Impact Evaluation of Smart Thermostats - Residential Sector - Program Year 2019

EM&V Group A

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SAFER, SMARTER, GREENER

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1 EXECUTIVE SUMMARY

1.1 Background

Smart thermostats allow users to control their home's heating, ventilation, and air conditioning (HVAC) system. While the primary function of these devices is to enable users to maintain desired temperature levels, their internet connectivity provides additional 'smart' means of managing a home's energy use. It is the ability to manage energy use remotely through internet connected devices and automatically adjust the setpoint of the HVAC system that promises better energy management while maintaining comfort.

In this report, DNV GL evaluated 2019 program installations of smart thermostats provided by Marin Clean Energy (MCE), Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas Company (SCG), and San Diego Gas and Electric Company (SDG&E), collectively the Program Administrators or PAs. The PAs delivered smart thermostats through 21 different programs at low or no cost to customers. The programs also provided other HVAC technologies meant to improve energy efficiency of the system and provide additional comfort to customers.

The programs, which were offered to both electric and gas customers, targeted different population segments including residential customers in single-family, multifamily, and mobile homes. Statewide, PA programs delivered over 160,000 smart thermostats to customers in 2019. The majority of program installations were Nest thermostats with over 70% of installations in all PA programs, with Ecobee and Honeywell comprising the remainder.

1.2 Research questions and objectives

DNV GL's three research objectives were to estimate the electric and gas savings achieved due to smart thermostat installations in program year 2019 (PY2019), determine to what extent evaluated savings estimates matched claimed savings, and determine the percentage of customers who would have acquired the devices in the absence of the program. We also sought to determine program participants' characteristics, including dwelling type, location, general demographic background, participation in energy efficiency programs, and energy consumption behaviors to help understand observed impact and factors that might affect them.

1.3 Study approach

DNV GL evaluated savings from smart thermostat installations using energy consumption data analysis and surveys. The two main processes we used to estimate smart thermostat program savings were:

- Estimating the energy savings of smart thermostats by comparing energy use data before and after installation of the device
- Conducting surveys to determine the portion of these savings attributable to program incentives

Statewide, PAs claimed 70% smart thermostat savings from direct install programs[1] and 30% from rebate programs in PY2019. To evaluate PY2019-rebated smart thermostats, we applied savings per whole home from the consumption data analysis we undertook for the PY2018 evaluation[2] and applied 2019 participant counts by PA, dwelling type, and climate zone. The PY2018 evaluation addressed rebate participants only and the consumption data analysis included only homes that participated in no other program. We adopted this approach to develop reliable savings estimates for smart thermostats in cases where this technology was installed on its own.

We designed a primary new consumption data analysis for PY2019 to address direct install participants. These participants typically have multiple measures[3] installed at once, which requires a method that can disaggregate whole-home savings into measure-level savings. This method is different than the approach we used for rebate programs because it involved estimating savings for the whole home, which were then allocated to the different installed measures using engineering estimates. To the extent practical, we also used separate consumption data analysis of direct-install homes that received smart thermostats and no additional measures to guide the allocation of the whole-home savings.

While rebate programs largely involved single-family homes, direct install programs provided smart thermostats to a substantial number of multifamily and mobile homes. Our analysis for direct install programs therefore provides savings per smart thermostat separately for single-family, multifamily, and mobile homes.

A typical consumption data analysis of 2019 participants would use pre-installation periods stretching into 2018 and post-installation periods extending through the end of 2020. However, COVID-19 related disruptions to occupancy and energy usage patterns made such an analysis with 2020 post-installation periods problematic. To avoid these problems, we conducted the direct-install consumption data analysis using data from 2018 program participants whose post-installation periods ended prior to COVID-19 disruptions.

Thus, both rebate and direct install savings for PY2019 are based on whole-home results from consumption data analysis of 2018 participants combined with actual program participation from 2019 by customer segment. DNV GL's consumption data analysis approach, considered a best practice for evaluation of opt-in programs,[4] is enshrined in California evaluation protocols and the Uniform Methods Project.[5]

We conducted surveys with 2019 participants (occupants and property managers) for both rebate and direct install programs. Sample sizes are shown in Table 1-1. In addition to informing program influence, surveys provided information on customer characteristics and changes to homes and behavior apart from the smart

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[1] Direct install energy efficiency programs are those in which energy saving upgrades are installed for no or low-cost to customers.

[2] http://www.calmac.org/publications/CPUC_Group_A_Report_Smart_Thermostat_PY_2018_CALMAC.pdf

[3] An energy efficiency measure is an energy-using appliance, equipment, control system, or practice whose implementation results in reduced energy use while maintaining a comparable or higher level of service

thermostats or other direct install measures. We also collected information from a sample of non-participant[4] customers with comparable energy-use patterns. Comparisons between participant and non-participant reported changes that impact household energy use[5] and smart thermostat adoption among non-participants provided the basis for making gross savings adjustments.[6] The sample size for these surveys satisfies overall confidence and precision requirements of 90/10.

Table 1-1. Survey efforts and sample size summary

Surveys	Mode	Sample Frame (program participant population)	Sample Size
Program participant survey - Occupants	Web	75,693	5,998
Program participant survey – Property Managers	Web and Phone	1,294	295
Non-participant survey – Occupants	Web	N/A	5,656

Strengths. The direct install gross savings estimation approach combines the advantages of energy consumption data analysis and engineering estimation. The consumption data analysis produces total savings identifiable at the whole-home level and some measure-level information, while the engineering analysis provides the relative magnitude of different measures to allocate the savings. From another perspective, the engineering analysis provides a reasonable savings estimate based on what is known about California homes and about the measures, while the consumption data analysis calibrates the engineering estimates to observed usage and changes in usage.

Limitations. The direct-install consumption data analysis calibrates measure-level engineering savings estimates to observed consumption and changes in consumption. As a result, the total savings estimate across all measures is well grounded, but there is some uncertainty in the allocation of this total among the measures. The analysis relied primarily on allocating savings in proportion to the engineering estimates, which used the best available information from recent evaluations and the 2019 Residential Appliance Saturation Study (RASS 2019).[7] We provide further detail in Section 5.4.

Both the rebate and direct install results assume that whole-home savings by customer segment are the same for 2019 participants as for 2018 participants, on a normal-year basis absent COVID-19 effects.

1.4 Key findings

Gross savings were lower and program attribution was higher than claims. Table 1-2 provides the number of households with electric service that received a smart thermostat through a direct install or rebate program, the expected electric savings (total gross claimed savings), and the achieved savings (total gross evaluated savings). Smart thermostats installed through the programs achieved approximately 6.4 GWh of gross electric savings, which is 23% of gross expected or claimed savings (gross realization rate).[8] Total gross savings are further adjusted to reflect the portion of savings that can be attributed to program influence. Our evaluation indicates that direct install and rebate programs caused electric savings of 5.0

[4] Non-participants are customers from the general residential population who have not participated in any PA programs.

[5] Surveys ask participants and non-participants to report on changes such as electric vehicle use, refrigerator use, addition of living space etc. which have an impact on the household’s energy use.

[6] Gross savings are a measure of change in energy use due to energy efficiency programs, regardless of why customers participated.

[7] DNV GL Energy Insights USA, Inc. 2020. 2019 California Residential Appliance Saturation Study. California Energy Commission (CEC). Final statewide survey dataset obtained from the California Energy Commission (CEC).

[8] Gross realization rate is the ratio of evaluated savings to the original claimed savings, without any adjustments for program influence.

GWh statewide. The statewide net-to-gross ratio (NTGR)[9] for electric savings smart thermostats is 94% for direct install programs and 60% for rebate programs.

Table 1-2. Total smart thermostat electric savings, 2019

Program Administrator	Program participants (Electric)	Total Gross Claimed Savings (kWh)	Total Gross Evaluated Savings (kWh)	Gross Realization Rate	Evaluated NTGR	Total Net Evaluated Savings (kWh)
Direct Install Total	83,590	19,115,836	3,568,874	19%	94%	3,342,445
Rebate Total	51,710	8,684,882	2,806,760	32%	60%	1,670,984
Statewide Total	**135,300**	**27,800,718**	**6,375,634**	**23%**	**79%**[10]	**5,013,429**

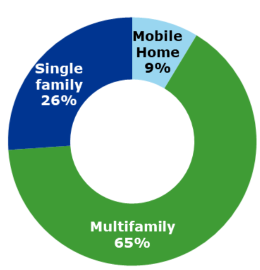
Table 1-3 provides the number households with gas service that received a smart thermostat through a direct install or rebate program, claimed gas savings, and the savings that they achieved. Our evaluation found no smart thermostat gas savings per household for direct install programs. Our evaluation indicates gross gas savings of 140,291 therms from rebate programs. Statewide total gross gas savings are 7% of expected or claimed gross gas savings (gross realization rate). Total gross savings were further adjusted to reflect the portion of savings that can be attributed to smart thermostat installations because of program influence. Our evaluation indicates that program attribution for gas savings from rebate programs is 51%.

Table 1-3. Total smart thermostat gas savings, 2019

Program Administrator	Program participants (Gas)	Total Gross Claimed Savings (therms)	Total Gross Evaluated Savings (therms)	Gross Realization Rate	Evaluated NTGR	Total Net Evaluated Savings (therms)
Direct Install Total	108,986	1,241,114	0	0%	90%	0
Rebate Total	51,212	724,980	140,291	19%	51%	71,577
Statewide Total	**160,198**	**1,966,095**	**140,291**	**7%**	**51%**	**71,577**

The mix of measures delivered in direct install programs varied by housing type and had an impact on smart thermostat savings estimates. Direct install programs delivered smart thermostats to multifamily, mobile, and single-family homes (Figure 1-1). Additionally, smart thermostats were often installed as part of a bundle of other HVAC and non-HVAC technologies. By contrast, rebate programs tended to install smart thermostats alone and in mostly single-family residences.

Figure 1-1. Direct install participants by dwelling type

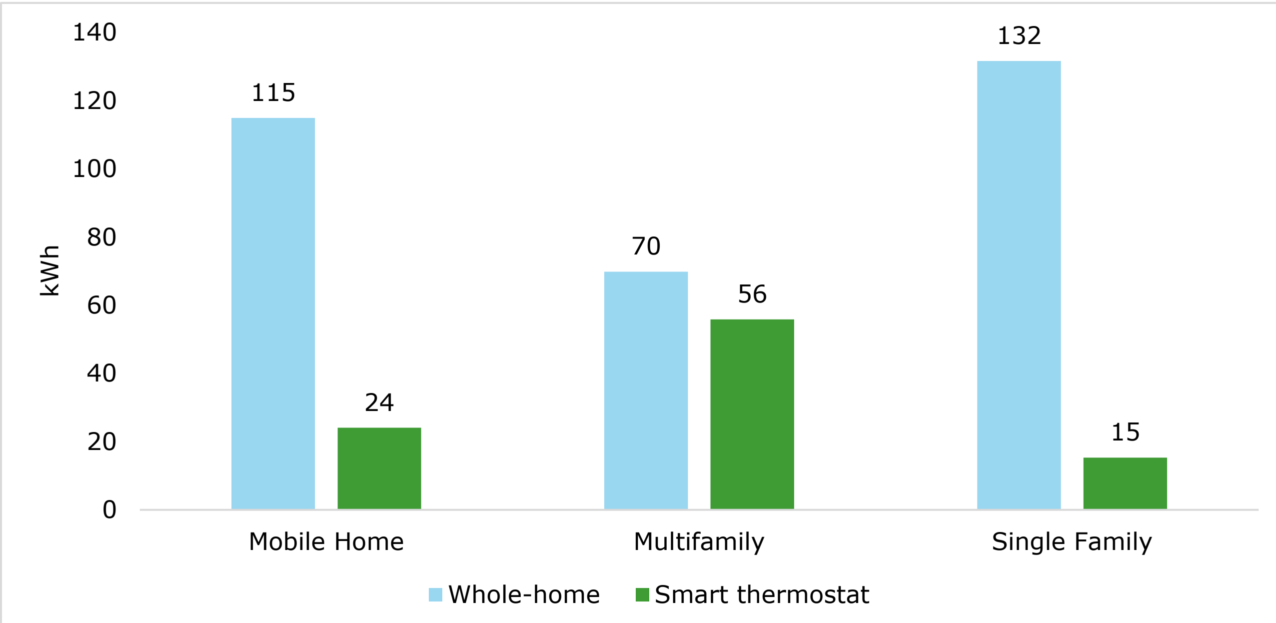


[9] Free-ridership is defined as the extent of program participation that would have occurred even in the absence of program incentives. Free-ridership ranges from 0% to 100%, with a with a lower value translating to greater program influence on a customer's decision to participate. The net-to-gross ratio (NTGR) is the complement of free-ridership and measures the amount of savings attributed to program incentives. For example, an 80% NTGR indicates 20% free-ridership.

