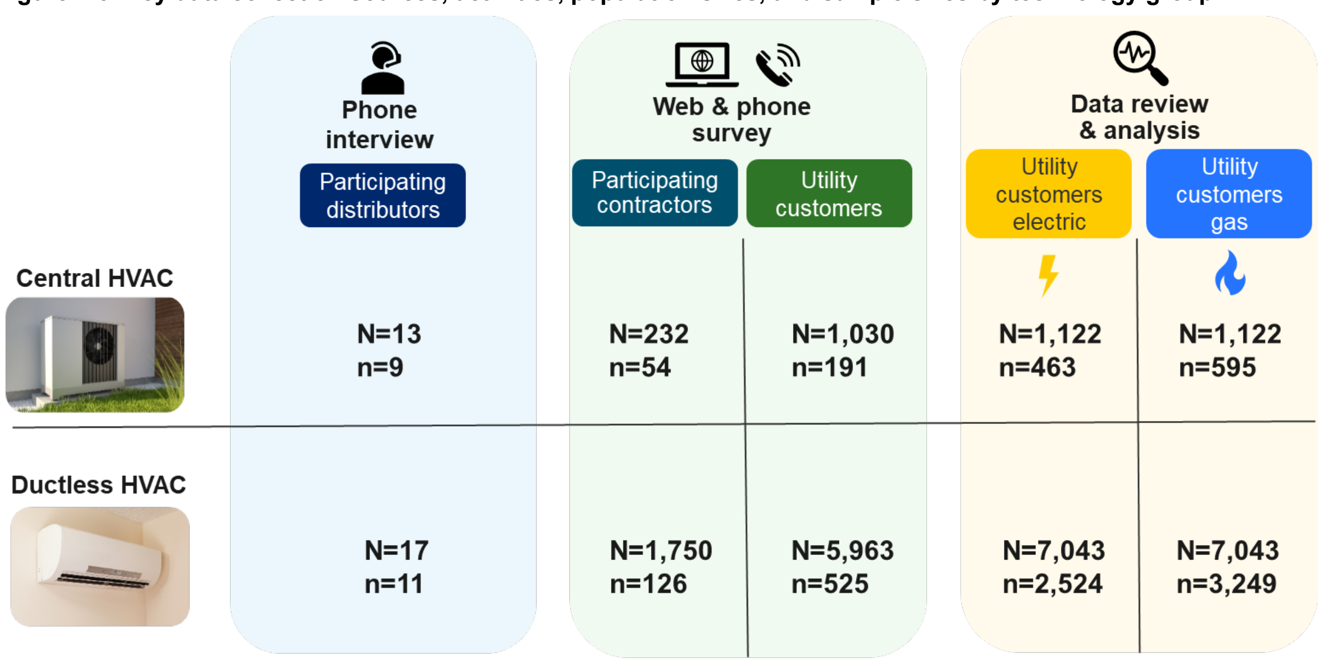
Of the total 1,122 utility customer addresses reported to have installed the central HVAC heat pump technology, nearly 27% of electric accounts and 41% of gas accounts were dropped because the addresses provided could not be confidently linked to account information. A further 32% of electric and 6% of gas accounts were dropped from the analysis during data cleaning due to more typical reasons such as insufficient data. We were ultimately able to conduct the consumption analysis on 463 electric and 595 gas utility accounts of the initial 1,122 central HVAC addresses.

For the ductless HVAC heat pump technology, 37% of electric accounts and 47% of gas accounts were dropped due to poor account identification, while the cleaning processes produced a further reduction of 27% for electric accounts and 7% for gas accounts. We were ultimately able to conduct the consumption analysis on 2,524 electric and 3,249 gas accounts out of the total 7,043 utility customer addresses reported.

We evaluated savings attribution using net-to-gross surveys with HVAC fuel substitution technology program participants and market actors (equipment distributors and HVAC contractors) to derive NTGRs. The program is implemented as a midstream design, targeting participation of HVAC equipment distributors for enrolment, as opposed to a downstream design aiming to directly engage the utility customers for example. To this end, we conducted surveys with 11 of the 17 HVAC equipment distributors participating in SCE's program and with 165 unique participating HVAC contractors.[2] We also surveyed 191 participating utility customers reported to have the central heat pump systems and 525 participating utility customers reported to have the ductless heat pump systems.

A summary of key data collection sources, activities, and the achieved sample sizes used to calculate the savings of the two HVAC technology groups are provided below in Figure 1-3.

Figure 1-3. Key data collection sources, activities, population sizes, and sample sizes by technology group



N=population size and n=sample size.

[2] We conducted 126 surveys with contractors providing ductless heat pumps and 54 surveys with contractors providing central heat pumps.

1.2 Evaluated savings results

The results for the residential HVAC fuel substitution technologies include reported and evaluated site energy savings, evaluated source energy savings, CO_2 emissions savings, and typical annual energy bill impacts. Site energy savings are the energy savings realized at the utility customer site. This is the value the PAs report as savings. Source energy savings are the savings from only natural gas combustion, “either through power generation or in direct combustion for the end-use.”[3] Emissions savings in this case are, “total CO_2 emissions over the EUL of the measure technology,” as identified in the CPUC’s Fuel Substitution Guideline document.[4] The fuel substitution Decision (D.19-08-009)[5] requires fuel substitution measures to pass the two-part test demonstrating a reduction in total source energy and environmental impact (emissions).

1.2.1 Site energy savings

Table 1-1 below provides a summary of the program’s success in providing gas and electric savings at the utility customer’s site through the two technologies. The table presents evaluated net savings compared with the PA-reported net savings, and then in the last column, the net realization rate (NRR). The NRR removes the savings from installations that would have happened even if there were no incentives and is calculated as the ratio of the evaluated net savings value to the PA-reported net savings value. Thus, the NRR indicates the true impact of the ratepayer-funded program. In general, the higher the NRR value, the greater the program’s achieved savings. However, because these are gas-to-electric fuel substitution measures, the electric impacts are not energy savings, but energy consumption increases, therefore a lower electric NRR and a higher gas NRR is desirable, and the ratio of gas energy savings to electric energy increases is important for the measure passing the fuel substitution test components.

Table 1-1. Net electric and gas savings results by technology

Technology (Measure) Group	Reported Net Savings	Evaluated Net Savings	Net Realization Rate (NRR)
Electric Consumption (kWh)			
Ductless HVAC	-3,277,158	-889,613	27%
Central HVAC	-1,254,168	-456,445	36%
Gas Consumption (therms)			
Ductless HVAC	1,713,517	31,202	2%
Central HVAC	226,990	97,092	43%

1.2.1.1 Ductless HVAC fuel substitution technology group

The ductless HVAC heat pump fuel substitution technology is intended to replace the use of an existing residential ductless natural gas furnace such as a gravity wall furnace, either with or without a separate existing residential ductless window air conditioner unit. Thus, the heat pump provides high efficiency electric heating and cooling as a substitute for gas heating

[3] California Public Utilities Commission. Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1. https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency.

[4] Ibid.

[5] CPUC Decision D.19-08-009, Decision Modifying the Energy Efficiency Three-Prong Test Related to Fuel Substitution, per rulemaking proceedings R1311005. (https://apps.cpuc.ca.gov/apex/f?p=401:56:0::NO:RP,57,RIR:P5_PROCEEDING_SELECT:R1311005) and can be located via the CPUC Document search, http://docs.cpuc.ca.gov/SearchRes.aspx?DocFormat=ALL&DocID=310159146

system and in many cases a standard efficiency cooling system as well. In general, relative to central ducted systems, ductless systems are more compact and have lower heating and cooling capacities, so they are usually installed in smaller residential dwelling units.

Table 1-2 presents the PY2020 statewide reported and evaluated savings summary for the ductless residential HVAC fuel substitution technology group. The evaluated gross gas (therm) savings is only 5% of the reported savings, while the evaluated gross electric (kWh) increase is 68% of the value the PA-reported value. Evaluation results indicate that the ductless HVAC fuel substitution is not meeting expectations to significantly offset pre-retrofit gas heating, yet it is adding year-round electric energy consumption.

Table 1-2. Ductless HVAC fuel substitution first-year savings

Reported Gross Savings	GRR	Evaluated Gross Savings	Reported NTGR	Evaluated NTGR	Reported Net Savings	Evaluated Net Savings	NRR
Electric consumption (kWh)							
-3,277,158	68%	-2,218,485	100%	40%	-3,277,158	-889,613	27%
Gas consumption (Therm)							
1,713,517	5%	77,810	100%	40%	1,713,517	31,202	2%

Drivers for the low gas savings results are likely due to ductless system not often replacing an existing gas heating system and utility customers continuing to use those gas systems. Our utility customer survey results suggest:

- Only about one-third (33%) of these systems replaced an existing heating system as intended
- About the same (30%) added the ductless heat pump without removing the old system
- 22% installed the ductless system in a previously unheated space.[6]

These results also imply that only about one-fifth (21%) of these systems were installed where there was an existing ductless furnace, but 50% of the time there was already a central furnace,[7] while 13% already had a ductless heat pump and 5% had a central ducted heat pump. A full summary of the factors contributing to the evaluated gross savings realization rate is found in section 5.2.

While the reported NTGR value is 100% in accordance with the CPUC's decision modifying the fuel substitution test,[8] the evaluated NTGR for the ductless HVAC systems is 40%. This evaluated NTGR is based on a triangulation of the information gathered from the distributor, contractor, and customer surveys. Program attribution scores were 63% for the contractor component, 56% for the utility customer component, and 1% for the distributor component. A highlight of contributing factors is presented in the following list:

- Contractors reported that distributor recommendations were the most important component of attribution.
- Approximately one-third (31%) of the utility customers who were aware of the incentives said they would not have purchased the units without the incentive and utility customers who were not aware of the incentive said that the seller's recommendation was the most important attribution component.

[6] This response is not inclusive of building additions or renovations and so should be interpreted as existing building space that was not directly served by an existing building heating system.
[7] Meaning these customers were only eligible to replace their existing furnace systems with the central heat pump technology.
[8] California Public Utilities Commission, Decision D. 19-08-009, Decision Modifying the Energy Efficiency Three-Prong Test Related to Fuel Substitution.

- The distributor survey scores indicate that the program did not increase distributors' percentage of sales of high efficiency ductless heat pumps. Distributors reported that high-efficiency ductless heat pump sales only increased 1% due to the program and that the program had zero effect on their stocking or upselling practices.

A full summary of the factors contributing to the evaluated NTGR is found in section 4.1.2.

Applying the evaluated NTGR value to the evaluated gross savings estimates yields net realization rates of just 2% for gas therm savings and 27% for the electric kWh energy increase.

1.2.1.2 Central HVAC fuel substitution technology group

The central HVAC heat pump fuel substitution technology is intended to replace the use of an existing residential central ducted natural gas furnace and air conditioning HVAC system. Like the ductless technology, the central heat pump provides high efficiency electric heating and cooling as a substitute to existing central gas furnace and AC systems.

Table 1-3 presents the PY2020 statewide reported and evaluated savings summary for central residential HVAC fuel substitution technology group. The evaluated gross gas (therm) savings is 75% of the value reported savings, while the evaluated gross electric (kWh) increase is 64% of the value the PA reported. The evaluation results indicate that the central HVAC fuel substitution is serving to offset a majority of pre-retrofit gas heating while also exhibiting a cooling efficiency improvement over the pre-retrofit condition. Almost all survey responses (98%) indicate that these central heat pump systems replaced an existing heating system, while a majority (78%) indicate the heat pump replaced a central furnace, and a minority (15%) indicate it replaced an existing central heat pump.

Table 1-3. Central HVAC fuel substitution first-year savings

Reported Gross Savings	GRR	Evaluated Gross Savings	Reported NTGR	Evaluated NTGR	Reported Net Savings	Evaluated Net Savings	NRR
Electric consumption (kWh)							
-1,254,168	64%	-802,188	100%	57%	-1,254,168	-456,445	36%
Gas consumption (Therm)							
226,990	75%	170,635	100%	57%	226,990	97,092	43%

The evaluated NTGR for the central HVAC systems is 57%, compared to the reported 100%, per CPUC's decision modifying the fuel substitution test. Program attribution scores were highest for the contractors (73%), whereas the utility customer score was lower (44%), and the distributor component (53%) was near the overall NTGR value. Unlike for the ductless HVAC, when asked about central systems, distributors reported that high-efficiency central heat pump sales increased approximately 50% due to the program. Survey responses indicate utility customers purchasing central HVAC heat pump systems are more willing to do so without the program's incentive than those purchasing the ductless systems. This suggests the program is strongly influencing the distributors and contractors but only moderately influencing the utility customers decision to purchase qualifying central heat pumps. A full summary of the factors contributing to the evaluated NTGR is found in section 4.1.2.

Applying the evaluated NTGR value to the evaluated gross savings estimates yields net realization rates of 43% for gas therm savings and 36% for the electric kWh energy increase.

1.2.2 Source energy savings

The evaluated source energy savings is based on the outputs of the CPUC's Fuel Substitution Calculator v1.1,[9] using the total gross evaluated site energy savings and other pertinent measure details[10] as the inputs into the custom calculator segment. In reviewing the source energy savings it is important context to understand that in the fuel substitution test "only the source energy from depletable fossil-fuel resources are currently considered," by the CPUC and that they "consider the source energy and emissions for renewable generation, such as solar, wind, and hydro-electric generation, to be zero."[11] Table 1-4 below presents the evaluated and reported first-year full energy savings and the lifecycle source energy savings, in MMBtu, for both the ductless and central HVAC technologies.

Table 1-4. First-year site and lifecycle source energy savings

Technology	First year Full Energy Savings (MMBtu equivalent)		Lifecycle Primary Energy Savings (MMBtu at generation source)	
	Per dwelling unit	Program total	Per dwelling unit	Program total
Ductless, evaluated	0.02	209	1.04	7,851
Ductless, reported	21.8	153,629	328	2,311,384
Ductless, ratio of evaluated to reported	**0.11%**	**0.14%**	**0.32%**	**0.34%**
Central, evaluated	12.8	14,326	193	216,588
Central, reported	16.4	18,383	248	278,411
Central, ratio of evaluated to reported	**77.9%**	**77.9%**	**77.7%**	**77.8%**

The results for ductless HVAC systems show a very small first year source energy savings, 0.02 MMBtu per household on average and 209 MMBtu in total, and a modest lifecycle source energy savings (7,851 MMBtu total). This means ductless HVAC systems barely pass the source energy savings test[12] for fuel substitution. However, accounting for measurement uncertainty, the evaluation finds the lifecycle source energy savings impact of this technology application questionable, and it falls short of meeting reporting expectations for achieving source energy savings. This first-year result is driven by the low evaluated gas saving and the moderate evaluated electric consumption increase from the site-level savings analysis, whereas the lifecycle measurement benefits from the calculator's assumed lowering of electric source energy intensity (Btu/kWh) over the lifetime of the technology.

Compared with the ductless HVAC technology group, the central HVAC technology group exhibits much greater first-year source energy savings of 12.8 MMBtu per household on average and 14,326 MMBtu in total. This is due to the greater evaluated gas energy savings and lower evaluated electric energy consumption increases relative to ductless systems. The lifecycle source energy savings result for the central HVAC technology is also significant at 193 MMBtu per household average and 216,588 MMBtu in total. Therefore, the central HVAC technology group passes the source energy savings test for fuel substitution with a considerable margin.

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9 California Public Utilities Commission. "Fuel Substitution in Energy Efficiency." https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/building-decarb/fuel-substitution-calculator-v11.xlsx.

10 Other inputs into the fuel substitution calculator include the measure life (15-year EUL), installation year (2020), and measure application type (normal replacement).

11 California Public Utilities Commission. Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1. https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency.

12 The threshold for passing is a positive (>0) lifecycle primary energy savings.

1.2.3 CO_2 emissions savings

As with the source energy savings methodology, the evaluated carbon dioxide (CO_2) emissions savings is based on the outputs of the CPUC's Fuel Substitution Calculator v1.1[13] using the total gross evaluated site energy savings and other pertinent measure data[14] as the inputs into the custom calculator segment. Table 1-5 below presents the lifecycle source energy savings, in metric tons of CO_2, for both the ductless and central HVAC technologies.

Table 1-5. Lifecycle emissions savings

Technology	Lifecycle Emissions Savings (Metric tons CO_2)	
	Per dwelling unit	**Program total**
Ductless, evaluated	0.06	417
Ductless, reported	17.4	122,666
Ductless, ratio of evaluated to reported	**0.32%**	**0.34%**
Central, evaluated	10.2	11,494
Central, reported	13.2	14,775
Central, ratio of evaluated to reported	**77.7%**	**77.8%**

The emissions saving results are similar to the source energy findings, in that the ductless HVAC systems produce a very small individual emissions benefit (0.06 metric tons CO_2 compared to the reported 17.4 tCO_2) and a moderate total emissions benefit given their volume of reported systems, whereas the central systems are achieving a substantial reduction in lifecycle emissions (10.2 metric tons CO_2) at the system level and overall. This is a direct result of the difference in achieved gas savings between the ductless and central HVAC heat pump technologies.

1.2.4 Bill impacts

We evaluated the bill impacts[15] of the HVAC fuel substitution by combining the consumption data analysis results with rate schedule information from SCE and SCG. We used SCG's residential general service rates for gas and SCE's residential service rates for electric that are applicable to each participating customer to illustrate the cost impact of gas use reduction and electric use increase from the fuel substitution installations. We assumed the same rates are applicable before and after retrofit to provide a practical comparison of pre-and post-installation results. We did not include fixed costs in this analysis, as most participants continued to have some gas service following the heat pump installations.

The results of the bill impact assessment are presented in section 4.4. Central HVAC systems that replaced less efficient heating systems afforded utility customers an average annual bill savings of $95 (Table 1-6). The gas bill savings associated with these systems outweighed cost increases from their increased electric load. On the other hand, ductless systems that supplemented existing HVAC equipment led to total average annual bill increases of $86. The gas cost savings from these systems did not outweigh the cost increase associated with their higher electric load. Overall, the program resulted in an

[13] California Public Utilities Commission. "Fuel Substitution in Energy Efficiency" https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/building-decarb/fuel-substitution-calculator-v11.xlsx

[14] Other inputs into the fuel substitution calculator include the measure life (15-year EUL), installation year (2020), and measure application type (normal replacement).

[15] This does not factor in the cost of installation or equipment upgrades. This is strictly the bill impact from energy consumption changes.

average annual bill increase of $58 since most installations were ductless HVAC rather than central HVAC fuel substitution heat pumps.

Table 1-6. Evaluated average annual energy bill impacts

Technology	Electricity costs	Gas costs	Total costs
Ductless HVAC	$151	-$66	$86
Central HVAC	$170	-$265	-$95
Overall	$154	-$97	$58

Negative values indicate a cost reduction while positive values indicate an increase.

1.3 Study findings and recommendations

This section provides a summary of key findings and recommendations from this evaluation study. A detailed discussion of findings, recommendations, and implications are provided in Chapter 6 of the report.