[10] The statewide NTGR is the weighted sum of direct install and rebate NTGRs. The individual NTGRs should be applied to specific programs to roll up to statewide totals.

Average estimated electric savings per home, which includes the savings for all technologies installed at the same time, are 115 kWh for mobile homes, 70 kWh for multifamily units, and 132 kWh for single family homes, or 1% to 2% of total annual electricity use. A portion of these savings are due to smart thermostats (Figure 1-2).

Figure 1-2. Average electric whole-home and smart thermostat savings, PY2019 direct install programs



To determine smart thermostat savings, we first estimated savings for the whole home and then explored statistical models to disaggregate these savings to measure-level savings. Our attempt to disaggregate savings statistically using measure-level consumption regressions did not produce reliable results.[11] We therefore apportioned the estimated whole-home savings to measure savings in proportion to engineering savings estimates.

While it is uncertain as to how much of the whole-home savings are due to each measure, the smart thermostat savings cannot be more than the total whole-home savings.[12] The smart thermostat estimates shown represent our best estimates of the contributions to savings out of all measures delivered to the homes.

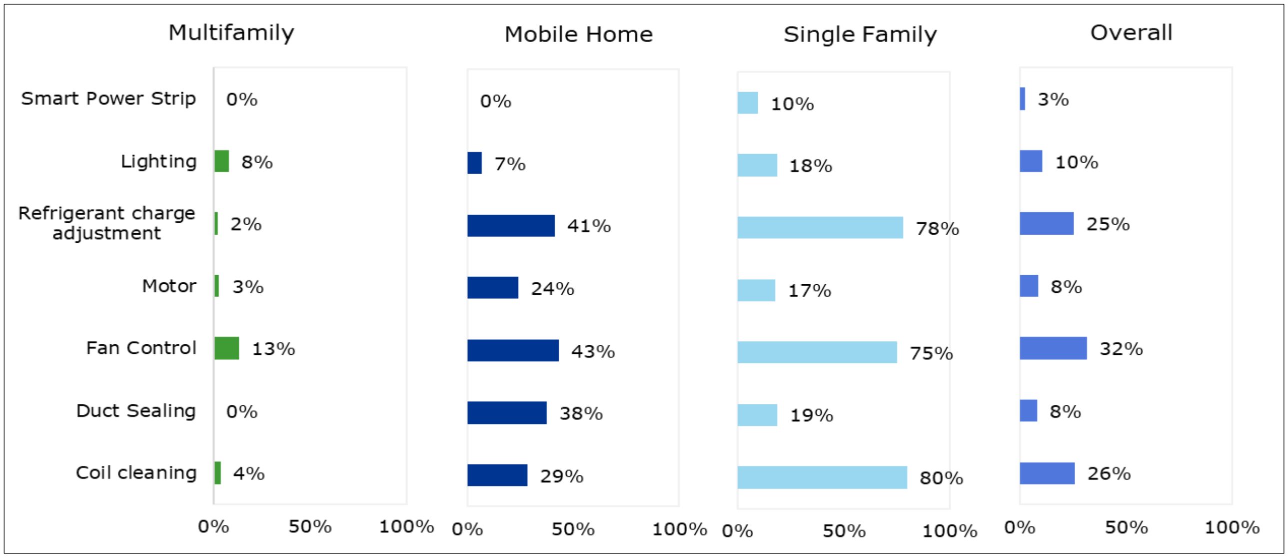
Figure 1-3 shows the proportion of other measures received by homes that installed smart thermostats through direct install programs. The mix of delivered technologies varied by dwelling type. In single-family homes, smart thermostat installations largely overlapped with the delivery of refrigerant charge adjustment (RCA), coil cleaning, and fan controls. Among mobile homes, smart thermostats installations also overlapped to some degree with energy-saving HVAC technologies, including duct sealing, high-efficiency HVAC motors,

[11] We provide further detail in section 5.1.3.

[12] Smart thermostat savings could, in principle, be more than the whole-home savings if the other measures combined produce negative savings. That would require substantial takeback for the other measures but not for smart thermostats, and there's no basis for such an assumption.

and fan controls. These overlaps, particularly with fan controls, appear to have reduced the electric savings that smart thermostats could deliver.[13]

Figure 1-3. Percent of technologies installed with smart thermostats by dwelling type, PY2019



Most multifamily homes only installed smart thermostats resulting in a savings estimate for this technology that is close to the multifamily whole-home savings estimate. The much lower smart thermostat savings estimates for single family and mobile homes compared to multifamily might suggest an over-allocation of whole-home savings to other measures. However, occupants of different dwelling types would not necessarily interact with the technology the same way. As we indicated earlier, our analysis also suggests that savings from fan controls compete with savings from smart thermostats, resulting in lower total savings than if they were installed separately.[14]

Average estimated gas savings per household for the direct install programs indicate a statistically insignificant change or increase in gas consumption associated with smart thermostats alone or in combination with other technologies. Supplemental analysis of gas consumption in homes that received only smart thermostats indicated savings were negative (increased consumption), but not statistically significant. The prior rebate program evaluation found very low gas savings, which were even negative for some climate zones. Other studies of smart thermostats have also found minimal gas savings. Thus, a finding of negligible smart thermostat gas savings is reasonable. We therefore assess the gas savings for thermostats as 0 and assign all gas savings from homes that had other measures to those other measures.

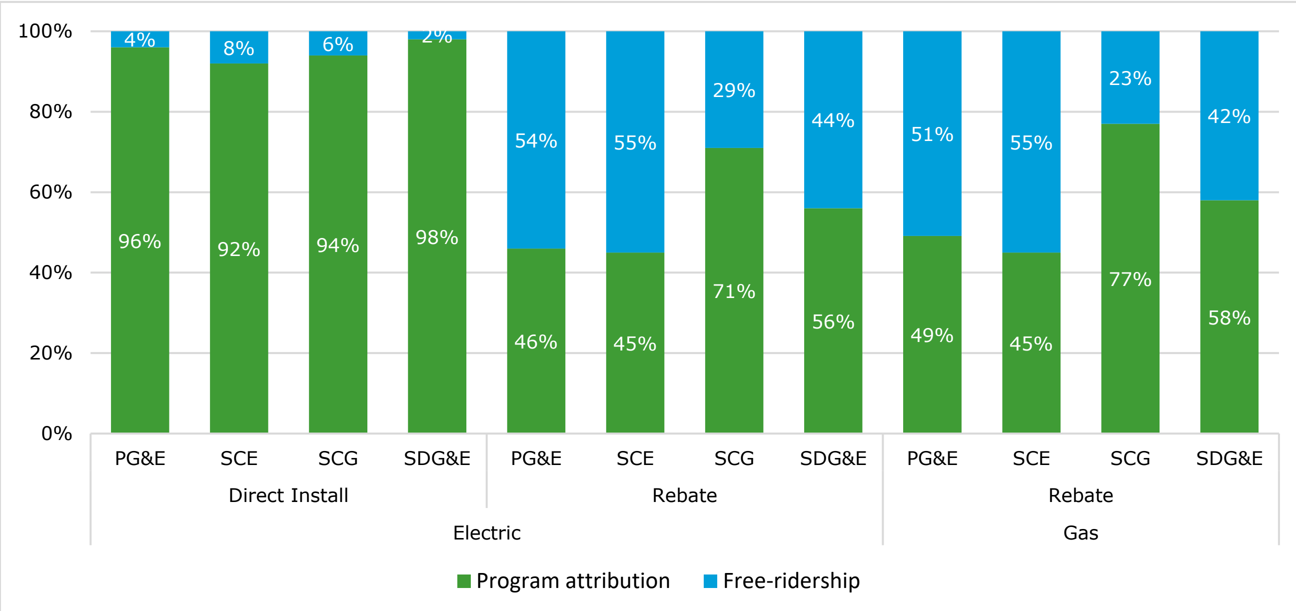
Program attribution was higher than those used in PA claims. Free-ridership is defined as the extent of program participation that would have occurred even in the absence of program incentives. DNV GL estimated free-ridership based on residential program participant and property manager surveys. Most smart thermostat installations through the PAs' programs in 2019 were through direct install programs rather than rebate programs. Program attribution varied by PA and program type. For direct install programs, electric

[13] Low electricity savings for smart thermostats possibly reflect competing effects of fan controls and smart thermostats, both of which are capable of delaying fan turn-off. Similar to what fan controls do, smart thermostats have a feature that uses the fan to spread remaining cool air in the HVAC coils through a home after switching off the air-conditioner compressor.

[14] This is not just due to the addition of another measure where the second measure has less potential after the first is installed, but rather the controls could be redundant because smart thermostats may delay fan turn-off, like fan controls, to distribute remaining hot or cold heat in exchangers.

savings program attribution ranged from 92% to 98% for all PAs (Figure 1-4).[15] For the PG&E, SCE, and SDG&E rebate programs, both gas and electric savings program attribution ranged from 45% to 60%. SCG's rebate program attribution was higher at above 70%.

Figure 1-4. Rebate and direct-install program attribution by fuel and PA



Both direct install and rebate program participants exhibited some differences in household characteristics compared to non-participants. In addition to informing the proportion of savings for which the programs should receive credit, surveys also provided relevant information on customer characteristics and behavior related to energy consumption and savings. DNV GL conducted surveys among participants (served by rebate and direct-install programs) and non-participants (customers who did not receive program discounted or free smart thermostats).

Survey findings indicated that:

- Compared to single-family direct install program participants, a higher proportion of single-family rebate program participants tended to be homeowners (95% vs. 90%), resided in larger homes (46% vs. 33%), and had household incomes greater than $100,000 (46% vs. 26%). This is in line with the high free-ridership observed for single-family rebate program participants relative to single-family direct install program participants (52% vs 18%). Buying a smart thermostat is something most of the single-family rebate participants would have done even without program incentives.

- A significantly[16] higher proportion of both rebate and direct install participants reported undertaking actions that on balance[17] contribute to greater energy consumption and may diminish savings. For example, some participants:

[15] We do not display program attribution for gas from direct-install programs as the evaluated gas savings are equal to zero for the PAs' direct install programs.