- The breadth of the program documentation data was good, but quality and the addition of documentation linking program data to utility customer database information are areas for improvement that would benefit the certainty of evaluated savings
    - **Recommendation**: To improve data quality, we recommend the PAs and their implementers increase efforts to train participating midstream program distributors on consistent and accurate data recording and conduct regular quality control reviews of the data prior to submittal.
    - **Recommendation**: To improve program evaluability, we recommend the PAs and their implementers design program documentation to include the PAs' premise and customer identifier fields.
- The midstream program delivered ductless HVAC fuel substitution systems fell short of expectations for gas savings, most probably because they are often not being installed or used to replace existing gas heating as the measure intends.
    - **Recommendation**: To ensure the gas savings expectations are met, we recommend only direct install and downstream delivery pathways should offer ductless HVAC systems. Additionally, we suggest the PAs revise the measure eligibility to follow the requirement for decommissioning the existing gas system before installing the new ductless HVAC system.
- The evaluation identified a NTGR of 57% for central HVAC fuel substitution systems delivered through the midstream design program. This NTGR is typical of other evaluation results for similar midstream HVAC programs and suggests the program is influencing the midstream market actors as intended.
    - **Recommendation**: The central HVAC fuel substitution measure package NTGR should be revised to use a 60% NTGR, rounding up 57% finding from the evaluation, for the upstream delivery type. We recommend the NTGR for the revised ductless HVAC measure package be evaluated and then considered for revision.

2 INTRODUCTION

The report presents DNV's energy savings estimates (impact evaluation) of residential heating, ventilating, and air conditioning (HVAC) heat pump fuel substitution technology groups (measures) that are part of the California Public Utilities Commission (CPUC) HVAC Research Roadmap. These measures are evaluated under CPUC's Group A evaluation contract group. The primary results of this evaluation are the estimated site energy savings (in kWh and therms), source energy savings (in Btu), and greenhouse gas emissions reduction (in metric tons of CO_2) achieved by two selected HVAC measures—residential ductless HVAC heat pump fuel substitution and residential central HVAC heat pump fuel substitution—in program year 2020 (PY2020).

Heat pumps are a type of reversible air conditioning technology that transfer thermal energy using the refrigeration cycle. HVAC heat pumps can provide both space cooling when operating as an air conditioning system, and space heating when the refrigeration cycle is operated in reverse. HVAC heat pumps therefore provide an opportunity for fuel substitution for existing gas-fired furnace and one-way direct expansion air condition systems. Space heating using heat pumps is less carbon emissions intensive when fueled with fully or partially emissions-free electricity sources compared to gas-fired furnaces. Heat pumps are also more efficient at providing space heat than electric resistance powered systems, which may be used to supplement central gas-furnaces. Heat pumps are an integral technology for building electrification undertaken to meet decarbonization goals, and thus these fuel substitution measures aim to accelerate the adoption of heat pumps replacing gas-fired heating equipment.

Two programs under separate program administrators (PA) Southern California Edison (SCE) and Bay Area Regional Energy Network (BayREN) filed claims for these measures in PY2020. SCE's program is responsible for almost all of claim counts and claimed savings and is the focus of this evaluation, as BayREN's claims fall under comprehensive Home Upgrade programs evaluated separately. SCE's Home Energy Efficiency Rebate program (formally SCE-13-SW-001B - Plug Load and Appliances Program) offered incentives that offset the cost to convert existing gas space heating and electric AC cooling equipment to electric heat pumps in PY2020. SCE offered these electrification measures following the 2019 CPUC Decision 19-08-009 that permitted the inclusion of fuel substitution measures in the energy efficiency portfolio of regulated investor-owned utilities as long as they meet the two-pronged fuel substitution test calculations. The fuel substitution test requires that the lifecycle source energy consumption (Btu) and emissions intensity (CO2 metric tons per unit) of the fuel substitution measure must be less than the baseline technology it is replacing. These requirements are driven by decarbonization policies including AB 32.[16] Section 2.2 provides the descriptions of the HVAC heat pump fuel substitution measures incentivized through SCE's program including the number of claims and claimed (ex ante) savings.

2.1 Project goals and objectives

The goals of this report are to present the estimated energy, environmental, and utility customer cost impact results from the evaluation project and to provide recommendations to stakeholders based on these findings. The specific research objectives of the heat pump fuel substitution measures include the following:

- Estimate the site and source energy savings for central and ductless HVAC measures.
- Determine reasons for differences between evaluated (ex post) and reported (ex ante) site energy savings, and as necessary, assess how to improve the ratio of evaluated savings to reported savings (realization rates). Identify issues with respect to reported impact methods, inputs, procedures and make recommendations to improve savings estimates and realization rates of the evaluated measure groups:

[16] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32

- Determine the prevalence of different existing condition baselines (equipment, fuel, use) for this fuel substitution measure.
  - Provide results and data that will assist with updating reported measure packages and the California Database for Energy Efficiency Resources (DEER) values.

- Estimate the proportion of program-supported HVAC heat pump fuel substitutions that would have been installed absent program support (free-ridership), determine the factors that characterize free-ridership, and as necessary, provide recommendations on how free-ridership could be reduced:
  - Conduct primary research to determine program satisfaction, participation barriers, customer installation and technology experiences.
  - Determine what situations led to the adoption of the fuel substitution measure.
  - Determine customer perceptions of non-energy impacts.

- Estimate lifecycle CO_2 greenhouse gas emissions reductions due to the fuel substitution.
- Calculate typical utility customer bill impacts of the fuel substitution for the participating utility customers.
- Provide timely feedback to the CPUC, PAs, and other stakeholders on the evaluation research study to facilitate timely program improvements and support future program design efforts and reported impact estimates.

2.2 Evaluated measure groups

The two residential HVAC fuel substitution heat pump measures — residential ductless HVAC heat pump fuel substitution (measure package ID SWHC044) and residential central HVAC heat pump fuel substitution (SWHC045) — were the only two HVAC fuel substitution measures claimed by the PAs in PY2020. The two residential HVAC fuel substitution heat pump systems measure groups, when combined, had the highest gross lifecycle gas savings claim in the residential sector and in the prescriptive portfolio overall in PY2020 as well as the largest contribution to lifecycle gas savings in PY2020. While they reduce the use of the fuel they substitute away from (gas), they necessarily increase the fuel they use in its place (electricity). Of the two measure groups, the PA reported nearly six times as many ductless HVAC fuel substitution measure claims (4,494) as they did central HVAC fuel substitution measure (763).

The ductless HVAC heat pump fuel substitution technology is intended to replace the use of an existing residential ductless natural gas furnace such as a gravity wall furnace, either with or without a separate existing residential ductless window air conditioner unit. Thus, the heat pump provides high efficiency electric heating and cooling as a substitute for gas heating system and perhaps standard efficiency cooling system as well. In general, relative to central ducted systems, ductless systems are more compact and have lower heating and cooling capacities, so they are usually installed in smaller residential dwelling units.

The central HVAC heat pump fuel substitution technology is intended to replace the use of an existing residential central ducted natural gas furnace and air conditioning HVAC system. Like the ductless technology, the central heat pump provides high efficiency electric heating and cooling as a substitute to existing central gas furnace and AC systems.

2.2.1 Characteristics of measure group claims

Table 2-1 below presents the measure tier minimum cooling performance seasonal energy efficiency ratio (SEER) and heating seasonal performance factor (HSPF) ratings by technology and tier, as well as average reported SEER, HSPF, cooling energy efficiency ratio (EER) and percent of capacity (tons) claimed for each tier. The majority of claimed ductless capacity meets the highest (tier 4) minimums, and the average reported SEER, EER, and HSPF ratings across all claimed ductless heat pump measures is 18.7, 10.9, and 10.1 respectively. The central heat pump claims are more evenly distributed across the four tiers, with the overall average central heat pump claim falling just under the tier 3 minimum requirements.

Table 2-1. Average reported SEER, EER, and HSPF rated heat pump efficiency, by measure tier

Technology	Measure Tier	Tier minimum SEER/ HSPF	Average SEER	Average EER	Average HSPF	Percent of Tons Claimed
Ductless	1	15/ 8.5	15.4	9.3	9.0	1%
	2	16/ 8.8	16.1	9.9	9.2	10%
	3	17/ 9.4	17.1	9.8	9.6	17%
	4	18/ 9.8	19.5	11.3	10.4	72%
	All	**-**	**18.7**	**10.9**	**10.1**	**100%**
Central	1	15/ 8.7	15.1	12.5	9.1	28%
	2	16/ 9.0	16.0	11.7	9.1	23%
	3	17/ 9.4	17.3	12.0	9.2	17%
	4	18/ 9.7	18.8	12.0	9.9	33%
	All	**-**	**16.8**	**12.1**	**9.3**	**100%**

Table 2-2 on the next page presents the percent of heat pump claimed capacity (tons) by building climate zones and measure tiers for teach technology. The assigned climate zones are based on the installation address zip code provided by SCE. A slight majority (57%) of ductless heat pump capacity claims were installed in the marine influenced climate zones 6, 8, and 9, while another 20% fall under the less mild climate zone 10. The balance of ductless claims falls under the southern central valley climate zone 13, the desert climate zones 14 and 15, or the mountainous climate zone 16. Comparatively, the climate zone distributions of central heat pump claims are similar to ductless but with a much higher percentage (35%) occurring in the low desert climate zone 15.

Table 2-2. Percent of heat pump capacity (tons) claimed, by climate zone and measure tier

Technology	Climate Zone	Tier 1	Tier 2	Tier 3	Tier 4	All Tiers
Ductless	6	0%	2%	2%	11%	**16%**
	8	0%	3%	4%	17%	**23%**
	9	0%	1%	3%	13%	**18%**
	10	0%	1%	4%	14%	**20%**
	13	0%	0%	1%	2%	**2%**
	14	0%	1%	2%	7%	**9%**
	15	0%	1%	1%	7%	**9%**
	16	0%	0%	1%	1%	**2%**
	All CZs	**1%**	**10%**	**17%**	**72%**	**100%**
Central	6	4%	2%	2%	5%	**13%**
	8	8%	4%	4%	8%	**24%**
	9	2%	5%	2%	3%	**13%**
	10	2%	5%	2%	3%	**12%**
	13	0%	0%	0%	0%	**0%**
	14	1%	1%	0%	1%	**2%**
	15	11%	6%	6%	12%	**35%**
	16	0%	0%	0%	0%	**1%**
	All CZs	**28%**	**23%**	**17%**	**33%**	**100%**

Figure 2-1 and Figure 2-2 illustrate the zip code-level distributions of claimed heat pumps capacities for ductless and central systems, respectively, with a choropleth map, The shading is color coded by climate zone, with color saturation correlating to installed capacities.

Figure 2-1. Choropleth map of ductless heat pump capacity (tons) claimed, color coded by climate zone

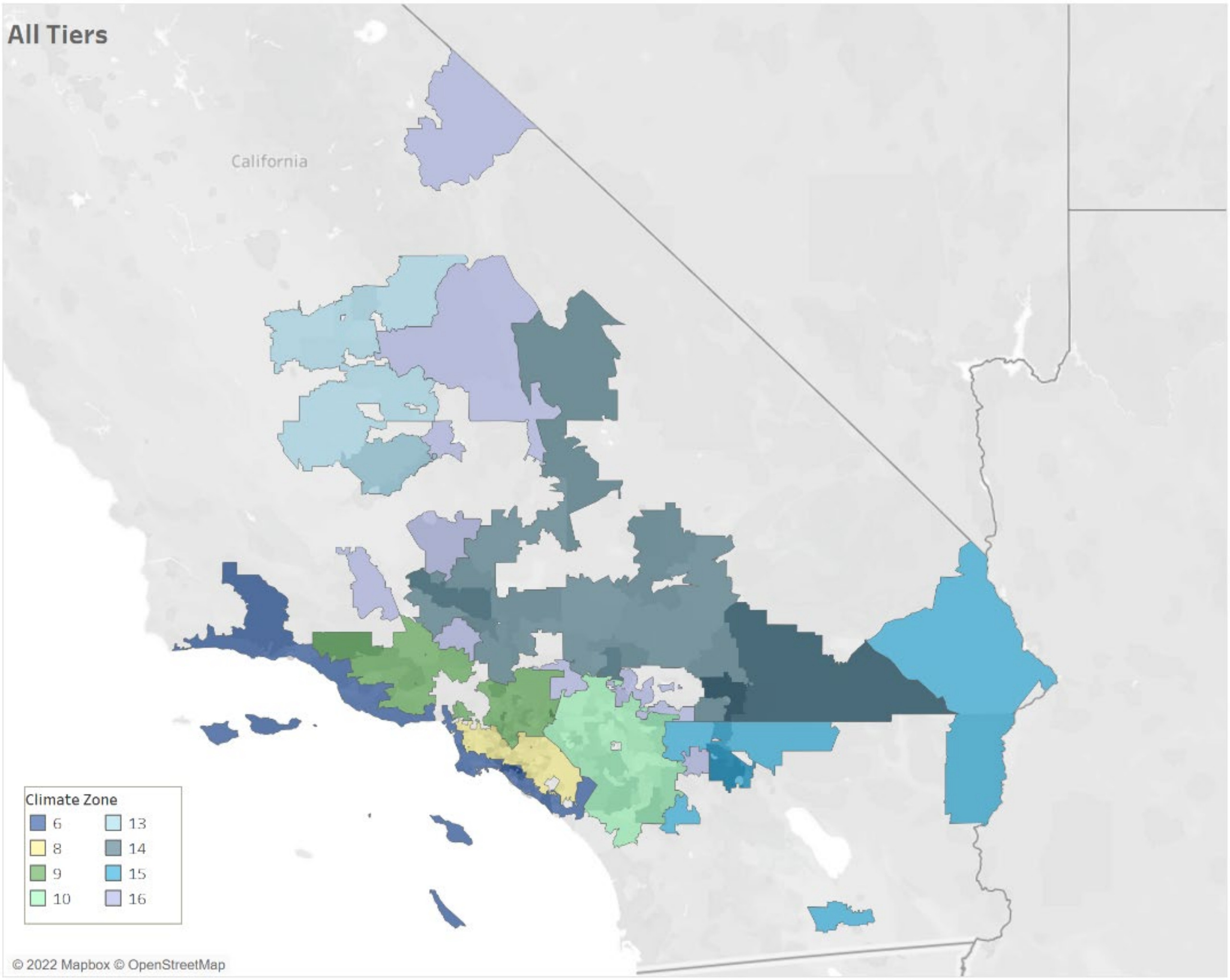
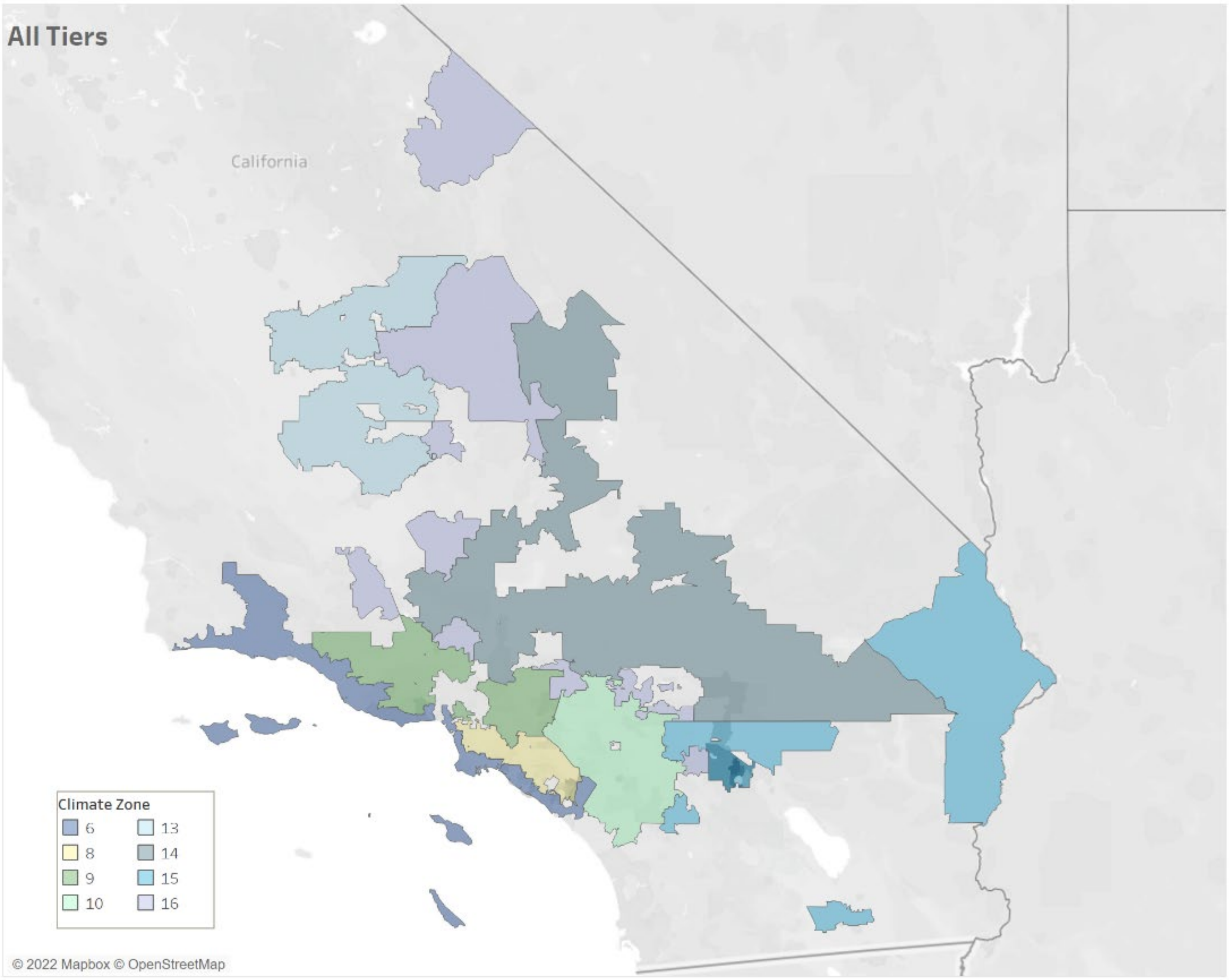


Figure 2-2. Choropleth map of central heat pump capacity (tons) claimed, color coded by climate zone



Lastly, Table 2-3 provides a breakdown of the percent of heat pump capacity that is reported to be installed within a recognized disadvantage community (DAC), based on the SCE provided installation zip code and the CalEnviroScreen 3.0 DAC definition. Across all the climate zones, 43% of the total ductless heat pump system capacity was reported to be installed in a zip code within a DAC, whereas only 13% of the total central heat pump system capacity was found to fall within a DAC.

Table 2-3. Percent of heat pump capacity (tons) claimed within and outside of a designated DAC, by climate zone

Technology	Climate Zone	Zip code within a DAC	Zip code outside a DAC
Ductless	6	4%	12%
	8	15%	8%
	9	9%	9%
	10	11%	10%
	13	2%	0%
	14	1%	8%
	15	0%	8%
	16	0%	2%
	All CZs	**43%**	**57%**
Central	6	1%	12%
	8	5%	19%
	9	2%	10%
	10	5%	7%
	13	0%	0%
	14	0%	2%
	15	0%	35%
	16	0%	1%
	All CZs	**13%**	**87%**

3 METHODOLOGY

This section provides high level descriptions of the data collection activities of the evaluation including the identification of participants and primary research data collection efforts, and the methods used to evaluate site energy savings, CO_2 GHG emissions reductions, and bill impacts. Table 3-1 provides a summary of DNV's research activities to evaluate the impact of fuel substitution heat pumps.

Table 3-1. Impact evaluation activities

Task	Research Activity
Identification of program participant data	Map end-user addresses to utility addresses to identify customer account IDs (premise and customer account numbers)
Primary research data collection	Survey the different types of participating actors to determine program attribution, energy use impact of the installed measures, and household characteristics
Calculate ex post site savings estimates	Calculate the change in annual gas and electric use of sites that installed HVAC fuel substitution heat pumps through SCE's PY2020 incentive program
Calculate source energy and CO_2 emissions impacts	Calculate the amount of lifecycle source energy savings resulting from the HVAC fuel substitution heat pumps through SCE's PY2020 incentive program
	Calculate the lifecycle CO_2 GHG savings resulting from the HVAC fuel substitution heat pumps through SCE's PY2020 incentive program
Bill impacts	Calculate the electric and gas bill impacts of energy use changes associated with installed heat pumps

3.1 Data collection

In this section, we review the tasks associated with data collection (including data sources and program participant identification), data preparation for site energy savings analysis, and the primary research sampling approaches used in the evaluation.

3.1.1 Data sources

We summarize the various data sources and the purpose of their inclusion in the evaluation in Table 3-2 below. The data will be used to provide a robust and accurate ex post estimates of measure impacts.

Table 3-2. Summary of data sources and applicable measure groups

Data Sources	Description	Purpose in Evaluation
Program Tracking Data	PA Program data includes number of records, savings per record, program type, name, measure groups, measure description, incentives etc.	To identify program participants, installed measures, installation dates, and claimed (ex ante) savings
Detailed Program Participation Data	Site level information including customer addresses, names, and contact information, installation dates, and details on installed equipment, distributor and contractor names and contact information	To identify participating sites (including customer and premise IDs), contact information for end-user, contractor, and distributor surveys
Energy Use Data	PA monthly billing electric and gas data, and hourly electric and daily gas interval (AMI) data	To construct comparison groups, estimate energy savings, and construct pre-post-participation daily load shapes
Customer Data	Customer location (zip code), climate zones, and household-related information (household size, age composition, income, ownership status)	To construct comparison groups and estimate ex post measure savings estimates

Data Sources	Description	Purpose in Evaluation
Manufacturer Specification Sheets	Data sheets that include equipment specifications such as horsepower (HP), efficiency, capacity, etc.	To inform installed HVAC unit characteristics
Weather Data	Hourly temperature and dew points for the relevant analysis period and locations, and typical meteorological year (normal) weather data	To weather normalize energy consumption
Telephone/Web Surveys	Surveys of participating utility customers, contractors, and distributors, and PA program staff.	To determine net-to-gross ratios (NTGRs) and net savings To inform baseline conditions, energy use behavior and site characteristics

The following list defines the data sources identified in the table above:

Program tracking data. DNV used information about program participation from the tracking data that each PA files with the CPUC in the California Energy Data and Reporting System (CEDARS). Data were at the claim level applicable to each participating distributor.

Detailed program participation data. Since the evaluated program offered heat pumps through a midstream channel, the tracking data provided information for midstream actors and not sites or end-users where the measures were installed. DNV requested and used site level program data associated with the claims in the CEDARS tracking data to get details on participation including installation site addresses, participant names and contact information, installation dates, the specific measures installed, and the names and addresses of contractors and distributors. Data were at installed equipment level for each participating site.

Energy use data: DNV obtained monthly and interval advanced metering infrastructure (AMI) energy consumption data from the PAs to identify matched non-participants, estimate ex post savings for installed measures, and analyze energy use patterns (including average pre- and post-installation daily load shapes). The energy use data were at the customer account level.

Customer data: Supplementary information (location, climate zones, rates) for both participating and non-participating customers used in the study were sourced from utility customer information tables obtained from the PAs. Data were at the customer account level.

Manufacturer specification sheets. As part of the gross data collection, we requested technical specifications of the evaluated equipment from manufacturers and equipment vendors. These data sheets typically include performance parameters of the equipment such as horsepower, efficiency, capacity, and energy efficiency ratio (EER) at the equipment level.

Weather data. DNV collected weather information such as temperature and dew points for site level models used to estimate gross kWh and therms savings. The data were sourced from the National Oceanic and Atmospheric Administration (NOAA) and climate zone 2020 reference temperature files (CZ2020) to include in regression models accounting for weather sensitivity.[17] CZ2020 provides typical meteorological year (TMY) weather data for select California weather stations that are useful for long-term weather normalization. The study also used climate zone information available by zip code from the CEC.[18] Data were at the hourly level for each station.

[17] National Oceanic and Atmospheric Administration Hourly Weather Data; California Energy Commission Title 24. https://www.energy.ca.gov/title24/; http://www.calmac.org/weather.asp.

[18] https://ww2.energy.ca.gov/maps/renewable/building_climate_zones.html

Survey data. The study collected primary information from end-users at participating sites, contractors, and distributors through telephone and web surveys to determine program attribution, customer characteristics, effect of the installed measures on energy use, and customer experiences. Information was collected at the customer account, distributor, and contractor level for the responding sample.

3.1.2 Participant account identification

PY2020 is the first time that fuel substitution heat pump measures were included in California energy efficiency offerings. SCE offered these residential measures in preparation for statewide incentives rolled out starting in PY2021 to increase awareness and adoption of these technologies.

SCE's program offered these measures through distributors that worked with contractors to install them at participating utility customer sites. Although the program did not collect utility customer identifiers, which are required to measure changes in energy use from the installation of the measures, it did collect installation street addresses and utility customer names and email addresses. DNV mapped the addresses, utility customers names and email information to utility customer information records to identify customer account and premise numbers.

Table 3-3 provides the steps DNV took to identify participant customer account IDs (including premise numbers that identify the location of participating sites and customer numbers that identify the households that participated) along with the number of participants identified. The process involved matching participant addresses provided by SCE with utility addresses that are linked to electric and gas premise numbers. While address matching provided the premise numbers of participation sites, two additional steps were taken to determine the customer numbers of participating households. One involved matching SCE provided customer names with customer names in SCE and SCG utility records and their associated electric and gas customer numbers. Another involved obtaining electric and gas customer numbers of participating sites with only one resident through all of 2020, the period during which all installations occurred.

Table 3-3. Residential fuel substitution heat pump participant identifications steps

Identification steps	SCE			SCG		
	Central HP	Ductless HP	Total	Central HP	Ductless HP	Total
Total participating household addresses with fuel substitution heat pump installations [A]	1,122	7,043	8,165	-	-	-
Participating households with identified premise numbers in utility customer information files by IOU [B]	1,063	5,875	6,938	798	4,594	5,392
Participating households with identified premise and customer names in utility customer information files by IOU [B1]	612	3,070	3,682	467	2,385	2,852
Additional addresses with identified premise number and only one resident during the installation year by IOU [C]	209	1,361	1,558	194	1,323	1,509
Total participating households for whom AMI data was requested [D = B1 + C]	821	4,431	5,240	661	3,708	4,361

3.1.3 Customer data cleaning attrition

Site-level energy impact models included data from participating electric and gas customers. The data for these participants were based on customer and premise IDs identified through DNV's address matching efforts, described in the prior section. The address matching effort resulted in the identification of approximately 5,200 electric and 4,300 gas customer counts for whom energy data was collected and cleaned. Of these, approximately 3,000 electric and 3,800 gas customers had sufficient data available for the analysis. Table 3-4 provides participants' data identified for inclusion in the study, data attrition, and final customer counts used in the analysis.

Table 3-4. Participant counts used in fuel substitution heat pump evaluation

Participant Data Attrition	Electric	Gas
Customers addresses with heat pump claims in 2020*	8,165	
Customers with mapped account IDs	5,240	4,361
Customers for whom data was received	5,206	4,323
Customers without on-site solar	3,973	-
Customers with matched and sufficient data used in the analysis**	2,987	3,844
Customers with ductless heat pumps included in the analysis	2,524	3,249
Customers with central heat pumps included in the analysis	463	595

*Claimed by SCE 's rebate program - SCE electric and SCG gas customer IDs identified through address matching
**Customers without onsite-solar (electric) and at least 90% of pre-and post-installation period data

3.1.4 Primary data collection effort

Table 3-5 summarizes primary data collection efforts including key details such as respondent group, sample frame source, and sample size. Following the table, we provide additional details regarding all data collection efforts for the evaluation.

Table 3-5. Summary of primary data collection efforts for PY2020 fuel substitution heat pump evaluation

Details	Primary Data Collection Effort			
	Participant Utility Customer Surveys	Contractor Surveys	Distributor Surveys	In-Depth Interviews
Respondent Group	Residential PA Customers	Participating Contractors	Participating Distributors	PA Program Managers
Data Collected	**Baseline conditions:** previous heating and cooling systems, heating fuel **Energy use behavior changes:** new heating and cooling system types and use **Program influence:** NTG **Participant experience:** Motivations for participation, barriers, contractor choice, satisfaction **Demographic data:** education, income, and household size	**Program influence:** NTG **Program participation**: participation satisfaction, type of equipment available, information from distributors	**Program influence:** NTG	**Program information**: Program updates, COVID effects, customer contact information, customer participation trends over the life of the program, changes in outreach, messaging, and incentive levels
Mode	Web	Mixed mode – Web followed by phone, as needed	Phone	Phone
Frame Source	Participating utility customers identified through detailed PA program participation data	Participating contractors identified through detailed PA program participation data	Participating distributors identified through detailed PA program participation data	PA program staff
Stratification Approach	PAs, climate zone, level of energy use	Business name	PAs	PAs
Sample Size	Census (100% of participants invited to participate)	Census (100% of participants invited to participate) but with a target n = 150	Census (100% of participants invited to participate)	Census (100% of staff invited to participate)

Details	Primary Data Collection Effort			
	Participant Utility Customer Surveys	Contractor Surveys	Distributor Surveys	In-Depth Interviews
Program year(s)	PY2020	PY2020	PY2020	PY2020
Data collection timing	Fall 2021	Fall 2021	Fall 2021	Summer 2021

3.1.5 Sample design and selection

The sampling approach for all interviews and surveys were attempted census. We issued a survey request via email to the entire population of participating end-user utility customers who installed fuel substitution heat pumps in PY2020 with a goal of a 10% or greater completed response rates to inform program attribution, understand baseline conditions, energy use behavior changes, and participant program experience. We made multiple phone calls and sent multiple emails in an attempt to survey all participating equipment distributors. A random stratified sampled based on combined kWh and therms savings that targeted results at 90/10 confidence was drawn based on the savings aggregated based on the contractor's business names. In addition, backup sites were identified as replacements for any primary selected sample points that were unable to be contacted or recruited. The intent of this sample was to identify a target stratified subset of contractors to pursue via phone-based survey recruitment and administration where the email survey platform fell short. The data gathered from the contractors and distributors were used to inform program attribution. The evaluation also collected program-related information from PA program staff.

3.1.6 Survey mode

Our data collection approaches were designed to efficiently capture information to support multiple goals: net savings and energy use impact of the installed measures. We also included general utility customer surveys to assess participant experience including motivations and barriers to program participation.

We conducted web surveys with utility customers to gather the information listed above. We gathered information from contractors using both web and telephone surveys. All distributor surveys were carried out via telephone.

3.2 Site energy savings

Site energy savings are those realized at the utility customer site and reported by the PAs as savings. DNV estimated site level gross energy savings and the portion of these savings that can be attributed to the programs that delivered the measures, net energy savings. This section details the approaches DNV used to estimate both gross and net energy savings.

3.2.1 Gross energy savings

DNV's gross energy savings analysis is based on a two-stage modeling approach that estimates the effect of program measures on energy consumption of homes receiving the measures. The first-stage uses site-level models to weather normalize energy consumption. The second stage uses a difference-in-difference (DID) approach based on the pre-to-post difference of weather normalized energy consumption of participant and matched comparison households to estimate savings. The first-stage models control for the effect of weather on energy consumption while the second stage models control for the effect of non-program changes on energy consumption.

The two-stage 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 energy savings estimation protocols for energy efficiency interventions that have whole-home impacts like heat pumps.[19] It is also consistent with CalTRACK, which involved efforts to develop agreed upon steps for site-level modeling.[20] Details of the comparison group development, and first-stage and second-stage models are described in Appendix B.

3.2.2 Net energy savings

DNV utilized a triangulation method to measure free-ridership, attribution, and NTG for the fuel substitution program. This approach produced four NTG estimates based on survey responses from distributors, contractors, and end-users (Figure 3-1).

- Distributors' answers to market effects questions produced one of the scores. Distributors also answered questions about how the program affected their stocking, upselling, and pricing behaviors (used in the "causal pathway" approach).
- Contractors answered questions about how the immediate availability of program-eligible units, distributor recommendations to purchase program-eligible units, and the price of those units affected their customers' decisions to purchase the units that received incentives. These answers were combined with the distributor causal pathway questions to produce a distributor → contractor causal pathway NTG estimate.
- End users were split into those that who were aware of the incentives and those who were not aware of the incentives:
    - Unaware end-users answered questions about how the immediate availability of program-eligible units, seller's recommendations to purchase program-eligible units, and the price of those units affected their decision to purchase them. These questions were combined with the distributor causal pathway questions to produce a distributor end-user causal pathway NTG estimate.
    - Aware end-users answered standard timing, efficiency, and quantity counterfactual free-ridership questions, which produced an end-user NTG estimate.

To triangulate the overall NTG ratio for the program, DNV first estimated an end-user NTG score by calculating a savings-weighted average of the NTG score for aware end-users with the NTG score for the unaware end-users. Then, DNV calculated a simple average of the distributors, contractor, and (combined) end-user NTG scores to estimate the final program NTG score.

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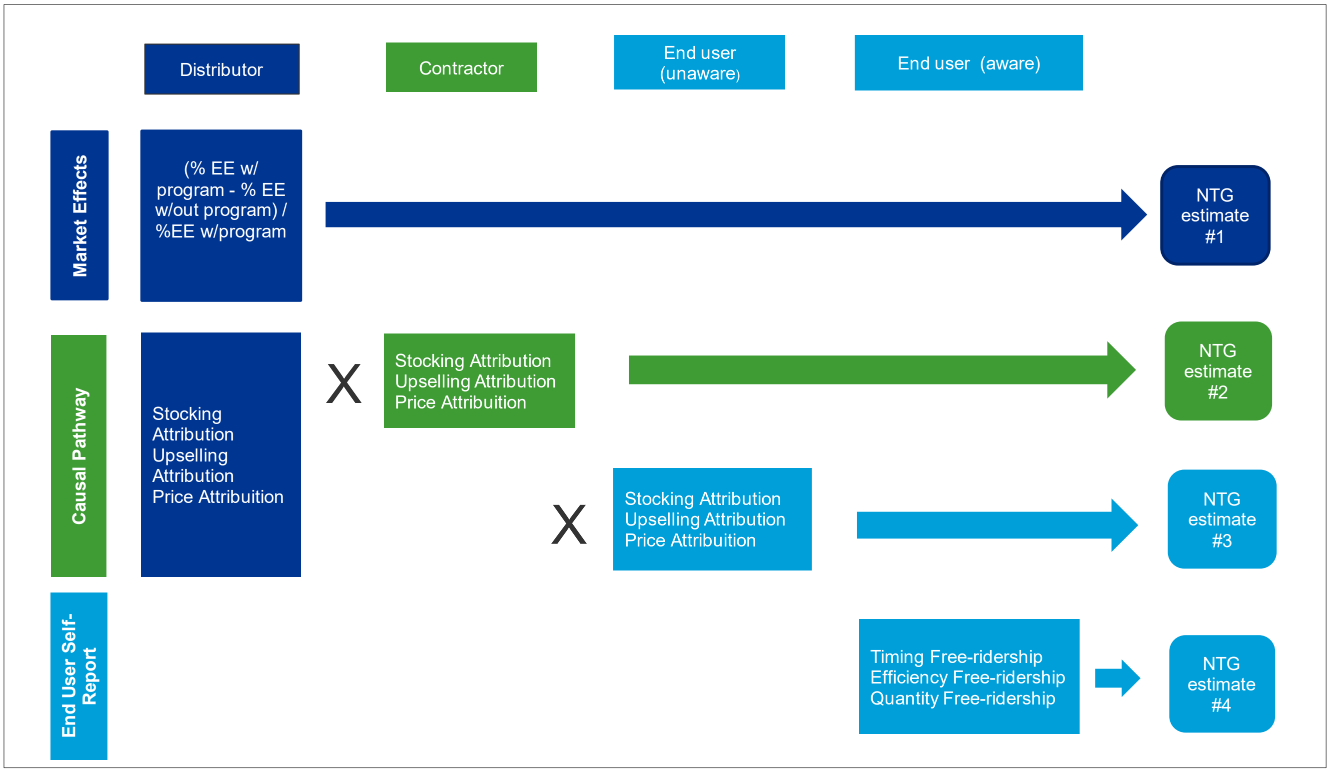
[19] Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. The Uniform Methods Project. https://www.nrel.gov/docs/fy17osti/68564.pdf

[20] CalTRACK, http://www.caltrack.org/

Figure 3-1. Fuel switching program NTG estimates



3.2.2.1 Additional details on the scoring methods are provided in distributor surveys

DNV attempted a census of the 17 distributors who participated in the program in PY2020. Semi-structured phone interviews gathered data needed to assess the causal pathway method of estimating attribution, data on the market effects of the program, and information about what market forces were the most important. DNV completed interviews with 11 distributors. All 11 sold ductless heat pumps (9 provided market effects answers); 9 sold central heat pumps (5 provided market effects answers). These distributors represented approximately two-thirds of the program volume in terms of units (tons), savings, and incentives.

3.2.2.2 Contractor surveys

DNV surveyed contractors associated with the program to gather data needed to assess the causal pathway method of estimating attribution. DNV completed online surveys with 165 of the 2,345 contractors listed in the program tracking database as having sales associated with at least one rebate. Most (126) of the 165 contractors sold or installed ductless systems; 54 sold or installed central systems. DNV offered to enter contractors into a drawing to win a $100 gift card for their participation in the survey.

3.2.2.3 Utility customer surveys

DNV surveyed utility customers (end-users) to gather data to assess the causal pathway version of attribution for respondents unaware of the program and the standard timing, efficiency, quantity method for respondents that were aware of the program. The surveys also gathered information used in the gross impact evaluations regarding the previous system specifications and uses.

Out of the 6,031 end-users in the population with valid email addresses, DNV completed online surveys with 191 that installed central heat pumps and 525 that installed ductless heat pumps. DNV offered to enter customers into a drawing to win a $200 gift card for their participation in the survey.