[16] Results noted as significant are statistically significant at the 90% confidence and 10% precision level.

[17] The term "on balance" reflects that while there were those that took actions that decreased energy consumption, there were greater number of customers undertaking actions that increased energy consumption. While these differences may be small and the actions undertaken have counteracting effects in some cases, the maximum cumulative impact of these changes is considered here. As noted in section 5.1.3, these differences are expected to have a relatively small effect on whole-home savings.

- Added a refrigerator. A total of 9% of both rebate single-family participants and direct install single-family participants added a refrigerator versus 7% of single-family non-participants; 6% direct install mobile home participants added a refrigerator versus 2% of mobile home non-participants.
- Added living space. A total of 2% of direct install single-family participants and 3% of rebate single-family program participants added living space compared to none (0%) for non-participants.

Weighting these differential actions using RASS 2019 values for end-use consumption indicates that they could accounted for a 10% and 21% increase in electric savings, at most, at the whole-home level for mobile home and single-family direct install program participants, respectively. The therm effects were negligible.

Direct install program participants indicated lower engagement with their smart thermostats. Over one-quarter (26%) of all non-participants indicated that they had a smart thermostat. Of these, roughly half installed their thermostat during the evaluation timeframe, which could potentially lower the savings estimates produced using the comparison group approach. As a result, the evaluated gross savings estimates for smart thermostats presented in this report include an upward adjustment for the prevalence of smart thermostats among non-participants.

We compared how program participants (direct install and rebate) and non-participants who installed their own smart thermostats used the devices and found that direct install participants had significantly lower engagement with their smart thermostat. The differences presented below shed light on the lower than expected savings estimates for these program participants:

- Use of the "auto-away" feature is lower at 13% for single-family direct install program participants compared with 23% for single family non-participants with smart thermostats and 27% for single-family rebate program participants. This feature adjusts temperature setpoints when the smart thermostat sensor does not register activity thus delivering savings. Limited use of this feature reduces this opportunity for savings.
- Use of the mobile app is lower at 47% for single-family direct install program participants compared with 61% single-family non-participants with smart thermostats and 66% for single-family rebate program participants. This lower engagement implies less information for the device's learning algorithm to draw upon as it continues to optimize the thermostat to deliver energy savings.
- Program participants report greater comfort in the home after installation of the smart thermostat at 60% for single-family direct install participants and 70% for single-family rebate program participants versus 53% for single-family non-participants with smart thermostats. We see a similarly higher proportion of mobile home direct install participants reporting being more comfortable in their homes than mobile home non-participants with smart thermostats at 55% vs. 38%, which could indicate of takeback among participants.
- Single-family direct install program participants report enrollment in demand response programs in lower proportion (20%) than single-family rebate program participants (26%) and single-family non-participants (24%). Demand response programs reduce consumption during times of high demand and are likely to provide a modest contribution to energy savings.

1.5 Recommendations

The key findings from the evaluation and the recommendations stemming from it are summarized in this section (Table 1-4).

Table 1-4. Key findings and Recommendations

 **Key findings**	 **Recommendations & Implications**
1. There are no discernible gas savings from direct install programs and low gas savings from rebate programs. These results are consistent with other studies.	Consider eliminating gas savings claims for direct install smart thermostats.
2. Electric savings have low gross realization rates.	Consider reducing utility reporting assumptions for electric thermostat savings, particularly for direct install applications. Review the potential for fan control measures to interfere with savings opportunities from smart thermostats. Consider restricting smart thermostat direct install to homes without fan control measures.
3. Lower engagement among direct-install program participants compared to rebate participants and non-participant installers implies underutilization of the learning algorithm to optimize and save energy, which reduces savings opportunities.	Require direct install programs to include or strengthen contractor training and customer education about settings (auto-away) and device use (pre-heating/pre-cooling) that will help save energy. Consider leveraging contractors and property managers to deliver customer education recommended above.
4. Direct-install program participants report lower rates of enrollment in demand response programs compared with rebate program participants and non-participants with smart thermostats.	Require direct install programs to include or strengthen education of participants receiving smart thermostats on demand response opportunities to achieve their full savings potential.

2 INTRODUCTION

2.1 Program description and participation

Smart thermostats allow users to control their home's heating, ventilation, and air conditioning (HVAC) system. While their primary function is to enable users to maintain desired temperature levels, their internet connectivity provides additional 'smart' means of managing a home's energy use from anywhere. The ability to manage energy use remotely through internet connected devices and make automated adjustments to the setpoint of the HVAC system provides additional and potentially improved energy management while maintaining comfort.

In 2018 and 2019 smart thermostats were offered by a broad variety of energy efficiency programs in California. As Table 2-1 indicates, smart thermostats were installed through 21 different programs in these two years across five California program administrators (PAs): Marin Clean Energy (MCE), Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SCG), and San Diego Gas and Electric Company (SDG&E). These programs provided a mix of energy efficiency measures including smart thermostats at low or no cost to customers. The programs targeted different customer segments including all those eligible living in single-family, multifamily, and mobile homes. The programs delivered the measures either through direct install or rebate channels. The majority (70%) of smart thermostats were delivered via direct install and the remainder (30%) through rebate programs.

Table 2-1. Programs offering smart thermostats, PY2018 and PY2019[18]

<table>
<tr><th>PA</th><th>Program Year</th><th>Program Name</th><th>Target</th><th>Delivery Method</th><th>Measures Offered</th></tr>
<tr><td>PG&E</td><td>2018, 2019</td><td>Plug-Load & Appliances (Residential Energy Efficiency)</td><td rowspan="6">All residential customers</td><td rowspan="6">Rebates and incentives (30%)</td><td rowspan="6">Plug load & appliances, including smart thermostats</td></tr>
<tr><td>SCE</td><td>2018, 2019</td><td>Plug Load And Appliances Program</td></tr>
<tr><td>SCG</td><td>2018, 2019</td><td>RES-Plug-Load & Appliances (Residential Energy Efficiency)</td></tr>
<tr><td>SCG</td><td>2019</td><td>RES-Plug Load and Appliances - POS</td></tr>
<tr><td>SDG&E</td><td>2018, 2019</td><td>SW-CALS-Plug Load And Appliances-HEER</td></tr>
<tr><td>SDG&E</td><td>2018, 2019</td><td>SW-CALS-Plug Load And Appliances-Pos Rebates</td></tr>
<tr><td>PG&E</td><td>2018, 2019</td><td>Residential Energy Fitness Program</td><td rowspan="6">Eligible residential customers</td><td rowspan="10">Direct Install (70%)</td><td rowspan="10">Comprehensive or mix of measures, including smart thermostats</td></tr>
<tr><td>SCE</td><td>2018, 2019</td><td>Residential Direct Install Program</td></tr>
<tr><td>SCG</td><td>2018, 2019</td><td>RES-Community Language Efficiency Outreach (CLEO)</td></tr>
<tr><td>SCG</td><td>2019</td><td>RES-Direct Install Program</td></tr>
<tr><td>SCG</td><td>2019</td><td>RES-LADWP HVAC</td></tr>
<tr><td>SDG&E</td><td>2018, 2019</td><td>Local-Cals-Middle Income Direct Install (MIDI)</td></tr>
<tr><td>PG&E</td><td>2018, 2019</td><td>Enhance Time Delay Relay</td><td rowspan="4">Multifamily customers</td></tr>
<tr><td>SCE</td><td>2018, 2019</td><td>Multifamily Energy Efficiency Rebate Program</td></tr>
<tr><td>SCG</td><td>2018</td><td>RES-Multifamily Energy Efficiency Rebate Program</td></tr>
<tr><td>SCG</td><td>2018, 2019</td><td>RES-Multifamily Direct Therm Savings ("Energy Smart" Program)</td></tr>
</table>

[18] Although the Home Upgrade Program (HUP) and Advanced Home Upgrade Program (AHUP) also offered smart thermostat measures, claims from these programs are not included in the smart thermostat evaluation. HUP and AHUP program savings are evaluated at the whole home level and not at the measure level.

PA	Program Year	Program Name	Target	Delivery Method	Measures Offered
SDG&E	2018, 2019	SW-CALS-Multi-Family Energy Efficiency Rebates (MFEER)	Manufactured /mobile home customers		
PG&E	2018, 2019	Direct Install for Manufactured and Mobile Homes			
SCE	2018, 2019	Comprehensive Manufactured Homes			
SCG	2018, 2019	RES-Manufactured Mobile Home			
SDG&E	2018, 2019	3P-RES-Comprehensive Manufactured-Mobile Home			

Source: PA Tracking Data filed with the CPUC

Table 2-2 provides claimed electric installations and savings by PA and delivery type in each program year. It shows that total direct install electric savings decreased from approximately 33 million to 19 million kWh in PY2018 compared with PY2019 while claimed electric rebate savings increased from 8 million to 8.7 million kWh for these program years. Overall, statewide claimed electric savings and smart thermostat installations decreased from PY2018 to PY2019.

Table 2-2. Smart thermostat installations and electric savings claims by PA, PY2018 and PY 2019

PA	Electric Installations				Gross Program Electric Savings (kWh)			
	Direct Install		Rebate		Direct Install		Rebate	
	2018	2019	2018	2019	2018	2019	2018	2019
MCE		77				8,876		
PG&E	17,136	21,388	18,386	13,730	4,564,171	5,966,581	3,018,614	1,784,905
SCE	69,444	34,767	7,478	4,357	15,963,941	7,884,130	1,476,366	935,192
SoCalGas	55,580	25,063	9,977	27,042	11,304,713	4,475,515	1,976,966	5,097,280
SDG&E	2,470	2,295	9,544	6,581	1,586,103	780,735	1,487,356	867,506
Statewide	**144,630**	**83,590**	**45,385**	**51,710**	**33,418,928**	**19,115,836**	**7,959,303**	**8,684,882**

Source: PA tracking data filed with the CPUC

Similarly, the PAs claimed more gas savings in PY2018 compared with PY2019. Table 2-3 shows that total claimed gas direct install savings decreased from approximately 1.8 million to 1.2 million therms in PY2018 compared to PY2019. Additionally, total claimed gas rebate savings decreased from 1.2 million in PY2018 to 0.7 million therms in PY2019. The declines in total claimed savings in PY2019 reflect lower installations in that program year. Statewide, PA programs delivered more than 220,000 smart thermostats in PY2018 and 160,000 smart thermostats in PY2019.

Table 2-3. Smart thermostat installations and gas savings claims by PA, PY2018 and PY2019

PA	Gas Installations				Gross Program Gas Savings (therms)			
	Direct Install		Rebate		Direct Install		Rebate	
	2018	2019	2018	2019	2018	2019	2018	2019
MCE		77				1,687		
PG&E	17,136	21,388	18,407	13,770	308,986	374,124	434,225	312,485
SCE	69,444	34,767	7,478	4,357	742,977	362,005	90,554	55,681
SoCalGas	58,854	50,460	41,642	27,045	674,552	467,919	593,205	301,580
SDG&E	2,470	2,294	7,026	6,040	89,770	35,379	70,512	55,234
Statewide	**147,904**	**108,986**	**74,553**	**51,212**	**1,816,286**	**1,241,114**	**1,188,496**	**724,980**

Source: PA tracking data filed with the CPUC

In PY2019, most smart thermostats (44% with electric savings and 42% with gas savings) were installed in multifamily dwellings through direct install channels. Compared to PY2018, these installations represent a decrease (from 60% with electric savings and 53% with gas savings) in thermostats installed in multifamily dwellings through direct install channels (Table 2-4). On the other hand, more direct installations occurred in single-family homes in PY2019 (15% to 24%) compared to PY2018 (6% to 7%). Another 7% to 11% were also directly installed in mobile homes in each year through direct install channels. Rebate installations making up approximately 25% to 35% of all installations occurred in both program years. Claimed savings for these devices reflect these general trends.

Table 2-4. Smart thermostats installed by program type, PY2018 and PY2019

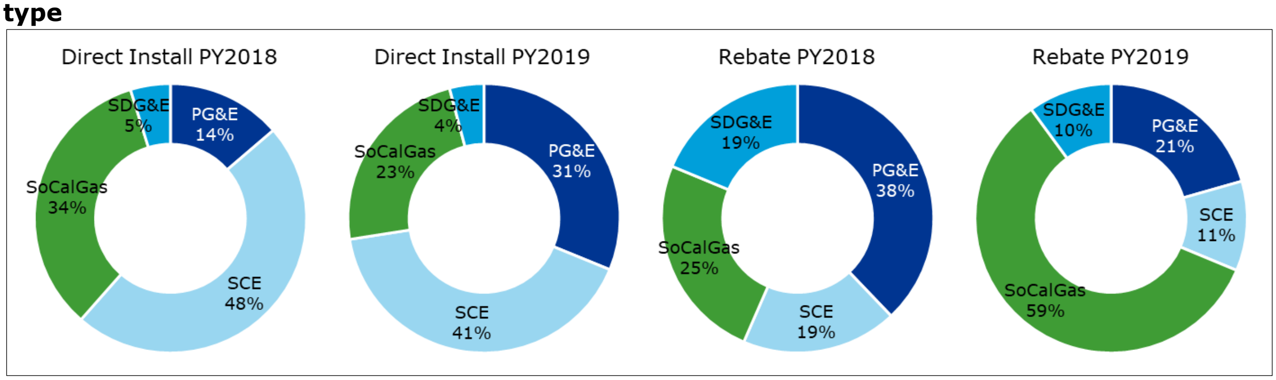
Program Type	Percent Households with Electric Savings		Percent Households with Gas Savings	
	2018	2019	2018	2019
Residential Rebate	24%	29%	34%	25%
Multifamily Direct Install	60%	44%	53%	42%
Mobile Home Direct Install	9%	11%	7%	10%
Single Family Direct Install[19]	7%	15%	6%	24%
Total	**100%**	**100%**	**100%**	**100%**

Figure 2-1 and Figure 2-2 summarize claimed electric and gas smart thermostat savings, respectively, by PA and delivery type. For direct install programs:

- SCE's share of claimed electric savings were the largest in both program years.
- PG&E's share of claimed electric savings more than doubled from PY2018 to PY2019.
- The share of gas savings among PAs remained largely the same in both program years.

For rebate programs, SDG&E's, PG&E's, and SCE's share of claimed electric savings decreased, while SCG's share of claimed electric savings increased dramatically from PY2018 to PY2019. The share of gas claimed savings remained largely similar in both program years.

Figure 2-1. PY2019 and PY2018 claimed electric smart thermostat savings by PA and delivery type



19 These direct install programs primarily deliver to single family homes, but some of the programs served other dwelling types as well.

Figure 2-2. PY2019 and PY2018 claimed gas smart thermostat savings by PA and delivery type

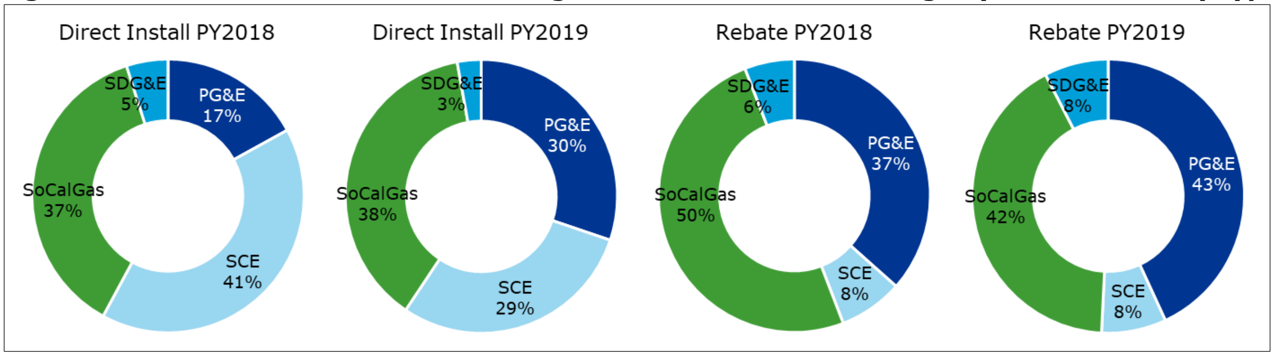
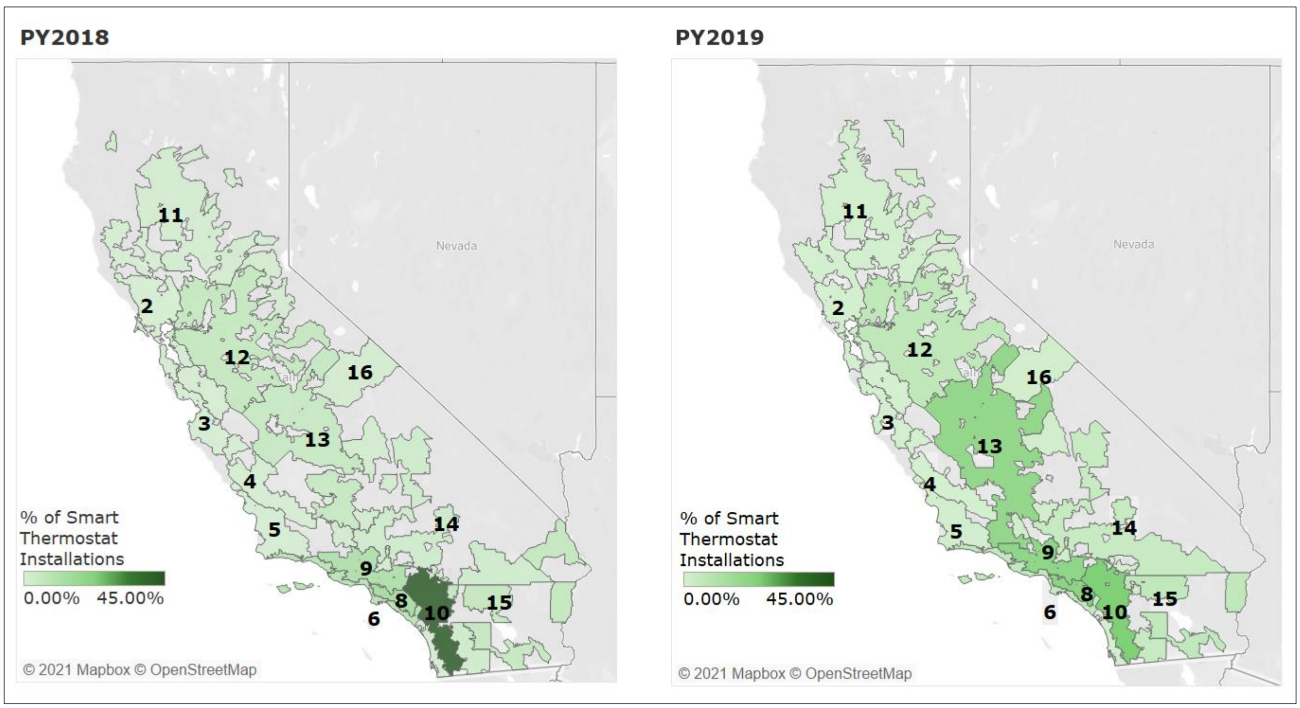


Figure 2-3 below shows the patterns of smart thermostat installations offered through direct install programs in PY2018 and PY2019 by climate zone. Direct install programs delivered the majority of smart thermostats in climate zone 10 with 43% of all installations in PY2018 and 22% in PY2019. In both years, these programs installed over 60% of smart thermostats in climate zones 8, 9, and 10.

Figure 2-3. Geographic concentration of direct install smart thermostats by climate zone, PY2018 and PY2019



The direct-install smart thermostat concentrations noted above are reflected in the count of such installations by climate zone provided in Table 2-5. The table indicates that the highest number of smart thermostat installations were in climate zones 6, 8, 9, and 10 in both PY2018 and PY2019 and, additionally, in climate zone 13 in PY2019. The normal (typical meteorological year – TMY) cooling and heating degree days (CDD and HDD)[20] for climate zones 6, 8, 9, and 10 (averaging 1,400 CDD and 2,000 HDD) indicate

[20] Cooling degree days and heating degree days are the number of degrees above or below, respectively, a base temperature such as 65. They are convenient expressions of temperature that correlate well with the amount of energy needed to cool or heat buildings as they begin accruing the approximate temperature at which the houses start to use their heating or cooling system. For instance, if a building starts cooling at an average outdoor temperature of 65°F and the average daily temperature on that day is 70°F, the CDD for that day is the difference between these two values (5). For general comparisons of degree days across geographies, a consistent base of 65°F was used for both CDD and HDD in the table.

that customers in these areas face mild cooling and heating conditions. Areas with the highest cooling needs in the state have CDD values that are above 2,000 while areas with significant heating needs have HDD values that exceed 3,000. Thus, PY2019 installations in climate zone 13 are in a region with notable cooling needs.

Table 2-5. PY2018 and PY2019 direct install and rebate smart thermostat installations by climate zone

Climate zone	Normal HDD	Normal CDD	Direct install pogram installations		Rebate program installations	
			PY2018	PY2019	PY2018	PY2019
2	3,029	414	0.3%	0.0%	1.1%	1.2%
3	2,652	299	0.2%	0.4%	6.7%	6.9%
4	2,458	294	0.3%	0.2%	6.0%	6.0%
5	2,510	375	0.1%	0.9%	0.7%	0.7%
6	1,391	866	8.6%	4.9%	5.7%	6.4%
7	1,176	889	0.1%	0.1%	6.0%	6.3%
8	1,310	982	14.2%	19.5%	9.8%	17.1%
9	1,566	1,402	11.8%	18.1%	35.9%	12.1%
10	1,231	1,822	43.2%	22.5%	12.4%	25.0%
11	2,420	1,873	1.2%	0.5%	1.6%	1.9%
12	2,398	1,360	5.4%	5.7%	7.3%	8.0%
13	2,237	2,308	5.2%	17.3%	2.8%	3.3%
14	1,830	3,109	2.4%	3.6%	0.9%	1.4%
15	863	4,945	5.9%	5.2%	1.5%	2.7%
16	2,841	1,771	1.1%	1.0%	1.8%	1.0%
Total smart thermostat installations			**147,904**	**108,986**	**74,553**	**51,212**

The majority of rebated and direct install smart thermostats in both PY2018 and PY2019 were Nest. Ecobee thermostats were the next most commonly installed thermostats by program participants followed by Honeywell devices (Table 2-6). While the composition of rebated smart thermostats changed to reflect the inclusion of other brands, including Honeywell and Emerson (part of the 'Other' category) in PY2019, smart thermostats offered through direct install programs remained predominantly Nest thermostats in both years. These choices reflect workpaper requirements, which prescribe the types of smart thermostats that are eligible for claims, and the bulk purchasing decisions of direct install programs that make the majority of the claims.[21]