3.3 Source energy and CO_2 emissions savings

Source energy savings are the savings from only natural gas combustion, "either through power generation or in direct combustion for the end-use."[21] The methodology for calculating evaluated source energy savings follows the approach prescribed in the CPUC's Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1. The reported and evaluated site-level energy savings values were input into the Fuel Substitution Calculator Version 1.1 for the determination of reported and evaluated source energy savings. The (first-year) full energy savings and lifecycle primary energy savings output values were extracted from the calculator for reporting the source energy impacts of the two HVAC fuel substitution measures.

Emissions savings in this case are "total CO_2 emissions over the EUL of the measure technology," as identified in the CPUC's Fuel Substitution Guideline document.[22] The lifecycle emissions savings (in CO2 metric tons) output values were extracted from the calculator for reporting the emissions impacts of the two HVAC fuel substitution measures.

3.4 Bill impacts

Uncertainty regarding potential utility bill increases could be a barrier to fuel switching. DNV evaluated the bill impacts of the fuel substitution heat pumps by combining the consumption data analysis results with rate schedule information from SCE and SCG. We assumed the same rate is applicable before and after retrofit to provide an apples-to-apples comparison of pre- and post-installation results.

To assess gas bill impacts, we used SCG's residential service rates that are applicable to participating customers. SCG has two-tiered residential service rates for the residential gas service it provides. The two-tiered rates are applicable to baseline and non-baseline consumption. The majority of residential customers are on the individually metered residential gas service rate (GR), but we used the rate that is pertinent to each customer to calculate the cost impact of the gas use reduction from heat pump installations. To assess electric bill impacts, DNV used SCE's residential service rates applicable to each participating customer. SCE's three-tiered domestic rates, which apply to three different usage levels, and time-of-use (TOU) rates, which vary by season and time of day, were relevant to customers included in the analysis. Additional information on the rate schedules used for calculating the bill impacts can be found in Appendix G.

[21] California Public Utilities Commission. Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1. https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency.

[22] Ibid.

4 EVALUATED SAVINGS RESULTS

We provide our savings results from the evaluation of residential HVAC fuel substitution technologies in this section. We report on site energy, source energy, and CO_2 emissions savings, and typical annual energy bill impacts.

4.1 Site energy savings

Site energy savings are the energy consumption reductions at the utility customer site and are the values the PAs report as savings. The PAs report both gross and net savings. Gross savings are the changes in energy consumption resulting from the installation of energy efficient technologies offered by PA programs, regardless of what factors may have motivated program participants to install these measures. Net savings are the portion of gross savings attributable to a program's influence.

4.1.1 Gross site energy savings

Fuel substitution heat pump technologies provide both the heating and cooling needs of the sites where they are installed. As fuel substitution measures, the heat pumps delivered by the program that DNV evaluated were intended to replace end users' gas heating with an efficient electric heating reducing the gas consumption of participating sites.

While heat pumps reduce gas consumption, they are expected to increase electricity consumption associated with the needed for heating. Electricity consumption of the sites can also increase when heat pumps are used for cooling at locations without prior cooling.

4.1.1.1 Ductless HVAC systems

DNV estimated the changes in annual weather normalized electricity and gas consumption of participating sites to evaluate the magnitudes of the decrease in gas and increase in electricity consumption from the installation of ductless heat pumps. Table 4-1 below illustrates the consumption change estimates. The results indicate a statistically significant but modest 3% annual savings in annual gas consumption. On the other hand, there is a statistically significant increase of 3% in annual electricity consumption. The savings in gas consumption is associated with an estimated 7% savings in gas heating load, while the estimated annual increase in electricity consumption is associated with an estimated 21% addition in electric heating load. Sites with ductless heat pumps also appear to have a modest electric cooling savings of 2%.

Table 4-1. Evaluated annual energy change per site for ductless heat pump systems[23]

Fuel	Model	Baseline consumption (therms)	Change (therms)*	% Change*	P-value	Relative Precision**
Gas	**NAC**	**415**	**11**	**3%**	**0.00**	**40%**
	Heating load	182	12	7%	0.00	28%
Fuel	**Model**	**Baseline consumption (kWh)**	**Change (kWh)***	**% Change***	**P-value**	**Relative Precision****
Electric	**NAC**	**9,035**	**-315**	**-3%**	**0.00**	**26%**
	Cooling load	1,947	32	2%	0.00	138%
	Heating load	326	-70	-21%	0.00	34%

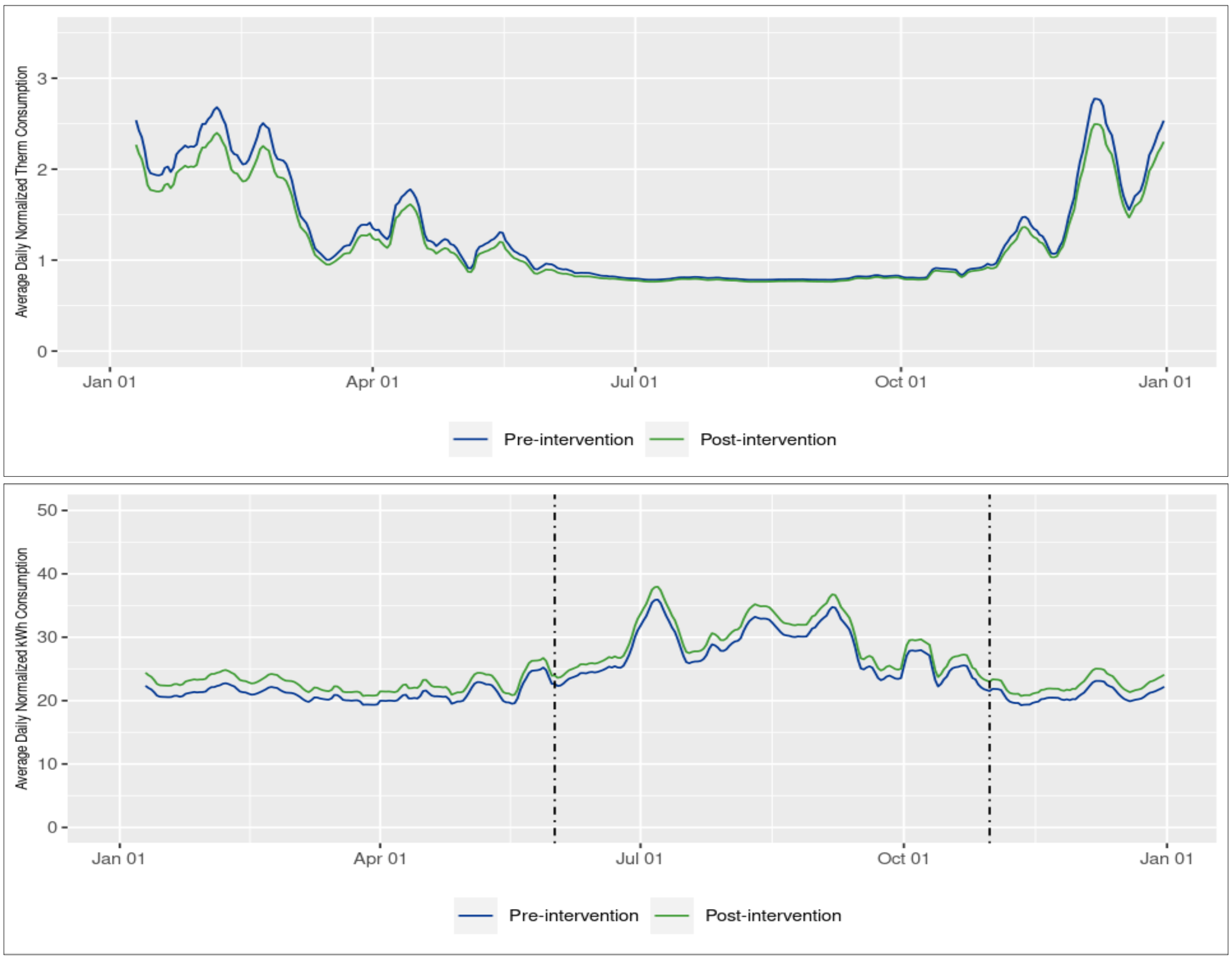
* Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption
**Relative precision values with 90% confidence

Figure 4-1 provides average daily weather normalized gas and electricity consumption pre- and post-installation of ductless heat pumps. The top panel illustrates average daily normalized gas (therm) consumption, which shows a modest reduction in daily gas consumption during the heating season. The bottom panel shows average daily normalized electricity

[23] In the table, the p-values indicate how certain we are that the estimated changes in energy consumption are statistically different from 0 while the relative precisions indicate how certain the estimated changes are.

consumption, which shows increases in average daily electricity consumption throughout the year including the cooling season (the period between the two dashed vertical lines). While the average daily electricity consumption plot does not show reductions during the cooling season, model estimates that consider the effect of exogenous change based on the DID model presented in the table above indicate a modest cooling reduction from the installation of ductless heat pumps. The DID model uses a comparison group to control for the effect of non-program related changes that affect energy consumption trend. In this case, the comparison group controlled for a general upward trend in energy consumption, which made evident the electric savings achieved from the ductless heat pumps.

Figure 4-1. Average daily normalized gas and electricity consumption pre- and post-installation of ductless systems



4.1.1.2 Central HVAC systems

Table 4-2 provides the estimated gas and electricity consumption changes per sites for central heat pumps systems. The results indicate annual gas consumption savings of 35% and gas heating load savings of 59%. Annual electricity consumption increases by 7% with an electric heating load addition of over 200% and cooling load reduction of almost 20% from the installation of central heat pumps. Gas consumption savings from central heat pumps are over ten times higher than such savings from ductless systems. Similarly, central heat pumps have electric heating increases and electric cooling savings that are ten times those of ductless systems.

Table 4-2. Evaluated annual energy change per site for central heat pump systems[24]

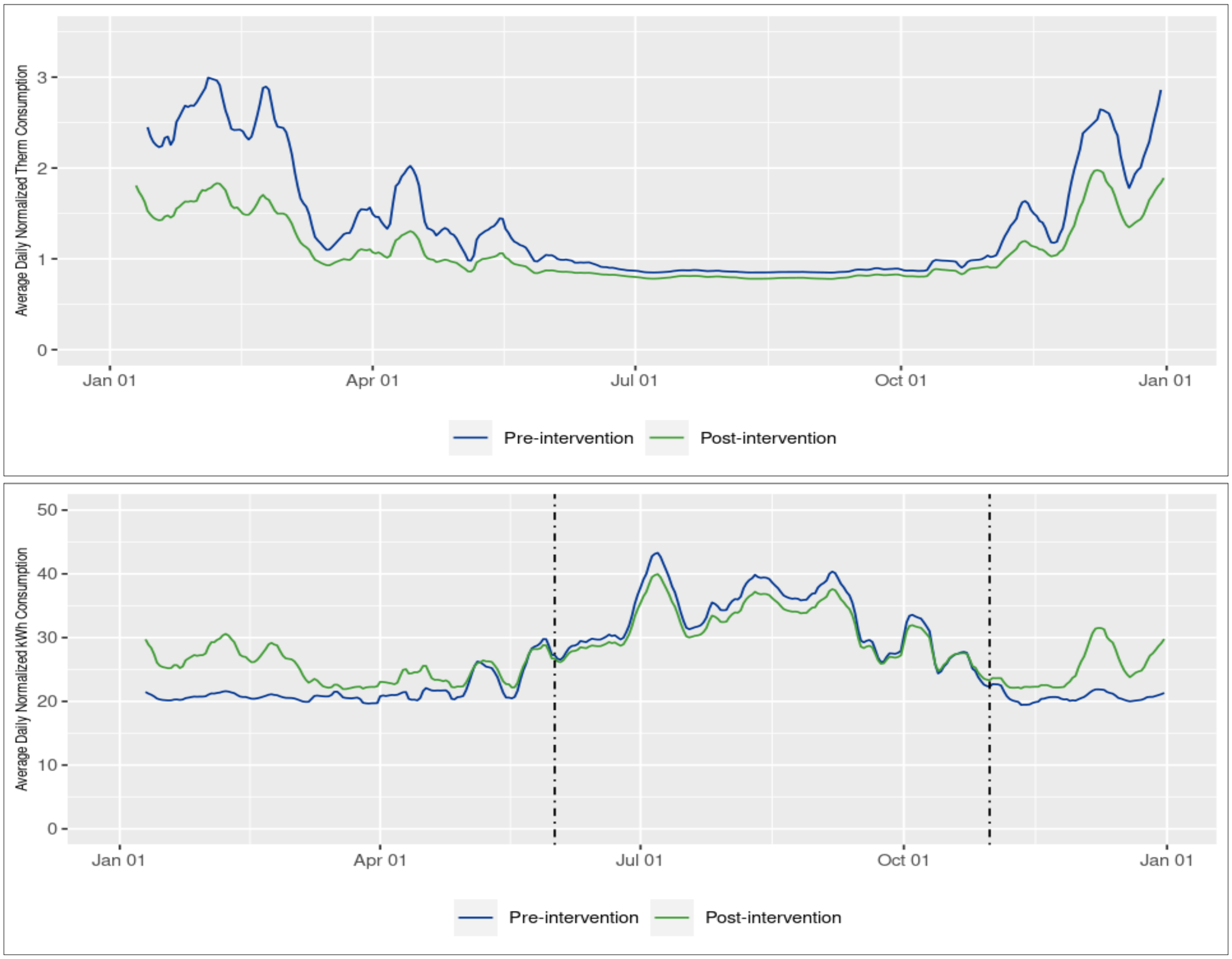
Fuel	Model	Baseline consumption (therms)	Change (therms)*	% Change*	P-value	Relative Precision**
Gas	**NAC**	**436**	**152**	**35%**	**0.00**	**12%**
	Heating load	199	118	59%	0.00	12%
Fuel	**Model**	**Baseline consumption (kWh)**	**Change (kWh)***	**% Change***	**P-value**	**Relative Precision****
Electric	**NAC**	**9,640**	**-715**	**-7%**	**0.00**	**27%**
	Cooling load	2,422	459	19%	0.00	30%
	Heating load	272	-562	-207%	0.00	25%

* Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption
**Relative precision values with 90% confidence

Figure 4-2 provides average daily normalized gas and electricity consumption pre- and post-installation of central heat pumps. The top panel, presenting normalized gas consumption, makes evident the notable reduction in gas load during the heating season following the installation of central heat humps. The bottom panel, showing normalized electricity consumption, shows the increase in electric load during the same time period. It also indicates the reduction of electric load during the cooling season. Similar to the ductless heat pump case, the DID model used to estimate the cooling reduction associated with this technology controls for a general upward trend in energy consumption, which made evident the electric savings achieved from the ductless heat pumps.

[24] In the table, the p-values indicate how certain we are that the estimated changes in energy consumption are statistically different from 0 while the relative precisions indicate how certain the estimated changes are.

Figure 4-2. Average daily normalized gas and electricity consumption pre- and post-installation of central systems



4.1.1.3 Overall gross site savings

Table 4-3 and Table 4-4 compare the evaluated gas and electric savings per site and per ton against reported values. Evaluated electric consumption increases from both technology types are about two-thirds of what is reported; gross realization rates (GRR) for these measures are approximately 65%. On the other hand, the ratios of evaluated to reported gas consumption savings are different for the two technologies. Central heat pumps delivered 75% of reported gas savings while ductless heat pumps delivered only 5% of reported gas savings. We discuss survey findings that explain the probable drivers of these results in the Section 5 of the report.

Table 4-3. Reported and evaluated annual gas energy change, GRR, and relative precision

Measure	Gas savings (therms)					
	Per site		Per ton		GRR	Relative precision**
	Reported	Evaluated*	Reported	Evaluated*		
Ductless	243	11	86	4	5%	40%
Central	202	152	46	35	75%	12%

* Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption
**Relative precision values with 90% confidence

Table 4-4. Reported and evaluated annual electric energy change, GRR, and relative precision

Measure	Electric savings (kWh)					
	Per site		Per ton		GRR	Relative precision**
	Reported	Evaluated*	Reported	Evaluated*		
Ductless	-465	-315	-165	-112	68%	26%
Central	-1,118	-715	-255	-163	64%	27%

* Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption
**Relative precision values with 90% confidence

4.1.2 Program attribution

While the preceding provided DNV's estimates of the impact of the installed measures on energy consumption, this section provides our estimates of the influence of the program on motivating these savings. This influence is measured by net-to-gross ratios for which we provide our findings below.

4.1.2.1 Ductless HVAC systems

The NTGR scores for ductless systems from each of the survey respondent types are presented in Table 4-5. Distributors indicated that the program had almost no effect (1%) on the proportion of their sales that were high efficiency ductless systems. Contractors (63%) and Customers (56%) gave the program higher attribution scores. Averaged together, the estimated NTGR for ductless systems in 40% ± 6%. This results in a relative precision of 15% with 90% confidence for the combined estimate.

Table 4-5. NTGR scores and relative precision values for ductless HVAC systems

Survey	NTGR Score	NTGR Relative Precision**
Distributor	1%	121%
Contractor	63%	18%
Utility Customer	56%	10%
Overall	**40%**	**15%**

**Relative precision values with 90% confidence

This NTGR is based on a triangulation of the information gathered in the distributor, contractor, and customer surveys. Key results from those surveys were:

- Distributors reported that high efficiency ductless heat pump sales only increased 1% due to the program. In verbatim responses, several distributors mentioned that the price of natural gas is so low compared to the price of electricity that it is difficult to sell these units.
- Distributors also reported that the program had zero effect on their stocking or upselling practices. They pass 100% of the rebates down to their buyers, and the distributors indicated that the ability of the rebates to reduce the cost of high efficiency units is a key factor in making sales.
- Contractor responses were partially consistent with the distributors. Contractors reported that distributor recommendation (upselling) was the most important component of attribution and price was the lowest. Contractors said that customers consider price and other features of the units such as noise, zone control, and warranty. They indicated passing approximately 75% of the rebates down to customers.
- Approximately one-third (31%) of the customers who were aware of the rebates said they would not have purchased the units without the rebate. Customers who were not aware of the rebates said that the seller's recommendation (upselling)

was the most important attribution component and price was the least important. Approximately 45% of the unaware customers said they would have purchased the unit anyway without the rebate, and approximately 39% said they would have waited, shopped elsewhere, or purchased a different but equivalent model if the seller did not have their preferred unit in stock.

4.1.2.2 Central HVAC systems

The NTGR scores for central systems from each of the survey respondent types are presented in Table 4-6. Distributors indicated that the program had substantial (53%) effects on the proportion of their sales that were high efficiency central systems. Contractors (73%) and Customers (44%) also gave the program moderate attribution scores. Averaged together, the estimated NTGR for central systems in 57% ± 11%. This represents a relative precision of 20% with 90% confidence.

Table 4-6. NTGR scores and relative precision values for central HVAC systems

Survey	NTGR Score	NTGR Relative Precision**
Distributor	53%	6%
Contractor	73%	32%
Utility Customer	44%	16%
Overall	**57%**	**20%**

**Relative precision values with 90% confidence

This NTGR is based on a triangulation of the information gathered in the distributor, contractor, and customer surveys. Key results from those surveys were:

- Distributors reported that high efficiency central heat pump sales increased approximately 50% due to the program. Of all the attribution survey results, the difference in market effects between central and ductless heat pumps was the greatest.
- Distributors also reported that the program had almost no effect on their stocking or upselling practices. They pass 100% of the rebates down to their buyers, and the distributors indicated that the ability of the rebates to reduce the cost of high efficiency units is a key factor in making sales.
- Contractor responses for central heat pumps differed very little with their responses for ductless heat pumps. Contractors reported that distributor recommendation (upselling) was the most important component of attribution and price was the lowest. Contractors said that customers consider price and other features of the units such as noise, zone control, and warranty. They indicated passing approximately 75% of the rebates down to customers.
- Approximately one-fifth (18%) of the customers who were aware of the rebates said they would not have purchased the central heat pump units without the rebate. Customers who were not aware of the rebates said that the seller’s recommendation (upselling) was the most important attribution component and price was the least important. Approximately 20% of the unaware customers said they would have purchased the unit anyway without the rebate, and approximately 35% said they would have waited, shopped elsewhere, or purchased a different but equivalent model if the seller did not have their preferred unit in stock.

4.1.3 Net site energy savings

We calculated evaluated net site savings by applying the NTGR attribution values to the calculated evaluated gross savings. Table 4-7 presents the reported and evaluated gross and net energy savings, NTGR, and net realization rates (NRR)[25] for the ductless and central heat pump fuel substitution measures.

Table 4-7. Reported and evaluated gross and net site energy saving

Measure	Reported Gross Savings*	GRR	Evaluated Gross Savings*	Reported NTGR	Evaluated NTGR	Reported Net Savings	Evaluated Net Savings*	NRR
Electric consumption (kWh)								
Ductless	-3,277,158	68%	-2,218,485	100%	40%	-3,277,158	-889,613	27%
Central	-1,254,168	64%	-802,188	100%	57%	-1,254,168	-456,445	36%
Gas consumption (Therm)								
Ductless	1,713,517	5%	77,810	100%	40%	1,713,517	31,202	2%
Central	226,990	75%	170,635	100%	57%	226,990	97,092	43%

* Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption

Overall, the central HVAC heat pump systems achieved a 43% net realization rate for gas energy savings, and a 36% NRR for the electric energy increase. Both NRRs are a product of applying the evaluated NTGR value of 57% to the gross savings, which reflect 75% and 64% gross realization rates for gas savings and electricity consumption increases respectively for the central systems. The ductless HVAC heat pump systems achieved a 2% NRR for gas savings and a 27% NRR for the electric energy increase. Compared to the central systems, the evaluated NTGR for the ductless HVAC heat pump systems is moderately lower (40%), while the beneficial gas energy savings is much lower at 5% GRR while the electric energy increase has a substantial GRR of 68%.

4.2 Source energy savings

The evaluated source energy savings is based on the outputs of the CPUC's Fuel Substitution Calculator v1.1, using the total gross evaluated site energy savings and other pertinent measure details as the inputs into the custom calculator segment. In reviewing the source energy savings, it is important to understand that in the fuel substitution test "only the source energy from depletable fossil-fuel resources are currently considered" by the CPUC. The CPUC approach considers "the source energy and emissions for renewable generation, such as solar, wind, and hydro-electric generation, to be zero." Thus, source energy savings are the savings only from natural gas combustion "either through power generation or in direct combustion for the end-use."[26]

Table 4-8 below presents the evaluated and reported first-year full energy savings and the lifecycle source energy savings, in MMBtu, for both the ductless and central HVAC technologies.

Table 4-8. Reported and evaluated first-year and lifecycle source energy savings

Technology	First year Full Energy Savings (MMBtu equivalent)	Lifecycle Primary Energy Savings (MMBtu at generation source)

25 NRR is the quotient of evaluated net savings relative to reported net savings.

26 California Public Utilities Commission. Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1. https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency.

	Per dwelling unit	Per ton	Program total	Per dwelling unit	Per ton	Program total
Ductless, evaluated	0.02	0.01	209	1.04	0.40	7,851
Ductless, reported	21.8	7.8	153,629	328	117	2,311,384
Ductless, ratio of evaluated to reported	**0.11%**	**0.14%**	**0.14%**	**0.32%**	**0.34%**	**0.34%**
Central, evaluated	12.8	2.9	14,326	193	44.0	216,588
Central, reported	16.4	3.7	18,383	248	56.6	278,411
Central, ratio of evaluated to reported	**77.9%**	**77.9%**	**77.9%**	**77.7%**	**77.8%**	**77.8%**

The results for ductless HVAC systems show a very small first year source average energy savings of 0.02 MMBtu per household, 0.01 MMBtu per ton capacity, and 209 MMBtu in total, compared to the calculated reported equivalent of 21.8 MMBtu per household, 7.8 per ton, and 153,629 MMBtu program total first year source energy savings. Lifecycle source energy savings, 1.04 MMBtu per household, 0.40 per ton, and 7,851 MMBtu total, are also modest in comparison to the reported equivalent savings (328 MMBtu per household, 117 per ton, and 2,311,384 MMBtu total). As a result, ductless HVAC systems barely pass the source energy savings test[27] for fuel substitution. However, accounting for measurement uncertainty, the evaluation finds the lifecycle source energy savings impact of this technology application questionable, and it falls short of meeting reporting expectations for achieving source energy savings. For instance, the uncertainty around the first-year full energy savings of 0.02 MMBtu per household for ductless systems means the source energy savings value could just as reasonably be higher, zero, or even be slightly negative, and certainly not the 21.8 MMBtu reported.

This first-year result is driven by the low evaluated gas savings and the moderate evaluated electric consumption increase from the site-level savings analysis, whereas the lifecycle measurement benefits from the calculator's assumed lowering of electric source energy intensity (Btu/kWh) over the lifetime of the technology. The ductless HVAC system claims will have to achieve higher gas savings in future program years to reach the source energy savings expected from these heat pump fuel substitution technologies.

Compared with the ductless HVAC technology group, the central HVAC technology group exhibits much greater first-year source energy savings of 12.8 MMBtu per household on average, 2.9 MMBtu per ton capacity, and 14,326 MMBtu in total. Therefore, the central HVAC technology group passes the source energy savings test for fuel substitution with a considerable margin. Relative to the reported first-year source savings of 16.4 MMBtu per household, 3.7 per ton, and 18,383 MMBtu for the program, the evaluated result for this technology comes much closer to meeting source savings expectations. The central HVAC technology group falls a little short of expectations for source energy savings because the evaluation result does not achieve as much gas savings as expected, but it does achieve this gas savings at a lower electric energy increase than anticipated. The lifecycle source energy savings result for the central HVAC technology is also significant at 193 MMBtu per site (44.0 per ton) and 216,588 MMBtu in total.

4.3 CO_2 emissions savings

As with the source energy savings methodology, the evaluated carbon dioxide (CO_2) emissions savings is based on the outputs of the CPUC's Fuel Substitution Calculator v1.1 that use the total gross evaluated site energy savings and other

27 The threshold for passing is a positive (>0) lifecycle primary energy savings.

pertinent measure data as the inputs into the custom calculator segment. Emissions savings results are “total CO_2 emissions over the EUL of the measure technology,” as identified in the CPUC’s Fuel Substitution Guideline document.[28] Table 4-9 provides reported and evaluated CO_2 reductions at per site, per ton capacity, and at the program level.

Table 4-9. Reported and evaluated lifecycle emissions savings

Technology	Lifecycle Emissions Savings (Metric tons CO_2)		
	Per dwelling unit	Per ton	Program total
Ductless, evaluated	0.06	0.02	417
Ductless, reported	17.4	6.19	122,666
Ductless, ratio of evaluated to reported	**0.32%**	**0.34%**	**0.34%**
Central, evaluated	10.2	2.3	11,494
Central, reported	13.2	3.0	14,775
Central, ratio of evaluated to reported	**77.7%**	**77.8%**	**77.8%**

The emissions saving results are similar to the source energy findings in that the ductless HVAC systems produce a very small individual emissions benefit (0.06 tCO_2 evaluated versus the 17.4 tCO_2 reported) and very limited total emissions benefit given the volume of the reported systems. On the other hand, the central systems achieved a substantial reduction in lifecycle emissions (10.2 tCO_2 evaluated versus the 13.2 tCO_2 reported per site) per household as well as at the program level and provide 77% of the expected CO_2 reductions. This is a direct result of the difference in achieved gas savings between the ductless and central HVAC heat pump technologies. Like with the source energy savings findings, the ductless HVAC system claims will have to achieve higher gas savings in future program years to reach the CO_2 emissions savings expected from these heat pump fuel substitution technologies.

4.4 Bill impacts

The results of the bill impact assessment are presented in Table 4-10. Central HVAC systems that replaced less efficient heating systems provided utility customers an average annual bill savings of $95. The gas bill savings associated with these systems outweighed cost increases from their increased electric load. On the other hand, ductless systems that supplemented existing HVAC equipment led to total average annual bill increases of $86. The gas cost savings from these systems did not outweigh the cost increase associated with their higher electric load. Overall, the program resulted in an average annual bill increase of $58 since most installations were ductless HVAC rather than central HVAC fuel substitution heat pumps.

[28] California Public Utilities Commission. Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1. https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency.

Table 4-10. Average annual energy bill impacts from fuel substitution heat pumps

Technology	Electricity costs	Gas costs	Total costs
Ductless HVAC	$151	-$66	$86
Central HVAC	$170	-$265	-$95
Overall	**$154**	**-$97**	**$58**

Negative values indicate a cost reduction while positive values indicate an increase.

Table 4-11 summarizes the average annual household bill impacts based on the change in average cost per customer for each fuel. Participants who received incentives to convert their gas space heating to heat pumps realized an annual average cost savings of $95. This savings equates to an estimated total program first-year savings of $106,669 for the 1,122 households that received this measure. On the other hand, the majority of participants (7,043) installed ductless systems through the programs, which were associated with an average cost increase of $86 per unit.

Overall, the estimated total program first-year increase for this measure was $604,177.

Table 4-11. Average annual bill impacts per site and for all participants from fuel substitution heat pumps

Measure	Average Annual Bill Impact			Total Participants	Total Bill Reduction
	Electric	Gas	Total		
Ductless HVAC	$151	-$66	$86	7,043	$604,177
Central HVAC	$170	-$265	-$95	1,122	-$106,669
Overall	**$154**	**-$97**	**$58**	**8,165**	**$471,929**

Negative values indicate a cost reduction while positive values indicate an increase.

5 ADDITIONAL SURVEY RESULTS

In addition to information for program attribution, survey responses from participating utility customers also provided insight into household characteristics, energy use attributes, and experience with heat pump installations. The sections that follow detail these findings.

5.1 Participant characteristics

Table 5-1 provides a summary of household characteristics for participants who installed central and ductless heat pumps. It indicates that households that participated in the program have relatively high incomes. The majority reported more than $150,000 in annual income with homes installing central systems being marginally better off than those installing ductless systems. In addition, participants are also well educated with 73% and 50% of those with central and ductless systems, respectively, reporting college or higher level of educational attainment. By comparison, 35% of Californians[29] have a bachelor's degree or higher, indicating that a disproportionate level of educated households is represented in the program. Further, the majority of participating households have two to three members, which is typical for single family homes.

Table 5-1. Household characteristics: education, income, and household size

Characteristics	PY 2020 Central Heat Pump Participants (n=171)	PY 2020 Ductless Heat Pump Participants (n=394)
Income		
Less than $50,000	*7%	10%
More than $50,000 and less than $150,000	*27%	21%
More than $150,000	*37%	33%
Education		
College or higher	*73%	50%
High school or less	*4%	15%
Household size		
1 person	13%	14%
2-3 people	*59%	45%
4 or more people	*20%	31%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level.

5.2 Energy use attributes

5.2.1 Heating system

A summary of the attributes of the previous and the new heating systems as well as participant behavior related to both is provided in Table 5-2. Based on the summary, most participants reported still receiving gas service (94% for central and 89% for ductless) indicating that there has not been complete electrification for almost all participants despite the addition of electric heat pumps for heating and cooling purposes. Further, all installed heat pumps (of both kinds) are still in use.

The results also show that almost all those with central heat pumps (98%) reported replacing their existing (mostly central furnace) heating systems that were fueled by natural gas. On the other hand, only about a third (33%) of those who installed ductless heat pumps reported replacing their existing system. Most (66%) of those with ductless heat pumps reported keeping their natural gas-fired heating systems when they added the heat pump. The low gas savings estimated for those with ductless heat pumps reflects this limited fuel substitution and apparent load building by this group of participants who installed their ductless heat pumps in previously unheated space (22%), as part of a new room addition (4%), or as part of a

[29] https://data.census.gov/cedsci/table?q=educational%20attainment&g=0100000US,%2404000%24001_0400000US06&tid=ACSST1Y2019.S1501

home renovation (10%). Moreover, a greater proportion (44%) of those who installed ductless systems compared to those with central heat pumps (23%) reported using more heat after installing their heat pumps.

Of those who added ductless heat pumps without replacing their existing heating system, about one-fifth (21%) had an existing ductless furnace (floor/wall furnace), 50% had a central furnace, and 13% already had a ductless heat pump.[30] In addition, a majority of participants who installed their heat pumps as a replacement or in addition to their existing system reported that their previous heating system worked well indicating a high incidence of early replacement than the normal replacement intended for this type of program.

Table 5-2. Heating system characteristics and changes

Characteristics	PY 2020 Central Heat Pump Participants (n=171)	PY 2020 Ductless Heat Pump Participants (n=394)
Heating System		
Heat pump still in use	100%	100%
Homes with gas service	*94%	89%
Percent utility gas	*93%	81%
Percent propane	1%	8%
Replacing existing heating system	*98%	33%
New heating load	*2%	66%
Installed in previously unheated space	*1%	22%
Installed in a new room added to home	*0%	4%
Added without removing existing system	*1%	30%
Part of home renovation	*0%	10%
Previous Heating System[1]		
Central furnace system	*78%	50%
Existing heat pump system	*15%	13%
Floor/wall heater	*2%	21%
Previous heating system did not work well	*40%	25%
Previous heating system worked well	*58%	70%
New Heat Use[1]		
More heat use	*23%	44%
About the same heat use	*63%	34%
Less heat use	*10%	17%

[1]Answers from a subset of respondents (n = 162 (central); n = 242 (ductless).
*Statistically significantly different from ductless installation responses, at least at the 90% confidence level.

5.2.2 Cooling system

Findings on the previous and new cooling systems of participants are provided in Table 5-3. As the table indicates, a small percentage (13%) of those with central heat pump installations reported adding new cooling load compared to those with ductless heat pumps, 78% of whom reported adding cooling load. These results line up with the findings of higher cooling savings for those with central heat pumps compared to those with ductless systems. Further, a higher percentage of those with ductless heat pump installations reported using more cooling (44%) than those with central heat pump installations

[30] The proportions of previous heating systems are the same for those who replaced their existing systems with ductless heat pumps. The survey question about participants' prior heating systems was asked of those that either replaced their existing system (98% for central heat pumps and 33% for ductless systems) or installed the heat pumps without such replacements (2% for central heat pumps and 30% for ductless systems). Participants who reported installing their heat pumps in a previously unheated space, in a new room added to the home, or as part of a home renovation were not asked this question and these responses do not represent their existing heating systems.

(26%) after receiving their heat pumps. These results support the notable cooling savings (19%) estimated for participants with central heat pumps compared to cooling savings of 2% for those with ductless systems.

Of participants who installed heat pumps as a replacement or an addition to their existing cooling system, a much higher percentage with central systems (93%) had central AC compared to only 55% of those installing ductless heat pumps. Further, 19% of those with ductless systems reported having windows and portable ACs while none of those with central heat pumps had such end uses prior to installing their heat pumps.

Table 5-3. Cooling system characteristics and changes

Characteristics	PY 2020 Central Heat Pump Participants (n=171)	PY 2020 Ductless Heat Pump Participants (n=394)
Cooling System		
New cooling load	*13%	78%
Replacing existing cooling system	*86%	19%
Previous Cooling System[2]		
Central A/C	*93%	55%
Heat Pump A/C	*6%	10%
Window or Portable A/C	0%	19%
Old A/C not working well	*59%	28%
Old A/C working	*41%	66%
New Cooling Use[2]		
More cooling use	*26%	44%
About the same cooling use	*63%	37%
Less cooling use	*8%	14%

[2]Answers from a subset of respondents (n = 149 (central); n = 150 (ductless))
*Statistically significantly different from ductless installation responses, at least at the 90% confidence level

5.3 Participant program experience

Participant satisfaction with various aspects of the program that delivered heat pumps is provided in Table 5-4. All participants are generally satisfied with their equipment and contractor, which is reflected in high overall levels of satisfaction of at least 85%. The one area that respondents reported having lower levels of satisfaction is the amount of savings generated by their heat pumps. The respondents reported varying perceptions of changes in annual energy costs with central heat pump respondents reporting slightly higher perceived energy costs decreases than those with ductless HVAC systems. This perception among those with central heat pumps accords with DNV's assessment of the bill impact from the installation for the typical participant in this group. Our estimates indicate that this group, on average, saved $95 which is about 3% of their pre-installation cost.

Table 5-4. Participant satisfaction with heat pump installations

Characteristics	PY 2020 Central Heat Pump Participants (n=171)	PY 2020 Ductless Heat Pump Participants (n=394)
Satisfaction		
Satisfaction overall	85%	87%
Satisfaction with contractor	91%	91%
Satisfaction with equipment	*89%	89%
Satisfaction with savings	*67%	76%
Reported Change in Annual Energy Costs		
Noticed energy costs increase a lot	*10%	7%
Noticed energy costs increase a little	*18%	23%
Noticed energy costs decrease a little	*31%	25%
Noticed energy costs decrease a lot	13%	13%
Did not notice a change in energy costs	17%	17%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level

Table 5-5 provides the motivations and barriers reported by participants. A majority (61%) of those with central heat pumps reported the desire to save energy and reduce carbon emission for motivating their installations while the majority of those with ductless heat pumps (69%) reported safety and comfort as their motivation for installing their system. These motivations explain the load building and lower savings estimated at the meter for the latter group. Recommendations, saving money, equipment failure, and better use of renewable energy round out the other top motivations for installing the heat pumps. The majority of both groups (54% and 59% for those with central and ductless heat pumps, respectively) reported no barriers or challenges in connection with their heat pump installation. But for those that did experience barriers, installation and cost posed challenges.

Table 5-5. Participant motivations and barriers to installation

Characteristics	PY 2020 Central Heat Pump Participants (n=171)	PY 2020 Ductless Heat Pump Participants (n=394)
Motivations		
Save energy/reduce carbon emissions	*61%	47%
Improve safety and comfort	*43%	69%
Based on recommendation	*37%	33%
Save money	*34%	32%
Equipment Failure	*31%	16%
Better use of renewable energy	*30%	15%
Based on reputation of heat pumps	21%	20%
Adding air conditioning	*13%	44%
No other options	*2%	14%
Barriers		
No barriers or challenges	*54%	59%
Installation Barriers	*23%	16%
Cost Barriers	*21%	18%
Availability of equipment	*3%	4%
Knowledge Barrier	*6%	5%
Qualified contractors	5%	4%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level

In terms of the resources, they used to make their purchase decision, the majority of both groups (66% and 55% for those with central and ductless heat pumps, respectively) reported contractors as being the main source of influence (Table 5-6). The recommendations that contractors provided could have contributed to the high level of satisfaction respondents reported with contractors. Other top resources that respondents used to inform their purchase decisions included brand reputation and web searches. Utility programming and marketing had limited influence in this regard.