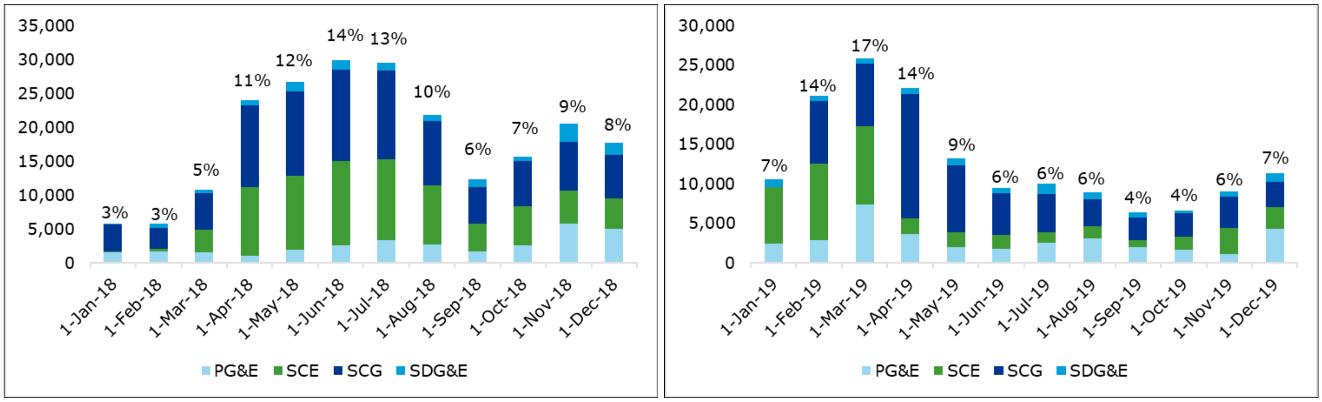
Table 2-6. Smart thermostat models statewide by delivery channel, PY2018 and PY2019

Model	2018 Rebate	2019 Rebate	2018 Direct Install	2019 Direct Install
Nest	87%	71%	97%	97%
Ecobee	10%	18%	3%	2%
Honeywell	2%	7%	1%	1%
Other	0%	4%	0%	0%

Figure 2-4 summarizes the timing of smart thermostat installation in PY2018 and PY2019 by PA. While part of this timing may reflect customers' seasonal need to regulate HVAC use, it could also be related to program delivery cycles.

[21] Requirements generally include that devices be two-way communicating and occupancy-sensing. Additional requirements such as schedule learning and capability for weather-enabled optimization are also included.

Figure 2-4. Timing of smart thermostat installations, PY2018 and PY2019



2.2 Evaluation objectives

DNV GL's research objectives in this evaluation were to:

- Estimate the electric and gas savings associated with program year 2019 direct install and rebate programs smart thermostat installations based on program year 2018 installations.
- Determine the extent to which evaluated savings estimates matched claimed savings.
- Estimate free-ridership by measuring which smart thermostat installations would have occurred in the absence of the programs.

DNV GL also sought to understand program participant characteristics, including dwelling type, location, general demographic background, energy-efficiency program participation, and energy consumption behaviors.

3 METHODOLOGY

This section details the approach DNV GL used for the data processing and analysis phases of the smart thermostat evaluation.

3.1 Data sources

DNV GL used the following five sources of data for the evaluation:

- Tracking data: DNV GL sourced information about program participation from tracking data that the PAs filed with the CPUC in the California Energy Data and Reporting System (CEDARS).
- Energy use data: energy consumption data were obtained from the PAs to analyze energy use patterns and changes related to the use of smart thermostats.
- Customer data: Supplementary information on both participating and non-participating customers used in the study was sourced from customer information tables obtained from the PAs.
- Weather data: Weather data were sourced from the National Oceanic and Atmospheric Administration (NOAA) and climate zone 2018 reference temperature files (CZ2018) to include in regression models accounting for weather sensitivity.[22] CZ2018 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.[23]
- Primary research data: The study used data from primary research (surveys) to understand customer engagement with the device and its effect on energy use.

DNV GL had investigated the feasibility of using device data from thermostat vendors in the evaluation in PY2018 and found that all vendors lacked the ability to provide data that could be linked to household and utility energy consumption data. Since it was clear that there was no transparent path to using device data at that time, we did not pursue this issue then or for the current evaluation. DNV GL is still open to working with vendors to see whether there is a way in future evaluations to work with vendor data in compliance with acceptable evaluation methodologies.

Table 3-1 summarizes the various sources of data used in the smart thermostat evaluation in PY2019.

Table 3-1. Data sources used for PY2019 smart thermostat evaluation

Data	Source	Period Covered	Contents
Tracking Data	CPUC Tracking Data	2017-2019	Program information (IDs, claims)
Program Participant Information	PAs	2018-2019	Program details (devices installed, dates, participant contact info)
Billing Data	PAs	January 2017 - June 2020	Monthly consumption data
Interval Data	PAs	January 2017 - June 2020	Hourly electric and daily gas usage data
Customer Data	PAs	2017-2019	Customer location (zip code) and climate zones

22 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.

23 https://ww2.energy.ca.gov/maps/renewable/building_climate_zones.html

Data	Source	Period Covered	Contents
Customer and Property Manager Surveys	Primary Research	2019	Program influence, dwelling characteristics, energy use behavior, demographics
Weather Data	NOAA and CZ2018 from CALMAC	January 2017 - June 2020	Actual and TMY3 California weather data

3.1.1 Program participants

The main source of program participant information is the tracking data filed in the California Energy Data and Reporting System (CEDARS) by PAs.[24] CEDARS provides counts of all program installations and the amount of energy savings these installations are expected to generate.

As noted in section 2.1, smart thermostats were offered by 21 different rebate and direct install programs across California's PAs in PY2018 and PY2019. These programs targeted different population segments and often offered different measure mixes that included smart thermostats. Program tracking data indicate that while many households receiving rebated smart thermostats only installed this measure, households served by direct install programs generally received a mix of measures. Different approaches are required to evaluate the energy use impact of smart thermostats when they are installed alone versus in combination with other measures.

The PY2018 evaluation was a first step in establishing methods for evaluating smart thermostats installed alone. It involved energy consumption analysis centered on single-family homes, which installed only smart thermostats through rebate programs, to estimate smart thermostat savings per household. PY2019 built on the approach used in PY2018 to evaluate this technology among homes that installed smart thermostats through direct install programs.

The natural extension of this effort would have been to estimate savings among homes that installed smart thermostats through PY2019 direct install programs. However, the disruptions to residential routines precipitated by the outbreak of COVID-19 was expected to result in a structural break in energy use in 2020, which is the post period for PY2019 installations. Such a break makes it difficult to determine energy use changes due to smart thermostat installations under typical conditions.

Thus, the primary focus of DNV GL's PY2019 evaluation was on estimating smart thermostat savings among homes that installed this measure in program year 2018 through direct install programs. This effort establishes savings per household that smart thermostats can deliver in settings where they are one among many measures installed. The development of measure-specific savings in cases where multiple measures are installed requires statistical decomposition of whole-house consumption changes into changes due to each measure.

Statistical noise and likely multicollinearity make this a challenging undertaking using statistical regression. A further complication of statistical decomposition of effects of multiple measures is that the physical incremental effect of a single measure (e.g., the smart thermostat) depends on what other measures are also installed. A description of the approach DNV GL used to obtain robust measure-specific savings under these conditions is detailed in section 3.2.5.

[24] https://cedars.sound-data.com/

PY2018 evaluation of rebate installations, along with the extension of that analysis[25] and PY2019 evaluation of direct installations, provide a more complete picture of smart thermostats savings per household available in different housing types and across program delivery channels. In both cases, post periods cover 2018 and 2019. Energy use from this period is unaffected by COVID-19 disruptions. Table 3-2 provides the time periods and comparison group types for different participant groups used in the PY2019 evaluation.

Table 3-2. Smart thermostat evaluation groups and periods in PY2019 evaluation

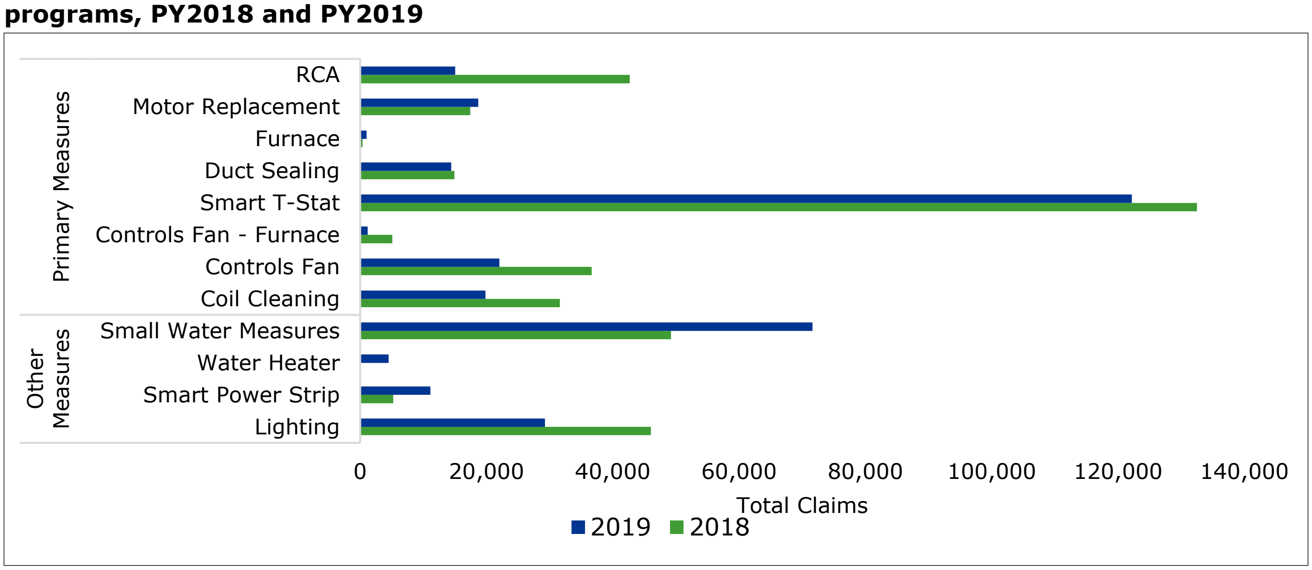
Participant Group	Installation Period	Comparison Group	Post Period
Multifamily Direct Install	2018	Matched comparison group	2019
Mobile Home Direct Install	2018	Matched comparison group	2019
Single-Family Direct Install	2018	Matched comparison group	2019
Single-Family Rebate	2018	Future (PY2019) participants, matched comparison group	2019[26]

3.1.2 Measure bundles

DNV GL assessed the tracking data to understand the measures with which smart thermostats were delivered through direct install programs and to choose the homes that will be included in the smart thermostat evaluation. The tracking data analysis indicates that residential direct install programs offering smart thermostats also installed other residential HVAC and non-HVAC measures.

Figure 3-1 provides the HVAC and non-HVAC measures installed along with smart thermostats, and the number of homes where these were installed in PY2018 and PY2019. Among the HVAC measures installed by these programs, some were chosen for evaluation by the HVAC roadmap in PY2019 (primary measures), but all measures in the figure including others not part of the HVAC or residential evaluations (other measures) were included in the analysis to separate whole-home savings into the relevant constituent parts.