Table 5-6. Participant resources used to inform purchase decision

Characteristics	PY 2020 Central Heat Pump Participants (n=171)	PY 2020 Ductless Heat Pump Participants (n=394)
Resources Used to Inform Purchase Decision		
Contractor	*66%	55%
Brand or reputation of manufacturer	*41%	31%
Web search	*42%	29%
Manufacturer website	*24%	18%
Friend / family	*15%	37%
Utility program/marketing	11%	11%
Prior experience	*9%	11%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level

6 FINDINGS AND RECOMMENDATIONS

We provide our findings and recommendations from the evaluation of central and ductless heat pumps in this section.

6.1 Program documentation

Finding: The breadth of the program documentation data was good, but the quality of additional documentation linking program data to utility customer database information can be improved:

- **Recommendation**: To improve data quality, we recommend the PAs and their implementers increase efforts to train participating midstream program distributors on consistent and accurate data recording and on conducting regular quality control reviews of the data prior to submittal.
- **Recommendation**: To improve data quality, we recommend the PAs and their implementers design program documentation to include the PAs' premise and customer identifier fields.

6.2 Gross savings

Finding: The midstream program delivered ductless HVAC fuel substitution systems fell short of expectations for gas savings, most probably because they are often not being installed or used to replace existing gas heating as the program intends:

- **Recommendation:** To ensure the gas savings expectations are met, we recommend only direct install and downstream delivery pathways should offer ductless HVAC systems. Additionally, we suggest the PAs revise the measure eligibility to follow the requirement for decommissioning the existing gas system before installing the new ductless HVAC system.

Finding: Program staff indicated that the mid-stream program they run had no mechanisms to control the type of installations that occurred or checks/controls on the application of the installations:

- **Recommendation:** We recommend program designs that target actual replacement applications to improve gross saving and market influence. PAs should use downstream applications where decarbonization controls can be enforced for ductless systems.

6.3 Net attribution

Finding: The evaluation identified a NTGR of 57% for central HVAC fuel substitution systems delivered through the midstream design program:

- **Recommendation:** The central HVAC fuel substitution measure package NTGR should be revised to use a 60% NTGR, rounding up 57% finding from the evaluation, for the upstream delivery type. We recommend the NTGR for the revised ductless HVAC measure package be evaluated and then considered for revision.

7 APPENDICES

7.1 Appendix A: Impact evaluation standard reporting (IESR) required reporting−first year and lifecycle savings

Adobe Acrobat
Document

7.2 Appendix B: IESR−Measure groups or passed through measures with early retirement

Adobe Acrobat Document

7.3 Appendix C: IESR−Recommendations resulting from the evaluation research

Table 7-1. IESR findings and recommendations

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Measure Package or DEER
1	All Programs	The breadth of the program documentation data was good, but the quality of additional documentation linking program data to utility customer database information can be improved		To improve data quality, we recommend the PAs and their implementers increase efforts to train participating midstream program distributors on consistent and accurate data recording and on conducting regular quality control reviews of the data prior to submittal.	All PAs	SWHC044-01, SWHC045-01
2	All Programs	The breadth of the program documentation data was good, but the quality of additional documentation linking program data to utility customer database information can be improved	Of the total 1,122 utility customer addresses reported to have installed the central HVAC heat pump technology, nearly 27% of electric accounts and 41% of gas accounts were dropped because the addresses provided could not be confidently linked to account information. For the ductless HVAC heat pump technology, 37% of electric accounts and 47% of gas accounts were dropped due to poor account identification.	To improve data quality, we recommend the PAs and their implementers design program documentation to include the PAs' premise and customer identifier fields	All PAs	SWHC044-01, SWHC045-01

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Measure Package or DEER
3	Ductless HVAC Fuel Substitution	The midstream program delivered ductless HVAC fuel substitution systems fell short of expectations for gas savings, most probably because they are often not being installed or used to replace existing gas heating as the program intends	The evaluated gross gas (therm) savings is only 5% of the reported savings, while the evaluated gross electric (kWh) increase is 68% of the value the PA-reported value. Evaluation results indicate that the ductless HVAC fuel substitution is not meeting expectations to significantly offset pre-retrofit gas heating, yet it is adding year-round electric energy consumption. These results also imply that only about one-fifth (21%) of these systems were installed where there was an existing ductless furnace, but 50% of the time there was already a central furnace, while 13% already had a ductless heat pump and 5% had a central ducted heat pump.	To ensure the gas savings expectations are met, we recommend only direct install and downstream delivery pathways should offer ductless HVAC systems. Additionally, we suggest the PAs revise the measure eligibility to follow the requirement for decommissioning the existing gas system before installing the new ductless HVAC system	All PAs	SWHC044-01

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Measure Package or DEER
4	Ductless & Central HVAC Fuel Substitution	Program staff indicated that the mid-stream program they run had no mechanisms to control the type of installations that occurred or checks/controls on the application of the installations		We recommend program designs that target actual replacement applications to improve gross saving and market influence. PAs should use downstream applications where decarbonization controls can be enforced for ductless systems	All PAs	SWHC044-01, SWHC045-01
6	Ductless & Central HVAC Fuel Substitution	The evaluation identified a NTGR of 57% for central HVAC fuel substitution systems delivered through the midstream design program	Unlike for the ductless HVAC, when asked about central systems, distributors reported that high-efficiency central heat pump sales increased approximately 50% due to the program. Survey responses indicate utility customers purchasing central HVAC heat pump systems are more willing to do so without the program's incentive than those purchasing the ductless systems. This suggests the program is strongly influencing the distributors and contractors but only moderately influencing the utility customers decision to purchase qualifying central heat pumps.	The central HVAC fuel substitution measure package NTGR should be revised to use a 60% NTGR, rounding up 57% finding from the evaluation, for the upstream delivery type. We recommend the NTGR for the revised ductless HVAC measure package be evaluated and then considered for revision	All PAs	SWHC044-01, SWHC045-01

7.4 Appendix D: Sample design and selection

This section provides details of the sampling and data collection methodology employed for the HVAC Fuel Substitution Impact Evaluation.

The net survey analysis approach attempted to assess the net savings of the program by contacting three distinct decision maker groups involved in the program participation: distributors, contractors, and end-users. The sampling approach for all interviews and surveys were attempted census. For the contractors an additional phone survey outreach effort was attempted.

For the contractor phone outreach effort, the sampling methodology employed a stratified ratio estimation technique. This stratified ratio estimation approach studied a subset of contractors, i.e., sample, drawn from the full population. The sample design approach placed contractors into strata by size, measured in terms of combined kWh and Therm savings. The methodology then estimated appropriate sample sizes to achieve the targeted relative precision (±10%) at a desired level of confidence (90%) based on an assumed error ratio.

The error ratio is the ratio-based equivalent of a coefficient of variation (CV) measuring the variability (standard deviation or root-mean-square difference) of individual evaluated values around their mean value, as a percentage of that mean value. Therefore, to estimate the precision that can be achieved by the planned sample sizes, or conversely the sample sizes necessary to achieve a given precision level, it was necessary to develop a preliminary estimate of the error ratio for the sample components. The sample design and projected precision were based on assumed error ratios from experience with similar work. For this sample design, we have assumed a conservative error ratio of 0.9 for the fuel substitution evaluation based on prior evaluations of California HVAC programs.

Table 7-2 presents the final stratified sample design used for the evaluation. A total of 5 consumption-based strata were created with 22 sample points in each stratum. In addition, a certainty stratum was created to select the 40 largest contractors into the sample. The largest 40 contractors represent over 37% of combined savings, so by sampling them with certainty we can increase the precision of the evaluation estimates by accounting for a large percentage of the overall program savings.

Table 7-2. Contractor Sample Design Stratification

Stratum	Accounts	Sample	Inclusion Probability
1	1110	22	0.02
2	309	22	0.07
3	174	22	0.13
4	112	22	0.20
5	65	22	0.34
99	40	40	1.00
Total	**1,810**	**150**	**-**

7.5 Appendix E: Consumption data analysis

This section provides the details of the two-stage consumption data analysis approach DNV used to estimate the impact of fuel substitution heat pumps.

7.5.1 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 and CalTrack, 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). DNV GL estimated site-level models using daily data. First-stage models were screened to remove estimates that had implausible (negative) cooling and heating coefficients.

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 CZ2020 TMY values, and produces an estimate referred to as normalized annual consumption (NAC). NAC 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 typical meteorological year (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 the NOAA sites. 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 were the basis of the second stage DID models.[31]

7.5.2 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 including climate zone and housing type. 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 two phases. The first phase identified 15 households for every participant with similar energy use levels (based on monthly electric and gas billing data) within strata defined by climate zone and housing type. In the second phase, we identified 1-to-1 matches based on interval consumptions data and chose the optimal match for each participating site from the initial 15 matches.

In all cases, matching models included annual energy use, the ratio of summer-to winter energy use for gas, and the ratio of summer-to-shoulder and winter-to-shoulder use for electricity to account for seasonality, and peak demand. For electricity, we used the level of energy consumption at 6 p.m. for identified 'heat wave' periods to capture peak demand conditions. 'Heat wave' periods were identified for climate zones with participating residential customers for weekdays between June through September where most customers had their maximum 6 p.m. kWh. For gas, we used daily energy use for identified 'cool wave' periods to capture peak demand conditions. Such periods were identified for weekdays between December and February for the same climate zone.

For both gas and electricity matching, we also used tenure as an additional matching variable. Tenure was included as proxy for trend in energy use and was defined as the length of time, measured in years, that a customer has resided at a premise.

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.

For each phase of matching, tests of balance were conducted to test the condition of matching. 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:

[31] 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.

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

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.[32]

7.5.3 Second-stage models

We estimate 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 produce the NACs with the site-level models and then capture the change in NAC between pre- and post-installation periods (∆NAC). Comparison group ∆NAC provides 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 defined in the population characterization process. The changes in consumption for each program and measure provide the basis for carbon calculations.

The precision of the program-wide savings estimates is a function of the number of participants who 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 AMI data makes it possible to ease this requirement to 90% of pre- and post-period allowing the retention of data from more customers. For participants, a full year of post-period gas data will not be required reflecting the transition in full or in part to electricity to power the home's end uses.

Pre- and post-program periods are based on a definition of a blackout period for each participant. According to CalTRACK, an intervention period is a "time between the end of the baseline period and the beginning of the reporting period in which a project is being installed." It advises the use of "the earliest intervention date as project start date and the latest date as the project completion date."[33] We used a 1-month blackout period for each site based on the reported installation date in the detailed tracking data provided by SCE.

The pre-to-post-installation difference in NAC or 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, $\hat{\beta}$.

7.5.4 First- and second-stage model results

In this section, we present all second-stage DID model results starting with those used to evaluate ductless heat pump installations followed by models used to evaluate central heat pumps. Each table provides estimated baseline consumption and the DID estimate for each load component and normalized annual consumption (NAC). Results include model estimates, their standard errors, p-values and the number of participant counts whose data is included in the model. Results in Section 6.2 including savings and load increase are based on the values provided in these tables.

Table 7-3 provides electric cooling, heating, and NAC model results for ductless heat pumps.

[32] 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

[33] http://docs.caltrack.org/en/latest/methods.html#section-2-data-management

Table 7-3. Electric cooling, heating and NAC savings models by for ductless heat pumps, PY2020

Fuel	Model type	Variable	N	Estimate	standard error	p-value
Cooling load	Baseline load	Intercept	2,001	1,947	39	0.00
		treat	2,001	-57	55	0.30
	DID	Intercept	2,001	-76	18	0.00
		treat	2,001	32	27	0.23
Heating load	Baseline load	Intercept	2,001	326	13	0.00
		treat	2,001	116	20	0.00
	DID	Intercept	2,001	22	9	0.02
		treat	2,001	-70	14	0.00
NAC	Baseline load	Intercept	2,029	9,035	111	0.00
		treat	2,029	357	160	0.03
	DID	Intercept	2,029	-145	33	0.00
		treat	2,029	-315	49	0.00

Table 7-4 provides electric cooling, heating, and NAC model results for central heat pumps.

Table 7-4. Electric cooling, heating and NAC savings models by for central heat pumps, PY2020

Fuel	Model type	Variable	N	Estimate	standard error	p-value
Cooling load	Baseline	Intercept	374	2,422	113	0.00
		treat	374	-417	150	0.01
	DID	Intercept	374	73	51	0.15
		treat	374	459	85	0.00
Heating load	Baseline	Intercept	370	272	26	0.00
		treat	370	546	45	0.00
	DID	Intercept	370	-7	19	0.71
		treat	370	-562	42	0.00
NAC	Baseline	Intercept	371	9,640	275	0.00
		treat	371	650	391	0.10
	DID	Intercept	371	16	71	0.82
		treat	371	-715	118	0.00

Table 7-5 provides gas heating and NAC model results for ductless heat pumps.

Table 7-5. Gas heating and NAC savings models by for ductless heat pumps, PY2020

Fuel	Model type	Variable	N	Estimate	standard error	p-value
Heating load	Baseline load	Intercept	2,435	182	3	0.00
		treat	2,435	-10	4	1.00
	DID	Intercept	2,435	21	2	0.00
		treat	2,435	12	2	1.00
NAC	Baseline load	Intercept	2,437	415	4	0.00
		treat	2,437	-9	6	1.00
	DID	Intercept	2,437	32	2	0.00
		treat	2,437	11	3	1.00

Table 7-6 provides gas heating and NAC model results for central heat pumps.

Table 7-6. Gas heating and NAC savings models by for central heat pumps, PY2020

Fuel	Model type	Variable	N	Estimate	standard error	p-value
Heating load	Baseline load	Intercept	378	199	10	0.00
		treat	378	-105	13	0.00
	DID	Intercept	378	21	5	0.00
		treat	378	118	9	0.00
NAC	Baseline load	Intercept	377	436	15	0.00
		treat	377	-134	19	0.00
	DID	Intercept	377	30	6	0.00
		treat	377	152	11	0.00

7.6 Appendix F: Net-to-gross methodology

While this is a midstream program, the program design suggests that buyers (end-users) should be aware of the incentives. If end-users are aware of incentive, DNV asked the standard timing, efficiency, quantity free-ridership question sequence. When end-users were not aware of rebates, DNV used the causal pathway method, which is described here:

The midstream attribution scoring method is based on the ‘causal pathways’ method of measuring attribution that DNV developed for use with California midstream and upstream programs. The program logic for mid- and up-stream programs is that the programs interact with the manufacturers (upstream) or distributors (midstream) to influence their marketing practices. In the case of the midstream programs specifically, the program attempts to increase how often distributors upsell to higher efficiency models and how often the distributors stock higher efficiency models. The program does not attempt to directly influence prices distributors charge, but it does offer an incentive and potentially changes the revenue calculus for dealers in a way that allows them to offer lower prices for high efficiency models than they would without the program. The program logic holds that these changes to distributor behaviors will influence buyers to purchase higher efficiency models more often than they would without the program.

The attribution measures follow the program logic. First, they attempt to estimate the degree to which the program has changed distributor upselling, stocking, and pricing behaviors. It then attempts to estimate how much dealer upselling, stocking, and pricing affects the buyer’s decision. The program can only influence the final decision when both elements exist: first it has to change distributor behavior, *and* that distributor behavior has to influence buyer decisions.

The instruments and scoring methods described here were based on the 2018 Midstream Rooftop Unit methods. We have adapted the instruments for boiler measures and streamlined in a few places to shorten them.

7.6.1 Identifying causal pathways of influence

To establish program attribution, we considered the pathways distributors take when selling a high efficiency boiler unit, and the related pathways buyers take when purchasing one. Our goal was to develop an approach that considered these pathways in the context of the program design and real-world complexity. We created the term “causal pathway” to represent how the program may indirectly influence the final purchase decisions of buyers. We then used this approach to integrate NTG survey responses between buyers and the distributors into an overall NTG score.

Our methodology assumed that there were three main causal pathways of influence which impacted the equipment distributor, installation contractors, and end users. We derived these assumptions from the program logic model provided from the IOUs and conversations with program implementers. Distributors and buyers are both important when evaluating program attribution of this nature, and both were taken into consideration to formulate an overarching attribution score.

The three main causal pathways of program influence included:

1. The program influenced distributors to **stock** high efficiency units, and what was in stock influenced what buyers purchased when their unit failed. This causal pathway was driven by the assumption that when buyers replace existing equipment in an urgent situation (replace on failure in five days or less), the stocking habits of distributors would be most influential.
2. The program encouraged distributors to **upsell or promote** high efficiency units, and buyers were influenced by the upselling and promotional efforts to purchase high efficiency units rather than standard efficiency models. Note, there is a circular relationship between upselling and stocking. Based on our conversations with program staff, distributors stock what sells and sell what is in stock. Therefore, program effects on stocking can have an indirect effect on upselling. We attempt to address this indirect effect through framing questions, but ultimately only capture a singular program

influence on upselling that includes indirect effects through stocking, coaching, the rebates, and other program activities.

3. The program offers distributors a rebate on high efficiency units but does not encourage nor require distributors to reduce the **price** of high efficiency units or pass along the rebate to buyers. The rebate is intended to compensate the distributors for indirect costs to maintaining high efficiency stock and upselling high efficiency units. Some distributors might pass rebates through to buyers, and in those cases, buyers might be influenced by the lower prices of these high efficiency units.

Thus, the primary attribution pathway for the program is through increasing upselling and promotion of high efficiency units. The program's intended effects on stock and price are captured within the upselling and promotion pathway. However, there are additional ways that stocking and price could affect final buyer decisions, so the surveys attempt to capture those influences as well. Table 1-1 shows the researchable questions themes that represent the three causal pathways across distributors and buyers.

Table 7-7. Question themes across causal pathways for distributors and buyers

Causal Pathways	Distributor Question Theme	Contractor Question Theme	End user Question Theme
Stock	Did the program influence the distributor to carry more high efficiency (HE) stock?	What would customers have done if program-eligible units were not immediately available?	What would the end-user do if the program-eligible unit was not immediately available?
Promotion/Upsell	How much did the program influence the distributor to promote or upsell the units?	How much does the seller's recommendation influence customer decisions?	How much influence did the distributor/contractor recommendation had on the buyer's decision?
Price of Units	How much of the rebate did distributors pass on to their buyers?	How many customers would have purchased the units at full price?	Would the end-user have purchased the unit at full price?

Each of the three causal pathways was contingent on the distributor changing their behavior in response to the program, and this change in behavior influencing the behavior of their buyers. The evaluation measured each causal path independently. For each causal path, the approach assumed that if the program failed to show attribution through the distributors or buyers, then the program did not affect the equipment sale on that particular causal path. This did not mean that the program had no influence on the sale, only that any influence it had was not through this path. If another causal path did show program influence, then we determined the sale to be at least partially program attributable.