Figure 3-1. Measures and the number of homes receiving measures through direct install programs, PY2018 and PY2019



25 DNV GL updated the PY2018 smart thermostat evaluation to investigate and account for the effect of differential trend in energy use (sign of self-selection issues) among participant and matched comparison households on estimated savings. The link to the full report is: http://www.calmac.org/publications/CPUC_Group_A_SCT_PY_2018_Report_Update_final_toCALMAC.pdf

26 Analysis for post period I, PY2018, completed in March 2020. The link to the full report is: http://www.calmac.org/publications/CPUC_Group_A_Report_Smart_Thermostat_PY_2018_CALMAC.pdf

3.1.3 Energy consumption data

DNV GL obtained consumption data from the PAs for both electricity and gas at multiple levels of granularity: billing month, daily, and hourly. Billing data were primarily used as a means of identifying customers who did not get program-sponsored smart thermostats (non-participants) and whose energy use patterns can help inform baseline energy consumption. Hourly electric and daily data served to fine-tune the identification of non-participants and served as the basis for site-level modeling. Additional information on this process is provided in section 3.2.1. Finally, hourly data were included in models used to estimate the effect of the program/measure on hourly energy demand. Like the other pieces of energy use data, we obtained these from each PA for program participants and selected non-participants.

To prepare the billing data, we screened the data to remove duplicate reads, total zero energy use for the year, and reads that correspond to onsite solar energy production. We also aggregated the billing data to the bill month so that there are 12 reads in a year; billing values that reflect multiple smaller read intervals were summed to the monthly level. We included only customers who have a full year of matching period data in the analysis.[27]

To prepare the daily gas data, we screened the daily data for duplicate reads at the customer and day level and aggregated or removed duplicates depending on the context. We also screened the data for negative values and for values that reflect no gas use (annual value of zero therms) over the analysis time period. Finally, we only included data from customers with full data from the matching period through the evaluation period.

To prepare the hourly electric data, we also used screening procedures. First, we excluded households with onsite solar production because there was no way to determine their true energy consumption given the available data.[28] Second, we excluded days missing more than four hourly reads. Third, we excluded days with zero total consumption.

Finally, for both daily gas and hourly electric data, we included data for only those customers with at least 90% of daily values in both the pre- and post-program period.[29] After screening the data, we checked it against billing records to ensure the integrity of the data.

Table 3-3 presents the number of customers for whom consumption data were considered and used in the study. The table indicates starting household counts from the tracking data considered for use in the evaluation; the number of customers without onsite solar and with daily data available for matching, customers with AMI data and 2018 installation dates, and finally customers with AMI data with the requisite pre- and post-data of at least 328 data available for the analysis. The table provides the breakdown by fuel.

Table 3-3. Smart thermostat customer counts used in the evaluation by PA and fuel type, PY2018

Participant Data Attrition	PG&E Electric	PG&E Gas	SCE Electric	SCG Gas	SDG&E Electric	SDG&E Gas
Customers with measures of interest in the 2018 tracking data	27,759	27,759	70,281	58,227	2,238	2,238
Customers for whom data was requested	25,071	25,071	69,055	57,404	2,033	2,033
Customers for whom some data was received	21,760	18,874	68,823	29,365	2,005	1,538

[27] The full disposition of customer counts used in the analysis is provided in Table 3-3.

[28] Utility records provide net-metered electricity use, which reflects the difference between delivered and received kWh, but not the amount of onsite solar production.

[29] These energy consumption data requirements are in line with CalTrack recommendations. http://docs.caltrack.org/en/latest/methods.html#section-2-data-management

Participant Data Attrition	PG&E Electric	PG&E Gas	SCE Electric	SCG Gas	SDG&E Electric	SDG&E Gas
Customers without onsite solar and the requisite data for second round matching[30]	13,715	13,525	28,948	19,044	1,151	1,270
Customers with sufficient pre- and post-period data	13,473	13,446	28,727	18,749	1,130	1,254
Customers with relevant and sufficient data used in the final analysis	13,473	5,917	28,727	18,749	635	613

We removed bundles with measures (such as split systems and pool pumps) that did not overlap with other measures installed widely among participating homes, which accounts for part of the attrition noted in the last line of the table. The notable drop in PG&E and SDG&E gas participant data is also due to the removal of accounts with negative gas savings claims largely associated with refrigerant charge and coil cleaning and no other gas saving measures. These are expected to affect the HVAC system in the summer but are not likely to have a notable effect on gas savings that can be estimated using consumption data analysis.

3.1.4 Weather data

Observed and typical meteorological year (TMY) data are important inputs for addressing changing weather conditions and their effect on energy consumption. DNV GL sourced hourly weather data for 82 National Oceanic and Atmospheric Administration (NOAA) weather stations across California that provide historical weather observations and for which TMY series were developed, climate zone 2010 (CZ2010) and, more recently, CZ2018. CZ2018 have TMY weather data for select California weather stations that are useful for long-term weather normalization. They are provided on California's Measurement Advisory Council site and update the 2010 typical year weather data to reflect more recent weather trends.[31]

DNV GL applied the following data filtering protocols in line with CalTrack recommendations and used weather data from 73 weather stations that have complete and usable data for the analysis.[32] The filtering protocols include:

- Interpolated gaps for up to six consecutive hours
- Used only daily average data for days missing no more than 12 hourly temperature reads
- Used data from stations that have at least 90% of the data for each year needed in the analysis

Figure 3-2 provides a summary of cooling degree-days (CDD) and heating degree-days (HDD) used in the study. DNV GL used 2018 TMY data to weather normalize consumption in this study. In general, weather normalization controls for the effect of weather variation by putting energy consumption on the same normal weather terms across time.

The 2018 TMY values reflect more recent weather patterns including warmer summers and more mild winters. The figure also indicates that the actual weather CDDs during 2017 and 2018 did not deviate significantly from CZ2018 normal weather CDDs. CDDs were lower in most CZs in 2019. Actual weather HDDs were more variable across the three years and climate zones, with 2019 HDDs higher than in the two prior years for most climate zones. The figure also illustrates areas of the PAs' service territories that have significant cooling needs (CZ13 through CZ15) and heating needs (CZ2 through CZ5, CZ11, and CZ16).

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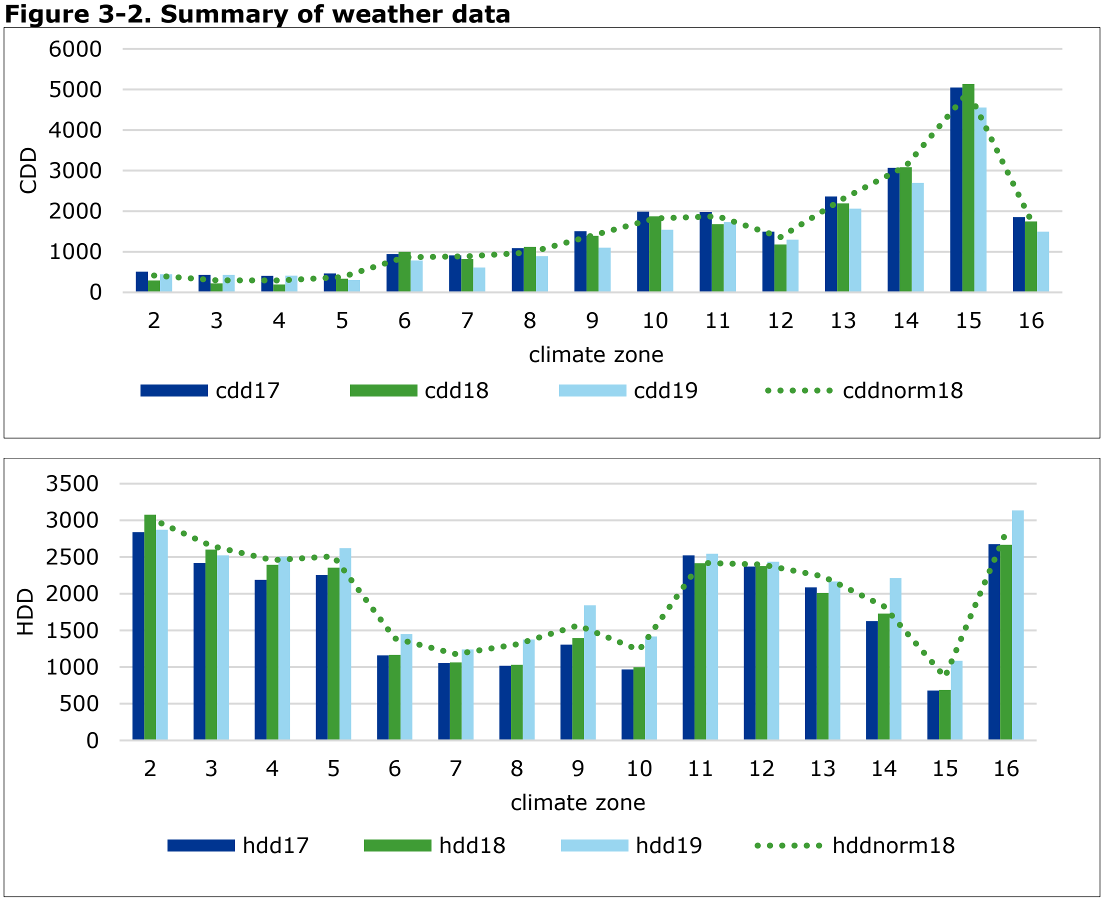
[30] Gas data was not excluded from the analysis for customers with onsite solar.

[31] http://calmac.org/weather.asp

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

Figure 3-2. Summary of weather data



3.1.5 Survey data

DNV GL surveyed participants, non-participants, property managers, and contractors to inform program attribution and provide data that help characterize participants and non-participants in terms of program exogenous characteristics that provide context to savings estimates.

3.1.5.1 Occupant surveys

DNV GL administered participant surveys to customers who are the decision makers for smart thermostat installations in their households and either availed themselves of a program rebate or accepted the free installed thermostat for these installations (participated in smart thermostat programs). The primary objective of these surveys is to inform estimates of free-ridership (and the complementary NTGRs or program attribution estimates). Surveys also gathered information on thermostat use, satisfaction, energy use behavior, and demographics.

DNV GL also surveyed non-participant customers from the matched-comparison group that support the billing analysis. The matched comparison households are a set of customers who have been matched to the participants based on their energy consumption patterns, but who have not participated in smart thermostat or other utility energy efficiency programs. The primary objective of the non-participant surveys is to provide a reference point related to demographics and energy use behavior.

3.1.5.2 Property manager surveys

Direct install programs provide customers with smart thermostats at no cost. For most smart thermostats installed through direct install programs, property managers are the decision makers responsible for smart thermostat installations. DNV GL interviewed property managers to inform free-ridership estimates for direct install programs.

3.2 Gross savings

This section presents the methodology DNV GL used to estimate smart thermostat savings for the direct install programs. The methodology used to estimate smart thermostat savings for rebate programs is provided in the PY 2018 Evaluation. PY2018 savings estimates per household were applied to PY2019 rebate claims by PA and climate zone.

As noted in section 3.1.1, DNV GL used data from PY2018 program participants to estimate direct install thermostat savings based on consumption data analysis and then applied those saving estimates to PY2019 direct install smart thermostat participants. Consumption data analysis provided gross savings per unit separately for single family, multifamily, and mobile homes by climate zone. DNV GL combined PA data in the same climate zone in order to produce a single and consistent savings per household estimate for the climate zone. Using this approach, DNV GL estimated savings per household a year post installation, 2018 through 2019.