We evaluated each causal path at the level of the individual buyers and their associated distributor for attribution. We then subtracted from 1 to get a free-ridership score on that pathway. To calculate the total program attribution score, we multiplied these three free-ridership scores together. We explore this calculation further below, but the overall approach captures multiple paths of attribution, as well as partial attribution when it exists.

After the distributor and buyer surveys were completed, we calculated the individual buyer and distributor attribution scores, mapped them together, and expanded to the whole population. Whenever possible, we attempted to connect specific distributors, contractors, and end users. When specific connections could not be made, we substituted average distributor and contractor values. This section will review the process of calculating the attribution scores individually, and then expanding them to the population.

7.6.2 Distributor attribution calculation

We began by asking distributors an open-ended question about how they think the program has impacted their business, and then asked questions related to the three causal pathways. Last, we asked distributors questions about how the program influenced their sales of high efficiency units. We used screening questions at the beginning of the survey to ensure that the respondent was the best person to speak to about program influence across all of these areas. For all these questions, we asked follow-up questions clarifying why the respondent gave certain answers. This allowed us to make sure that the respondent understood the question, and to collect additional information on how the program might have influenced their business practices.

Stocking, upselling, and pricing scores were calculated for distributors as follows.

Stocking:

$$Stocking = \frac{S7 - S8}{S7}$$

> S7. For the heat pumps you kept in stock, approximately what percent are high efficiency?

> S8. If the program wasn't available, what percent of high efficiency heat pumps would you have stocked?

The yes/no answer to S5 served as an additional check on the calculated value for stocking.

> S5. Did the [utility] utility incentives influence the selection of high efficiency heat pump equipment the company keeps in stock?

Upselling:

$$Upselling = \frac{U8 - U9}{U8}$$

> U8. In situations where you were selling [central HPs / ductless HPs], about what percent of the time did you recommend the high efficiency equipment? [IF NECESSARY: High efficiency means Tier 1 or above]

> U9. For [central HPs / ductless HPs], what percent of the time would you recommend the high efficiency equipment if utility-sponsored program had not exist? [PROBE: and what we mean by "without the program" is supposing the program ran out of funding next month]?

The yes/no answer to U6 served as an additional check on the calculated value for stocking.

> U6. Did the program incentives influence the equipment efficiency level your company recommends to buyers?

Pricing:

$$Pricing = P6$$

> P6. On average, what percent of the program incentive were passed on to the buyer for [central HPs / ductless HPs], either directly or indirectly?

7.6.3 Contractor attribution calculation

We began by asking contractors an open-ended question about how they think the program has impacted their business, and then asked questions related to the three causal pathways. We used screening questions at the beginning of the survey to ensure that the respondent was the best person to speak to about program influence across all of these areas. For all these questions, we asked follow-up questions clarifying why the respondent gave certain answers. This allowed us to make sure that the respondent understood the question, and to collect additional information on how the program might have influenced their business practices.

We calculated contractor causal pathway results using the following questions and equations

Stocking:

$$Stocking\ Attribution = 1 - sum\big(a * 1 + c * weighted\ average + b * (d * 1 + e * 0 + f * 0.5)\big)$$

Q18. We would like to ask you about times when a customer agrees to install high efficiency {Q11} equipment, but you and the distributor do not have the preferred model and size equipment available in your inventory. In these cases, what percent (%) of the time did your customers… The total of all three categories for each type of heat pump should add up to 100%.

a) Delay the project until the preferred model, size and efficiency is available?
b) Select an alternative model that is in stock?
c) Do something else?

Q20. How often did a customer select an alternative model? The total of all three categories for each type of heat pump should add up to 100%.

d) A different high efficiency model (Tier 1 or above)
e) Standard efficiency
f) Something between high efficiency (Tier 1 or above) and standard efficiency

Upselling:

$$Upselling\ Attribution = \frac{Q23}{10}$$

Q23. On a scale of 0 to 10 where 0 is 'Not at all influential' and 10 is 'Extremely influential', how influential were the equipment recommendations made by distributors on the decision of what ultimately gets installed?

Pricing:

$$Pricing\ Attribution = Q28$$

Q28. If your distributor charged you less for a piece of equipment, how much if any of that price difference would you pass on to your customers? [Answer in terms of percent of the discount]

7.6.4 End user attribution calculation

For the buyer survey, we first asked buyers to list all of the factors that influenced their decision to purchase the unit. Then we asked them questions about the three causal pathways shown in Table 1-1. Finally, we asked them about the minimum energy efficiency they were considering before buying their equipment. Once again, for all these questions, we asked follow-up questions that allowed us to confirm the respondent's understanding of the question, and to collect additional information on how the program might have influenced the equipment purchase.

We calculated end-user causal pathway results using the following questions and equations

Stocking:

$$\begin{gathered} if\ q58 = a, then\ attribution_{stocking} = 0 \\ else\ if\ q58 = b, then\ attribution_{stocking} = 1 \\ else\ if\ q58 = c, then\ attribution_{stocking} = 0 \end{gathered}$$

Q58. If the model and size of the {measure} you purchased was not available from your preferred vendor/contractor, would you have ….?

a) Waited until that specific equipment was in stock
b) Selected the next best available alternative
c) Contacted an alternate vendor to get the same equipment you wanted

Upselling:

$$Upselling\ Attribution = \frac{Q42}{10}$$

Q42. On a scale of 0 to 10, where 1 is 'not at all influential' and a 10 is 'extremely influential', how influential was the contractor's recommendation or information on your decision to purchase and install the {measure}?

Pricing:

$$\begin{gathered} if\ Q59 = a, c, e, k, then\ attribution_{pricing} = 1 \\ else\ if\ Q59 = b, then\ attribution_{pricing} = 0 \\ else\ if\ Q60 = m, then\ attribution_{pricing} = 0 \\ else\ if\ Q60 = n, then\ attribution_{pricing} = 0.5 \\ else\ if\ Q60 = o, then\ attribution_{pricing} = 1 \end{gathered}$$

Q59. If the {equipment} had been sold at the full price and did not qualify for the SCE incentive of {incentive amount}, which of the following heating equipment would you have installed?

a) I would not have installed any heating equipment at all
b) I would have installed the same equipment as I got through the program
c) Gas floor or wall heater
d) Electric floor or wall heater
e) Gas central furnace (central system with vents in each room)
f) Electric central furnace
g) Central ducted heat pump (central system with vents in each room)
h) Ductless heat pump / mini-split
i) Hot water radiator
j) Electric baseboard
k) Fireplace (gas/wood/pellet)
l) Plug-in portable space heater

Q60. Without the program benefits, which of the following efficiency levels would you have selected for the {Q59}? Higher efficiency systems usually cost more and have more features than lower efficiency systems.

m) Highest efficiency level available in the market at the time of purchase
n) Mid-level efficiency
o) Lowest efficiency level available in the market at the time of purchase

7.6.5 Combining attribution scores

We calculate the overall attribution scores for each end user survey completed. The basic approach is to multiply the individual distributor, contractor, and end user component scores to get an overall component score. Then we combine the overall component scores into a total attribution score.

The scores as calculated from the flowcharts above are attribution. We first combine the attributions across the three market levels: distributors, contractors, and end users by multiplying them. This method of combination takes into account the multiple indirect steps the program influence has to go through to eventually affect the end-user decision. If the program fails to influence any of the three market actors, then it would not influence the final decision for that particular causal pathway.

We then compute the overall attribution for each of the three causal pathways to free-ridership by subtracting from 1. We multiply the three-component free-ridership scores together to get overall free-ridership. Then we subtract that from 1 to get overall attribution. We chose this approach because we wanted to give the program the maximum opportunity for attribution, and believe this provides the following benefits:

1. Ensures that attribution is capped at 100%
2. If multiple paths of partial attribution exist, they are fairly represented in the equation
3. If one of three paths is 100% attribution (0% free-ridership), then the total program score gets 100% attribution
4. If one of three paths is 100% free-ridership (0% attribution), then the path has no impact on the total score by turning into a 1, and it does not reduce the scores produced by the other two paths.

The equations below show the flow of these calculations. We calculated the buyer attribution scores from survey responses related to an individual purchase, and the distributor attribution scores based on the equipment type the buyer purchased.

Calculation steps:

1. The program tracking data did not allow us to make specific connections from distributors to end users, so we combined the weighted (based on ex ante kWh claims) average distributor score with all end-user scores for each causal pathway.

$$\text{Combined Attribution}_{\text{Stock}} = \text{Distributor Attribution}_{\text{Stock}} \times \text{End} - \text{user}_y\text{Attribution}_{\text{Stock}}$$

$$\text{Combined Attribution}_{\text{Upsell}} = \text{Distributor Attribution}_{\text{Upsell}} \times \text{End} - \text{user}_y\text{Attribution}_{\text{Upsell}}$$

$$\text{Combined Attribution}_{\text{Price}} = \text{Distributor Attribution}_{\text{Price}} \times \text{Buyer}_y\text{Attribution}_{\text{Price}}$$

2. Convert attribution scores to free-ridership

$$\text{Freeridership}_{\text{Stock}} = 1 - \text{Combined Attribution}_{\text{Stock}}$$

$$\text{Freeridership}_{\text{Upsell}} = 1 - \text{Combined Attribution}_{\text{Upsell}}$$

$$\text{Freeridership}_{\text{Price}} = 1 - \text{Combined Attribution}_{\text{Price}}$$

3. Combine free-ridership into overall attribution

$$\text{Combined Program Attribution} = 1 - \left((\text{Freeridership}_{\text{Stock}}) * (\text{Freeridership}_{\text{Upsell}}) * (\text{Freeridership}_{\text{Price}})\right)$$

After we calculated this combined distributor/buyer attribution score for every single buyer, we expanded these estimates to the population. The next section describes how we reviewed all of the buyers for each distributor, as well as equipment type, to create a weighted overall attribution score for the program.

Combining the distributor and contractor scores works the same as for the end-user scores described above, except for substituting in the contractor stocking, upselling, and price attributions where the formulas list end-user.

7.6.6 Distributor market effects scoring

In addition to the causal pathways question sequence, DNV asked the distributors how their sales of high efficiency electric heat pumps had changed since the program began. DNV repeated the following approach separately for central heat pumps and ductless heat pumps. These questions asked the distributors what percent of their sales of heat pumps were high efficiency in 2019, what percent were high efficiency in 2020, and what percent of their high efficiency heat pumps in 2020 received a rebate.

$$NTG = \frac{(ME2 - ME1)}{ME3}$$

These questions were worded in the survey as follows:

> Next, I'd like to ask about the incentive programs influence on your company sales. When responding to these questions, please try to think about your sales volume based on the rated capacity of the equipment. If this is not feasible, please respond in terms of the percent of your revenue ($ dollars) to represent sales.
>
> ME1. In 2019, what percentage of your California sales were high efficiency?
>
> ME2. In 2020, about what percentage of [central HPs / ductless HPs] your sales in California would you estimate were high efficiency? [IF NECESSARY: High efficiency means Tier 1 or above]
>
> ME3. In 2020, what percent of all the high efficiency equipment had an incentive claimed?

7.6.7 End-user timing, efficiency, quantity scoring

DNV's standard NTGR calculation method assesses three dimensions of free-ridership: timing, quantity, and efficiency. The program induces savings if it accelerates the timing of an efficient measure installation, if it increases the number installed, or if it raises the efficiency level of what was installed. For fuel substitution heat pumps, the survey determined "efficiency" in terms of the type of heating system that would otherwise have been installed. The NTGR survey scoring elements are summarized below in Table 7-8.

Table 7-8. Free-ridership elements by survey respondent type

Survey Respondents	Free-ridership Dimension	Question Wording	Answer	Free-Ridership Score
End users (aware)	Timing (FR_t)	Without the program benefits (e.g., equipment discount, energy savings information), when would you have completed this project (or installed this system)?	At the same time or sooner	1
			1 to 24 months later	(24 - # of months)/24
			More than 24 months later	0
			Never	0
			Don’t know	Average of non-Don’t know answers
End users (aware)	“Efficiency” (FR_e)	Without the program benefits (e.g., equipment discount, energy savings information), which of the following heating system type would you have installed?	I would not have installed any new heating equipment at all	0
			Gas floor or wall heater	
			Gas central furnace (central system with vents in each room)	
			Fireplace (gas/wood/pellet)	
			I would have installed the same equipment as I got through the program	1
			Electric floor or wall heater	Lowest efficiency available on market = 0 Mid-level efficiency = 0.5 Highest efficiency available on market = 1
			Electric central furnace (central system with vents in each room)	
			Central ducted heat pump (central system with vents in each room)	
			Ductless heat pump / mini-split	
			Hot water radiator	
			Electric baseboard	
			Plug-in portable space heater	
			Don’t know	Average of non-Don’t know answers
End users (aware)	Quantity (FR_q)	Our records indicate you had {n} {measure}(s) installed through SCE's Heat Pump program. Without the program benefits (e.g., equipment discount, energy savings information), how many {measure} system(s) would you have purchased? A system is defined by an outdoor unit, that looks similar to this picture. So how many outdoor units would you have purchased without the program.	None	0
			1	1-((n-answer)/n)
			2	
			3	
			4	
			5 or more	
			Don’t know	Average of non-don’t know answers

Using these metrics in combination allowed DNV to fully assess the amount of savings that could be attributed to measures that participants would have installed absent program support. DNV assigned each respondent a score for each free-ridership metric based on their survey responses and combined those scores into an overall free-ridership score using the algorithms in Equations 1.

Equation 1: Free-ridership Scoring Algorithm

$$Free\text{-}ridership = FR_t * FR_e * FR_q$$

Program attribution or net-to-gross ratios (NTGRs) are simply the complement of free-ridership and is estimated as: *NTGR = 1- Free-ridership.*

7.7 Appendix G: Bill impact rate schedules

Table 7-9 provides the gas rates and Table 7-10 provides the gas baseline levels used in the bill impact calculations. Sources for each are provided below the tables. We did not include fixed costs in this analysis, as most participants continued to have some gas service following the heat pump installations.

Table 7-9. Gas rates use in bill impact calculations

Rate Type	Usage	Rate ($/therms)
Residential Gas Service, Individually Metered (GR)	Baseline	1.43
	Non-Baseline	1.85
Residential Gas Service, Individually Metered, Transportation-Only Service Option (GT-R)	Baseline	0.82
	Non-Baseline	1.24
Residential Sub-metered Customer (GS)	Baseline	1.43
	Non-Baseline	1.85
Residential Small Master Metered (GM-E)	Baseline	1.43
	Non-Baseline	1.85
Residential Small Master Metered with separately metered service to common facilities (GM-C)	All Usage	1.85

Source: https://www.socalgas.com/sites/default/files/RES2022.xlsx

Table 7-10. Gas baseline levels used in bill impact calculations

SCG Baseline Climate Zone	Time Period	Daily Therm Allowance
1	Summer (May 1 - Oct. 31)	0.42
	Winter On-Peak (Dec., Jan., and Feb.)	1.60
	Winter Off-Peak (Nov., Mar., and Apr.)	0.87
2	Summer (May 1 - Oct. 31)	0.42
	Winter On-Peak (Dec., Jan., and Feb.)	1.87
	Winter Off-Peak (Nov., Mar., and Apr.)	0.92
3	Summer (May 1 - Oct. 31)	0.42
	Winter On-Peak (Dec., Jan., and Feb.)	2.60
	Winter Off-Peak (Nov., Mar., and Apr.)	1.71

Source: https://www.socalgas.com/sites/default/files/RES2022.xlsx

Table 7-11 provides the electric rates and Table 7-12 provides the baseline usage levels used in the analysis.

Table 7-11. Electric rates used in bill impact calculations

Rate type	Usage	Rate ($/kWh)
Domestic (DOMESTIC)	Baseline	0.17
	Non-Baseline (101% - 400% of Baseline)	0.24
	High Usage (More than 400% of Baseline)	0.33
Domestic - Care (D-CARE)	Baseline	0.12

Rate type	Usage	Rate ($/kWh)
	Non-Baseline (101% - 400% of Baseline)	0.17
	High Usage (More than 400% of Baseline)	0.24
Domestic - FERA (D-FERA)	Baseline	0.14
	Non-Baseline (101% - 400% of Baseline)	0.20
	High Usage (More than 400% of Baseline)	0.27
Domestic - Employees (DE)	Baseline	0.13
	Non-Baseline (101% - 400% of Baseline)	0.18
	High Usage (More than 400% of Baseline)	0.25
TOU	June - September, Mid Peak (Weekdays, 4 p.m. – 9 p.m.)	0.49
	June - September, Mid Peak (Weekends, 4 p.m. – 9 p.m.)	0.40
	June - September, Off Peak (Remaining hours)	0.30
	October - May, Peak (4 p.m. – 9 p.m.)	0.43
	October - May, Super Off Peak (8 a.m. - 4 p.m.)	0.29
	October - May, Off Peak (Remaining hours)	0.32

Source: https://www.sce.com/regulatory/tariff-books/rates-pricing-choices
Source: https://www.sce.com/residential/rates/Time-Of-Use-Residential-Rate-Plans

Table 7-12. Electric baseline levels used in bill impact calculations

Climate Zone	Time Period	kWh Per Day
5	Summer (June 1 - Sep. 30)	17.2
	Winter (Oct. 1 - May 31)	18.7
6	Summer (June 1 - Sep. 30)	11.4
	Winter (Oct. 1 - May 31)	11.3
8	Summer (June 1 - Sep. 30)	12.6
	Winter (Oct. 1 - May 31)	10.6
9	Summer (June 1 - Sep. 30)	16.5
	Winter (Oct. 1 - May 31)	12.3
10	Summer (June 1 - Sep. 30)	18.9
	Winter (Oct. 1 - May 31)	12.5
13	Summer (June 1 - Sep. 30)	22.0
	Winter (Oct. 1 - May 31)	12.6
14	Summer (June 1 - Sep. 30)	18.7
	Winter (Oct. 1 - May 31)	12.0
15	Summer (June 1 - Sep. 30)	46.4
	Winter (Oct. 1 - May 31)	9.9
16	Summer (June 1 - Sep. 30)	14.4
	Winter (Oct. 1 - May 31)	12.6

Source: https://www.sce.com/regulatory/tariff-books/rates-pricing-choices
Source: https://www.sce.com/residential/rates/Time-Of-Use-Residential-Rate-Plans

7.8 Appendix F: Analysis of peak demand impacts

In response to stakeholder comments regarding peak demand impacts of the heat pump fuel substitution claims, the evaluation team conducted an analysis of peak demand impacts based on the hourly consumption data models used to determine annual kWh impacts. Table 7-13 provides the results of the peak demand analysis by technology type and climate zone, and across all climate zones (All CZs). The relative precisions and p-values for the estimates of demand impacts for ductless heat pumps in climate zones 9, 13, 15, 16 as well as central heat pumps in climate zone tell us that they are more uncertain but likely near zero.