The consumption data analysis involved a two-stage modeling that combined variable degree-day PRISM-inspired,[33] site-level models with a matched comparison group to estimate program level estimates in a difference-in-difference (DID) framework. This is a well-established and accepted methodology that is appropriate for the evaluation of energy changes at the home level after an energy efficiency intervention.

The two-stage approach has a long track record in energy program evaluation and is effectively the basis for current methods developed for new pay-for-performance programs in California and beyond. The methodology is attractive for a variety of reasons including:

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

The methodology is also consistent with the approach laid out in the Uniform Methods Project (UMP) Chapter 8 modeling approach, which provides whole-house savings estimation protocols for energy efficiency interventions that have whole-home impacts like smart thermostats.[34] The modeling approach is also closely related to all other forms of program analysis that use energy consumption data including time-series, cross-section approaches. Finally, it is also consistent with CalTRACK's recent effort to develop agreed-upon steps for the site-level modeling portion of the analysis.[35]

The first stage of the approach uses weather data to set energy consumption pre- and post-intervention on equal weather footing to isolate the effect of the intervention from weather effects. The second stage model

[33] Princeton Scorekeeping Method or PRISM is a software tool for estimating energy savings from billing data.

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

[35] CalTRACK specifies a set of empirically tested methods to standardize the way normalized meter-based changes in energy consumption are measured and reported. http://www.caltrack.org/

uses a quasi-experimental method, the best and only option in the absence of a randomized experimental design, to control for non-program related changes.

The two-stage approach relies on the comparison group to control for non-program, exogenous change. It assumes that the comparison group is a reasonable proxy for the counterfactual of the participant group. The intent of matching as a basis for choosing a comparison group is to develop a group that has similar characteristics and can serve this purpose. However, though matched on pre-period consumption and various other characteristics, the approach still must assume that participant and comparison groups have similar underlying trends over time. To the extent there are differential underlying trends, the savings estimates may be biased up or down. The comparison group may over- or under-compensate for the trend in participant consumption over time, over- or underestimating savings in the process. There are no accepted alternatives to this quasi-experimental design approach for this kind of after-the-fact (opt-in) evaluation of a rebate program.

In the sections that follow, we present the construction of matched comparison groups, and site level and DID modeling approaches used to estimate whole-home savings followed by the approach we used to decompose these savings to measure savings.

3.2.1 Matched comparison group construction

DNV GL based its quasi-experimental design on energy consumption data from PY2018 participants and matched comparison non-participants. Matching underpins the construction of matched comparison groups used in this strategy. It involves the identification of non-participant households that are similar to participants in relevant observable characteristics and whose energy use data can be used to form the baseline against which changes in energy consumption due to program intervention can be evaluated. This approach is commonly used when randomized control trial (RCT) is not feasible to estimate the effect of an intervention.

We constructed matched comparison groups from general population customers for the two-stage consumption data analysis. This effort involved two phases. The first phase identified 10 households for every participant with similar energy use levels (based on monthly billing data) and trends (proxied by tenure[36]) within strata defined by characteristics such as dwelling type and geography. In the second phase, 1-to-1 matches were based on interval consumptions data to choose the optimal household from the initial 10 matches.

In all cases, matching models included annual energy use, the ratio of summer-to-winter energy use to account for seasonality, tenure to control for trend, and variables to capture peak demand conditions (6 p.m. kWh, for electricity, and daily therm, for gas, for identified ‘heat wave’ periods). For electricity, ‘heat wave’ periods were identified for each climate zone as weekdays between June through September where most customers had their maximum 6 p.m. kWh. For gas, such periods were based on weekdays from December to February.

DNV GL used Mahalanobis 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

[36] Tenure is the length of time, measured in years, that a customer has resided at a premise. DNV GL's updated PY2018 smart thermostat evaluation to deal with self-selection indicated that tenure is useful proxy for trend in energy use, although its usefulness in matching is limited. http://www.calmac.org/publications/CPUC_Group_A_SCT_PY_2018_Report_Update_final_toCALMAC.pdf

variance of participant to matched comparison households, and visual inspection of the distribution of covariates of participants to matched comparison households.

The standardized mean difference used to test the condition of matches is given by:

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

A standardized mean difference value that exceeds 0.2 shows extreme imbalance, while the closer to 0 this value gets, the better the condition of matching. For the variance ratio, a value close to 1 indicates balance while values that are 0.5 or less and 2 or greater indicate extreme imbalance.[37]

3.2.2 Site-level modeling

DNV GL used a widely applied method based on the PRISM approach to weather-normalize electricity and gas consumption at the individual site level. Weather-normalization makes it possible to determine trends in energy use based on typical or normal weather, effectively removing the impact of yearly weather fluctuations on energy use. The method involves estimating a set of regression models of energy use as a function of weather. The regression model 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 or reference temperature, τ_h.

$C_{im}(\tau_c)$ - Cooling degree-days (CDD) at the cooling base or reference 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.

DNV GL estimated site-level models using daily energy use data and observed weather data from the NOAA. Consumption was estimated over a range of reference temperatures (64°F to 80°F for cooling and 50°F to 70°F for heating) to identify the optimal temperature base points for each site (household. The site-level models produced 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). 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 was put on a typical weather basis, using CZ2018 TMY values, and produced an estimate referred to as normalized annual consumption (NAC). NAC for the pre- and post-installation periods were calculated for each site and analysis time frame by combining the

[37] 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

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:

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

For each home in the analysis, NAC values were determined separately for the pre- and post-installation years, and were the basis of the pre-post difference ΔNAC_i (delta NAC). Delta NAC values were in turn the basis of second-stage DID models.

3.2.3 DID modeling

To determine the whole-home energy consumption effects of direct install programs, DNV GL estimated DID models based on the pre-to-post difference in NAC of participant and the matched comparison households.[38] This model 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 smart thermostat households and 0 for the matched comparison homes. The effect of the program is captured by the coefficient estimate of the term associated with the treatment indicator, $\hat{\beta}$.

Pre- and post-program periods were based on a definition of a blackout period for each participant. According to CalTRACK, a blackout 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."[39]

Based on the CalTRACK recommendation and the IOU-provided tracking data, DNV GL defined a blackout period that reflects installation months reported in the tracking data for all the measures installed by the direct install programs that delivered the measure bundles including smart thermostats. All the sites used in this evaluation indicated no more than two installation months for the mix of measures they delivered. These installation dates were used to define a two-month blackout period.

3.2.4 Gross savings adjustments

Non-participants surveys included a question that asked respondents to indicate whether they had installed smart thermostats before 2019, in 2019, or in 2020. Installations that occurred in 2018 and 2019 overlap with the post period of smart thermostat participant installations. If comparison group smart thermostat installations are assumed to have the same savings effect in the matched comparison households as program thermostats, then their presence during this period will have the effect of diminishing the magnitude of estimated savings for participants. The adjustments made for the PY2019 evaluation are detailed in Appendix G, section 7.7.2.

3.2.5 Decomposition of whole-home savings

Where multiple measures are installed, consumption data analysis can most accurately provide estimates of whole-home savings that occur due to the combination of all the installed measures. The DID models DNV GL estimated provide average whole-home savings by dwelling type, which are expected to vary based on

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

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

the measures installed. DNV GL used statistically adjusted engineering models to decompose whole-home savings to measure-specific savings for homes that received smart thermostats and other measures through direct install programs.

Engineering models that simulate savings for measures and measure bundles offered by the direct install programs form the basis of the decomposition of whole-home savings. The engineering models, discussed in section 3.2.6, are based on the California Database for Energy Efficiency Resources (DEER) residential prototypes. These models provide estimates of the percent reduction in load from typical baseline use by climate zone and housing type, for individual measures and for measure bundles offered by direct install programs.

The relative measure savings (in percent terms) the engineering simulation models provide are both on a first-in (standalone) basis and as part of a bundle on a last-in (incremental/marginal) basis. Results from engineering simulations are used as inputs in statistically adjusted engineering (SAE) models to determine both whole-home savings and decompose these savings to the measure-level. The common SAE model used for these purposes has the following specification:

$$\Delta NAC_i = \alpha_0 + \gamma E_i + \varepsilon_i$$

where E_i, total engineering measure savings received by participant i, replaces the treatment dummy from the whole-home DID model for a more informed estimate of savings.

However, since the size of participant homes vary, we estimated SAE models where the percent change in NAC is explained by percent measure savings provided by engineering simulation models. We also allowed for the possibility that a treatment dummy along with the informed engineering percent savings estimate may be needed to account for constant savings associated with the program installations. The SAE model we estimated is thus specified as:

$$\%\Delta NAC_i = \alpha_0 + \beta T_i + \gamma \%E_i + \varepsilon_i$$

Where

> $\%\Delta NAC_i$ is percent change in NAC (normalized annual consumption) for individual i, defined as (pre-NAC – post-NAC)/pre-NAC
>
> $\%E_i$ is savings of the total measure bundle that participant i received as a percent of typical energy consumption, estimated by the engineering model
>
> T is a treatment indicator variable, which is 1 if i is a participant or 0 otherwise

In this model, the coefficient associated with total engineering percent savings estimate, γ, is an adjustment factor of these savings and the treatment dummy coefficient, β, is an estimate of the constant percent change in NAC across customers with any measure bundle.

Total savings for the home receiving a given measure bundle is given by:

$$S_i = (\hat{\beta} + \hat{\gamma}\%E) * PreNAC_i$$

These estimated savings are converted into measure savings for each participant i based on the relative engineering savings proportions of each measure for that participant. Total measure savings are averages of the measure savings across all participants receiving the measure.

3.2.6 eQUEST engineering modeling

We based our SAE models on engineering simulated values rather than tracking measure savings in order to use the most consistent and accurate dwelling type and climate zone-level estimates of savings as a percent of baseline consumption. The more accurate the relative savings across measure bundle savings and climate zones are, the more effectively the adjustment parameter of the model will scale the variable savings.

We estimated the impacts of simultaneously installed residential measures using DEER prototypes in eQUEST, adjusted based on the best data available from workpapers, studies, and previous evaluation findings. We developed savings estimates by building type and climate zone for each of the residential HVAC measures under evaluation in PY2019. Table 3-4 lists the source we used to adjust the eQUEST inputs for smart thermostats.

Table 3-4. eQUEST model inputs for smart thermostat adjustments

Measure Group	Measure	Sources
HVAC Smart Thermostat	Smart Thermostat	A customized set of baseline schedules and measure schedules were created and applied to eQuest models for simulation. Baseline t-stat schedules were based on RASS 2019 data. After cleaning RASS 2019 data, at least 100 datapoints were used to create an average baseline t-stat schedule (heat + cool) for each climate zone (except for CZ1 and CZ5, neither of which had a statistically significant number of data points, so simulations for these CZs used the average of all other CZs). Measure t-stat schedules implemented an additional setback algorithm based on the existing setback of the baseline t-stat. T-stat setpoints/degrees of setback were then adjusted so that cooling and heating savings were 2% to 3%, in line with PA workpaper estimates.

Once the best available simulation inputs were established, we simulated every combination of measures that occurred in the population. For instance, some households might have received duct sealing and testing, refrigeration charge adjustment, and fan control measures; others might have received only duct sealing and testing. Still others received other measure combinations. For each of these combinations we ran a “last-in” simulation to determine the savings contribution of that measure to that combination. For installed measures where engineering simulation estimates were not developed, we used tracking savings in the SAE models.

3.3 Load shapes

Hourly load and savings shapes estimates provide an understanding of when energy savings (in kW) occur from programs and measures customers install. Such estimates allow the identification of load variation on an 8,760 or average hourly basis. Understanding when savings occur can potentially inform program improvement, determine peak-period impacts for any definition of peak, and indicate the extent to which program energy savings can be used as a resource.