Table 7-13. Results of the peak demand analysis by heat pump technology and climate zone

Technology	Climate zone	kW per ton	kW per site	Relative precision	P-value	% of baseline	Program total kW
Ductless	6	-0.06	-0.12	0.14	0.00	-9%	-150
	8	-0.13	-0.23	0.07	0.00	-13%	-398
	9	0.00	0.00	0.00	0.88	0%	0
	10	-0.06	-0.10	0.33	0.00	-3%	-158
	13	0.01	0.01	9.87	0.87	0%	2
	14	-0.10	-0.19	0.26	0.00	-7%	-130
	15	0.01	0.02	3.29	0.63	0%	15
	16	-0.03	-0.05	2.30	0.49	-2%	-9
	All CZs	**-0.07**	**-0.12**	**0.08**	**0.00**	**-5%**	**-941**
Central	6	-0.09	-0.31	0.11	0.00	-28%	-52
	8	0.03	0.12	0.27	0.00	6%	37
	9	0.04	0.14	0.47	0.00	5%	20
	10	0.09	0.37	0.22	0.00	10%	51
	14	0.01	0.05	1.97	0.37	2%	1
	15	0.19	0.74	0.11	0.00	16%	261
	All CZs	**0.07**	**0.25**	**0.12**	**0.00**	**9%**	**290**

Figure 7-1 below illustrates the kW peak demand savings per site by heat pump technology and climate zone, as well as across all climate zones. For the ductless heat pumps, demand impacts savings was near zero or negative at the climate zone level, with a per site impact result across all climate zones of -0.12 kW. For the central heat pump systems, the per site impact result across all climate zones is 0.25 kW, with a substantial demand savings per site for installations in climate zone 15 and positive demand savings at the individual climate zone level for all except the mild coastally influenced climate zone 6 sites.

Figure 7-1. Peak demand savings per site by climate zone and overall

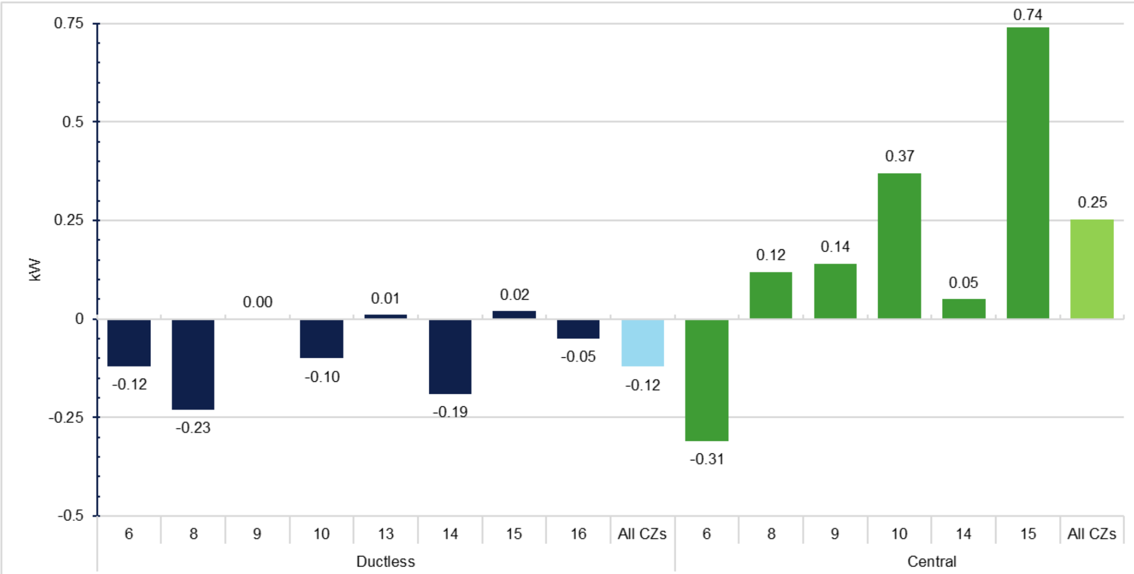
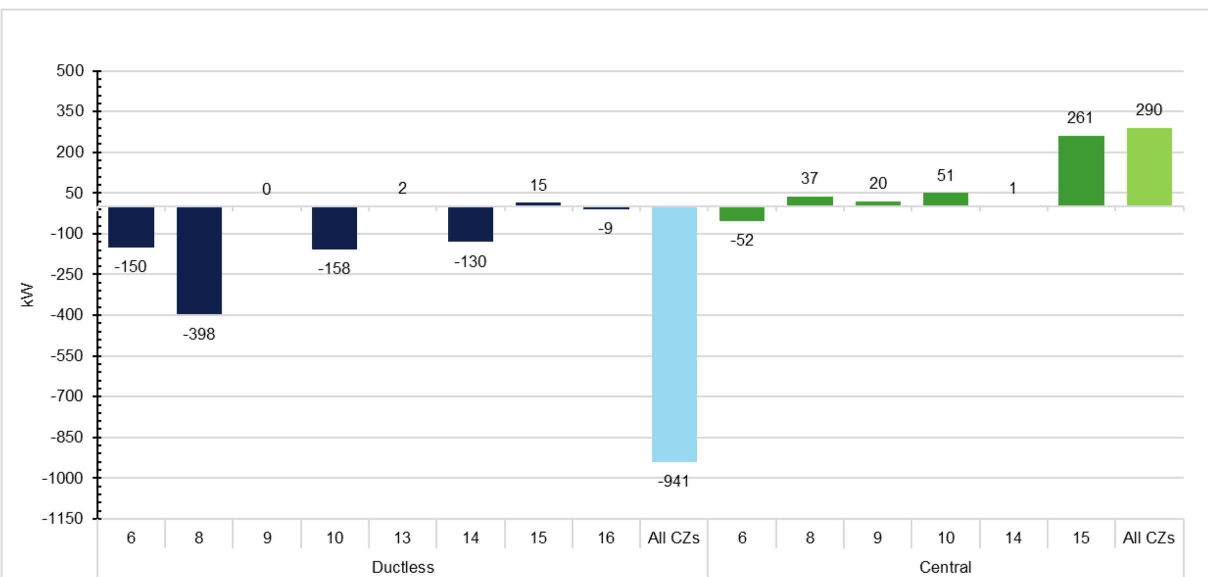


Figure 7-2 below presents the program total peak demand savings by climate zone and across all climate zones for each heat pump technology. These results represent the product of the per site demand impacts and the program populations in each climate zone and so are weighted by the proportion of claims in a respective climate zone. For program total demand impacts, overall ductless is a larger increase in peak demand (-941 kW) than central is a decrease in peak demand load (290 kW), due to the considerably higher number of claims for ductless systems.

Figure 7-2. Program total peak demand savings by climate zone and overall



7.9 Appendix G: Stakeholder comments and evaluator responses

Table 7-14. Stakeholder comments on the study and evaluators response

#	Subject:	Entity:	QUESTION or COMMENT:	Evaluator Response:
1	Peak demand in HVAC fuel substitution programs	Proctor Engineering Group, Ltd.	We recommend that this and future evaluations of fuel substitution programs address peak demand impacts. Given the State of Emergency Proclamation issued by the Governor on July 30, 2021 and related initiatives to improve electric grid reliability, peak demand should be a primary concern for the CPUC and for all of California. Fuel substitution programs have the potential to substantially increase electrical demand during peak times if programs are not designed and implemented in a manner that minimizes peak impacts. Summer peak demand in California is largely driven by air conditioning, or by heat pumps operating in cooling mode. The national energy efficiency rating metric that most closely reflects peak demand impacts of a particular HVAC system is the EER rating, which is the full load cooling efficiency at an outdoor temperature of 95 °F. The EER rating is the best currently available rating metric to represent cooling efficiency and energy use on hot afternoons and evenings when cooling loads are high. The US Department of Energy sets minimum requirements for the EER rating of air conditioners installed in the Southwestern region, but there is no regulation of EER for heat pumps. While heat pumps exist with EER ratings meeting or exceeding the DOE standards for air conditioners, there are also residential heat pumps currently on the market with EER ratings as low as 7, compared to the federal minimum of 12.2 EER for air conditioners in the Southwest region. A heat pump with an EER rating of 7 can be expected to have approximately 74% higher peak demand than an air conditioner with an EER rating of 12.2. We suggest that evaluations address the following questions related to peak demand in HVAC fuel substitution programs: 1) Were programs designed to ensure peak demand impacts are minimized? 2) Was program implementation effective in enforcing peak demand reduction aspects of the program design? 3) Based on the reported efficiency ratings, how would estimated peak demand of the heat pumps installed through	1) The SCE Plug Load and Appliances program was designed around "incentivizing energy-efficient electric heat pump technologies that can deliver greater efficiency, improve indoor air quality and comfort, and reduce greenhouse gas (GHG) emissions" (Southern California Edison Company's 2020 Annual Report for Energy Efficiency Programs, Pg. 12). The fuel substitution measures evaluated under this program are all for HVAC systems exceeding code minimum efficiency requirements. 2) As the Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1 document states, 'there will not be any peak demand reduction or penalty towards peak demand goal achievement from fuel substitution measures,' thus the program did not submit claims for demand impacts, and none were analyzed as part of the evaluation. 3) While not included in this impact evaluation for the above reason, this is an interesting research question. Constructing the proposed comparisons would be difficult with the survey data available. The average reported EER for central heat pumps was 12.1, which falls within the California Title 20 minimum of 12.2/11.7 for split system air conditioners, and the average reported EER for ductless heat pumps was 10.9, which is near the upper range of the California Title 20 minimum EER requirements 9.4-11.0 for ductless (room) air conditioners as well as the range of the federal minimum EER requirement for terminal air conditioners of 8.7-11. We have added statistics on the reported efficiencies to the report in response to this request. 4) While not included in this impact evaluation for previously stated reason, this is an interesting research question. The proposed non-participant and their control group could be challenging to develop for such a method. We have added the analysis of peak demand impacts under Appendix F in response to these comments. 5) DNV has added data on the reported location to the report in response to this request.

#	Subject:	Entity:	QUESTION or COMMENT:	Evaluator Response:
			the programs compare to peak demand that would have occurred with the air conditioners that likely would have been installed in the absence of the program? 4) Does analysis of short interval AMI data show different peak demand impacts for participants in HVAC fuel substitution programs compared to non-participants who installed a new air conditioner during the same timeframe? 5) Are there other noteworthy trends, for example installation of heat pumps into spaces that did not previously have air conditioning? In mild climate coastal regions this may contribute relatively little annual kWh but represent a very large increase in peak demand on the few days each year, like the August 2020 heat wave, when the coastal areas are sufficiently hot for a substantial fraction of residences to operate the heat pump in cooling mode. These trends would be important to document for grid reliability planning.	
2	kWh GRR	Southern California Edison Company	SCE believes that the impact evaluation incorrectly estimates "electric GRR." The ex-ante reported savings or impact to the grid (e.g., -kWh, or reported "electric load" we expected to be added to the grid) was "overestimated" NOT "underestimated". As such, the GRRs should reflect an improvement over ex ante load building impact estimates. For example, if our ex-ante estimate matched the evaluated gross, we believe the GRR would be 100% based on this table. Since the evaluated is actually less than forecast, we believe it should be better than 100%.	DNV has reported the negative electric energy realization rates in a manner consistent with previous evaluations and established expectations.

#	Subject:	Entity:	QUESTION or COMMENT:	Evaluator Response:
3	Source energy savings	Southern California Edison Company	SCE is not able to match (reported) lifecycle primary energy savings using FS Calculator v1.1 and Table 4-6 inputs for Ductless and Central HP at measures' EUL. Additionally, all calculations should be done using corresponding units of "per-ton" consistent with measure characterization. Using "per dwelling" units is misleading since it is not clear how system capacity and/or tons are being normalized on a per dwelling basis. Further, system capacity is expected to vary significantly per system type, climate zone, vintage, single story vs two stories, etc. making evaluation's "per dwelling" units ambiguous.	Utilizing the reported and evaluated per site gas and electric savings found in Table 4-3, and the reported and evaluated gas and electric savings for the whole program found in Table 4-6 together with the additional calculator inputs described in footnote 14 (section 1.2.3) should yield the lifecycle energy savings presented in Tables 1-4 and 4-7. DNV has added results on a per-ton basis in response to this request.
4	Disaggregation of gross results	Southern California Edison Company	SCE would like to see results in the report based on various replacement scenarios (such as like-for-like replacement) vs. technology types. Grouping results in this way will be critical to understand impacts of various use cases (such as room additions where old systems are left intact and a new system is added on top) which will provide PAs with valuable information. SCE would also like to understand DNV's baseline assumptions such as for space add-ons and whether the baseline is assumed to be unconditioned? SCE will appreciate if DNV provides access to disaggregated data for further analysis.	The limited intersection of the gross AMI and survey achieved samples precludes us from developing gross results with meaningful precision at the level requested by the PA. DNV did investigate providing gross results based on a categorization of survey responses but the resulting sample size is too small to confidently report the result. The assumed baseline for all claims is a like-for-like code-compliant replacement. SCE already has access to the disaggregated electrical consumption data utilized for this evaluation. An SCE request for disaggregated gas consumption data should be directed to SCG.

#	Subject:	Entity:	QUESTION or COMMENT:	Evaluator Response:
5	Ductless heat pump delivery type recommendation	Southern California Edison Company	SCE does NOT agree with evaluation's recommendation to only support offering of Ductless HP via direct install and downstream delivery pathways. Given that even at low GRR for natural gas, Ductless HP measures still yielded lifecycle energy and emissions savings, SCE recommends for statewide programs (inclusive of Downstream and Downstream DI) to maintain measures for Midstream programs to continue supporting statewide de-carbonization goals. Given improved data collection requirements recently prescribed in E-5152 for Midstream programs, realization rates on both Ductless and Central HP measures are expected to improve in future program cycles. Additionally, SCE plans to expand measure eligibility requirements for HVAC Fuel Substitution measures that include capping the gas line (at the existing equipment).	The evaluated lifecycle source energy and emissions savings for midstream delivered ductless HVAC fuel substitution measures fails to meaningfully achieve the expectations of this measure. SCE argument for retaining the midstream delivery on the basis of E-5152 prescribed midstream data collection requirements is false as it conflates data collection requirements with the program's due diligence to implement HVAC fuel substitution measure eligibility requirements predating E-5152. While DNV appreciates SCE's claimed plans to design programs to verify eligibility requirements are met, we would also point out that the referenced requirement to cap existing gas service lines, as well as the requirement to remove the existing furnace equipment, were in place for PY2020 but not enforced or verified in the midstream design. This is likely difficult to achieve for a midstream program but is critical to the success of this measure.
6	NRRs and NTGRs	Southern California Gas Company	As a general comment, the executive summary should clearly indicate the extremely low net realization rates (NRRs) for fuel substitution measures, as evaluated. SoCalGas agrees that the Net-to-Gross Ratio (NTGR) for the central HVAC Fuel Substitution measure package should be revised to 60%. However, SoCalGas strongly recommends also revising the ductless HVAC measure package NTGR through this evaluation, rather than continuing it at 100% and waiting for further evaluation results.	The evaluation recommends discontinuing the midstream delivery type for the ductless fuel substitution measure because of low gross savings so a recommendation to adopt the evaluated NTGR for this delivery type is superfluous.

#	Subject:	Entity:	QUESTION or COMMENT:	Evaluator Response:
7	High Relative Precision (RP) used in table 4.1, 4.2, 4.5, 4.6	Southern California Gas Company	The conclusions derived in these tables are based on the relatively high percentages on RP such as table 4-3 with 26% or 27%. The higher the RP, the more error and uncertainty is involved in the work. SoCalGas would like to know in table 4-4, please elaborate how the 15% RP was calculated with three RPs in the table being 121%, 18% and 10%.	Relative precision expresses the range of the confidence interval for the estimates in terms of the value of the estimates themselves. When the point estimate is low, as is the case in some of these tables, the same confidence interval in absolute terms will appear to be larger in relative terms. The absolute confidence interval can be calculated by multiplying the point estimate by the relative precision. Then add and subtract that value to the point estimate to get the upper and lower bounds of the 90% confidence interval. For example, for table 4-1, Gas NAC has a point estimate of 3% with a relative precision of 40%. 3%*40%=1.2%, so the 90% confidence interval is 1.8% to 4.2%. In other words, there is a 90% likelihood that the true point estimate is within this narrow range. In this case, it is highly likely the change in NAC is greater than 0, which is reflected in the p-value of less than 0.01. As a result, the estimates provided actually allow us to make a valid and relatively robust inference. In table 4-4 and 4-5, the relative precisions for net were calculated by taking the average of the error for each of the survey respondent types. The error is calculated as the estimate multiplied by the relative precision of the estimate. For the 15% listed in table 4-4, the errors work out to be: distributor .01 * 1.21 = 0.0121, contractor 0.63 * 0.18 = 0.1134, and customer 0.56 * 0.1 = 0.056. The average of 0.0121, 0.1134, and 0.056 is .15 or 15%. The 20% in table 4-5 was calculated in a similar fashion, with slightly different input values from the three respondent types. In the case of the 15% relative precision for NTGR in table 4-4, the point estimate of NTGR is 40%. 40%*1.5% = 6%, so the 90% confidence interval in absolute terms is 34% to 46%. In other words, there is a 90% probability that the true net to gross ratio is within this range. Using similar math, the 90% confidence interval for the 57% NTGR in table 4-5 equals 46% to 68%. In both cases, it is extremely unlikely that the ex post NTGR is equal to the ex ante NTGR value of 100% (as listed in table 4-6).

#	Subject:	Entity:	QUESTION or COMMENT:	Evaluator Response:
8	2. General comment on Source energy savings values on table 1-4-conversion of Btu to kWh	Southern California Gas Company	Page 7 of this report in section 1.2.2 says “The evaluated source energy savings is based on the outputs of the CPUC’s FS Calculator v1.1, using the total gross evaluated site energy savings and other pertinent measure details as the inputs into the custom calculator segment. In reviewing the source energy savings, it is important context to understand that in the fuel substitution test “only the source energy from depletable fossil-fuel resources are currently considered,” by the CPUC and that they “consider the source energy and emissions for renewable generation, such as solar, wind, and hydro-electric generation, to be zero.”. Table 1-4 below presents the evaluated and reported first-year full energy savings and the lifecycle source energy savings, in MMBtu, for both the ductless and central HVAC technologies.” SoCalGas’ comment here refers to the CPUC FS Calculator v1.1 and the assumption that was used in this calculator relevant to the source energy equivalent Btu to kWh. This conversion factor is called Heat Rate (HR). The calculation merits a proper heat rate that fits the situation. The figure 1 below is a screen shot of the “reference” tab in the CPUC calculator that shows a Heat Rate of 7,000 Btu/kWh for this purpose, this HR is related to a Combined Cycle Gas Turbine. Source energy changes are proportionally related to the HR. The following table is an example of the importance of selecting the correct HR. If the selected HR is smaller than the right HR, it shows more Fuel Substitution (FS) saving and more added load at the source and if it is higher than the right HR, it would arrive at less FS saving and less added load at the source. SoCalGas requests to have a discussion with the DNV and CPUC teams on the assumption of the HR in the calculator. Due to the importance of this matter a simple average would not be mathematically suitable for the situation.	The scope of the PY2020 impact evaluation of HVAC fuel substitution measures claimed by SCE's Plug Load and Appliances did not include an assessment of the CPUC's Fuel Substitution Calculator or its underlying assumptions. SoCalGas can engage the CPUC Energy Division directly in regard to the assumptions supporting fuel substitution calculator.

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