We estimate hourly load and savings shapes for homes that received smart thermostats through direct install programs using customer- or site-level (weather normalization) regression models and an hourly DID method. The site-level hourly regression models we estimated were based on pre- and post-program hourly data and take the following form:

$$Y_{ijh} = \alpha_{sh} + \beta_{sh}^{H} H_{ij} + \beta_{sh}^{C} C_{ij} + \varepsilon_{ijh}$$

Y_{ijh} = consumption for a given customer i for day j and hour h

H_{ij}, C_{ij} = customer-specific heating and cooling degree days from a specified base

α_{sh} = baseload for hour h and season s

β_{sh}^{C}, β_{sh}^{H} = Cooling and heating trends for hour h and season s as a function of degree days

Using model results, hourly estimates of consumption for each day-type in the pre- and post-program period were generated based on the following formula:

$$\hat{Y}_{ijh} = \hat{\alpha}_{sh} + \hat{\beta}_{sh}^{H} \dddot{H}_{ij} + \hat{\beta}_{sh}^{C} \dddot{C}_{ij}$$

$\hat{Y}_{ijh}$ = estimated consumption for a given customer i for day j and hour h

$\dddot{H}_{ij}$, $\dddot{C}_{ij}$ = HDD and CDD based on TMY/CZ2018 and the selected base used in the regression.

We applied this model to a full year of hourly data and seasonal subsets using data from both participant and comparison group (non-participant) households and provided predictions of consumption for all hours of the year based on TMY/CZ2018 weather data.

We then used predicted consumption for all hours from the pre- and post-period in a DID regression to produce an hourly load savings shape. We fit the DID model using the methodology as published in Chapter 17, section 4.4.5 of the Uniform Methods Project.[40] Estimated hourly savings load shape is given by:

$$\Delta Y_{jh} = \left(\hat{Y}_{jh}^{part,pre} - \hat{Y}_{jh}^{part,post}\right) - \left(\hat{Y}_{jh}^{np,pre} - \hat{Y}_{jh}^{np,post}\right)$$

ΔY_{jh} = treatment effect for hour h in day j

$\hat{Y}_{jh}^{part,pre}$ = the average load across participants in the pre-period for hour h in day j

$\hat{Y}_{jh}^{part,post}$ = the average load across participants in the post-period for hour h in day j

$\hat{Y}_{jh}^{np,pre}$ = the average load across non-participants in the pre-period for hour h in day j

$\hat{Y}_{jh}^{np,post}$ = the average load across non-participants in the post-period for hour h in day j

The estimated hourly difference-in-difference estimates in this case have substantial noise, a limitation overcome by using average monthly or seasonal weekday and weekend hourly loads rather than annual 8,760 individual hour loads.

3.4 Program attribution

This study also examined PA program influence on smart thermostat installations to understand what percentage of the installations would have occurred in the absence of the program. Participants that would have installed the same smart thermostats in the absence of the program are called free riders. They are referred to as free riders because they are receiving incentives from programs for actions they would have taken without the programs' existence. Gross smart thermostat savings measure change in energy use due to program participation, regardless of why customers participated, while net smart thermostat savings measure change in energy use without free riders.

[40] NREL. https://www.energy.gov/eere/about-us/ump-protocols

We developed estimates of the ratio of net to gross savings (the net-to-gross ratio or NTGR) to estimate net savings. A NTGR equal to 1.0 indicates that PA-sponsored programs influenced every single smart thermostat installation—none of the program-tracked installations would have occurred in the absence of the program. The difference between the NTGR and 1.0 is the free ridership proportion; for example, 25% free ridership would yield a ratio of 0.75, meaning 75 percent of the installations were attributable to the program and would not have occurred in the absence of the program.

DNV GL surveyed participants who were decision makers for single-family program installations, and participating property managers who were decision makers for direct install programs targeting multifamily properties and mobile home parks. From the survey responses, DNV GL calculated the level of free-ridership and its complement, the proportion of program installations that could be attributed to the program.

DNV GL's approach focuses on assessing three dimensions of free-ridership: timing, quantity, and efficiency. Taken together, these dimensions allow for estimates of net energy (kWh) savings attributable to the measure, because that savings depends on the number of measures installed (quantity), the efficiency of the measures (efficiency), and the duration that the measures are installed (timing).

DNV GL's method of calculating NTGR for a smart thermostat participant assesses two dimensions of free ridership: quantity and timing. The quantity question asks how many units would have been installed absent the program. This question is applicable to property managers who approved installation of multiple thermostats, but not to single-family occupants, who were limited by the programs to a single thermostat per home. The timing question asks how soon the thermostats would have been installed absent the program. The program gets full attribution for any smart thermostat that would not otherwise have been installed at all, and gets partial credit for increasing the number installed, or accelerating the timing compared to when they would have been installed. Section 4.2.1 presents program attribution estimates for the smart thermostat evaluation.

4 SURVEY RESULTS

4.1 Survey approach

DNV GL surveyed PY2019 rebate and direct install program participants (occupants and property managers) and occupants who did not participate in the programs, referred to as non-participants. The primary survey objective was to develop estimates of free-ridership. The survey data also provide information to identify and understand any trends observed in the results from factors outside the program. This information includes participant demographics, dwelling characteristics, as well as changes in energy usage behavior.

The non-participant survey serves as a point of comparison with respect to thermostat use and any self-reported changes in the household that are separate from the program. Non-participants were selected as a random sample from the matched comparison group for the direct install sample. We also conducted surveys among property managers who are the decision makers for installations in the case of direct install programs that serve multifamily properties. The complete surveys are provided in Appendix J. Topics covered by the participant, non-participant, and property manager surveys are summarized below (Table 4-1).

Table 4-1. PY2019 Smart thermostat survey topics – participants, non-participants, and property managers

Survey Topic	Participants	Matched Non-participants	Property Managers
Acquisition/installation year	•	•	•
Rebate received	•		•
Brand and model of smart thermostat installed	•	•	•
Free-ridership questions (overall likelihood, timing, and efficiency)	•		•
Type of thermostat installed previously in the home	•	•	•
Previous and current smart thermostat use	•	•	•
Comfort post smart thermostat installation	•	•	
Satisfaction with the smart thermostat	•	•	•
Participation in demand response program	•	•	
Main heating/cooling system	•	•	
Changes in home: EV, refrigerator, lighting, pool, spa etc.	•	•	
Dwelling characteristics: Own/rent, dwelling type, square footage, building vintage	•	•	•
Demographics: Household size and composition by age, education, primary household language, home ownership, income	•	•	

4.1.1 Survey mode and sample disposition

Participant and non-participant occupant surveys. DNV GL administered web surveys among participants and matched non-participants over an approximate 10-week period from November 2020 to January 2021. The sample frame for participant surveys were customers who had received rebated or direct install thermostats in PY2019. The sample frame for non-participant surveys was drawn from the set of matched comparison households used in the direct install billing analysis. Matched comparison households are a set of non-participants who have been matched to the participants, post-hoc, based on multiple variables including location and energy consumption patterns (see section 3.2.1).

DNV GL attempted a census approach for the participant occupant survey and included all customers with available email contact information who were not on the PAs' do-not-contact list in the final survey sample frame. A random sample from the matched comparison households which included customers with email information and not on the PAs' do-not-contact list was drawn for the non-participant survey. Respondents were offered a $100 lottery incentive to complete the survey. Survey invitees were encouraged to complete the participant and non-participant surveys and two reminders were sent through the survey fielding period.

The surveys included both CPUC and IOU branding to boost customer response. The survey also included a link to a dedicated page on the CPUC website that allowed respondents to validate the sponsor and the legitimacy of the surveys. The sample disposition for the occupant surveys of participants and non-participants is summarized in Table 4-2.

Table 4-2. Sample disposition for participant and non-participant occupant surveys

Occupants (Participants)	PG&E	SCE	SCG	SDG&E
Invites sent	23,701	13,034	28,922	7,902
Not started	20,874	11,273	24,621	6,524
Incomplete	386	303	640	152
Completed	2,441	1,458	3,661	1,226
Response rate	12.2%	11.2%	12.7%	15.5%
Occupants (Non-Participants)	**PG&E**	**SCE**	**SCG**	**SDG&E**
Invites sent	20,310	19,338	19,331	15,710
Not started	18,506	18,114	17,095	13,682
Incomplete	233	175	190	293
Completed	1,662	962	1,150	1,882
Response rate	7.7%	5.4%	6.4%	11.0%

Property manager surveys. DNV GL administered property manager surveys for direct install program installations where property managers served as the primary point of contact at a multifamily building(s) or mobile home park. DNV GL used a mixed-mode approach to administer the surveys. However, due to a poor web survey response rate, non-respondents were subsequently contacted by telephone. Additionally, calls were placed in instances where property managers managed multiple properties. Surveys were fielded for an approximate 6-week period beginning December 1, 2020 through January 14, 2021. The sample frame was constructed from the list of PY2019 properties that received no cost thermostats through direct install programs. Similar to the participant and non-participant surveys described above, DNV GL offered a $100 lottery style incentive for assistance in completing the survey. The sample disposition for the property manager surveys is summarized below (Table 4-3).

Table 4-3. Sample disposition for property manager surveys

Property Managers	PG&E	SCE	SCG	SCE-SCG	SDG&E
Invites sent	430	323	210	31	245
Incompletes	6	2	2	0	0
Completed	73	81	76	7	58
Response rate	17%	25%	36%	23%	24%

4.1.2 Sample weights

DNV GL applied sample weights to balance participant (occupants and property managers) and non-participant survey samples to population proportions by PA, fuel type, climate zone category, and consumption level combination. Details of the weighting procedure are found in Appendix I. Overall, the primary research conducted for this evaluation had balanced survey samples requiring minor corrections for over and under representation by any strata.

4.2 Survey results

4.2.1 Free-ridership and program attribution

The central objective of the smart thermostat participant surveys was to capture participants' self-reported responses that provide information on free-ridership and allow estimation of NTGRs that were then used to adjust gross savings estimates. This self-reported NTGR approach involved asking program participants a series of questions that were aimed at establishing if smart thermostats would have been installed in the absence of program incentives, and if so, the extent to which the installation timing might have differed in the absence of the program. For property managers of multiple homes, the survey also asked if the program increased the quantity of smart thermostats installed. Program incentives for smart thermostats range from $50 to $75. Customers served through direct-install programs receive the smart thermostats for free (100% rebate).

Property manager surveys inform free-ridership estimates in the case of direct install programs where the property manager is the decision maker for multiple smart thermostat installations rather than the occupants in the individual households receiving smart thermostats. In the case of the rebate programs, participant surveys with occupants inform free-ridership. The details of the free-ridership scoring algorithm used are provided in Appendix H.

Participant and property manager survey based free-ridership estimates are weighted by electric PA gross savings claims to arrive at final electric program attribution estimates (Table 4-4). Responses reveal a general pattern of lower levels of free-ridership and higher program attribution of kWh savings for direct install programs relative to rebate programs at 92% - 98% versus 45% - 71%.

Table 4-4. Smart thermostat electric program attribution (NTGR) by PA program, delivery mechanism, and survey

Delivery Mechanism	Program ID	Program Name	PA Gross Savings Claims - kWh	Weight	Survey	NTGR			PA Relative Precision[41] +/-
						Program	Type	PA	
Rebate	PGE21002	Residential Energy Efficiency	1,784,905	23%	Participant	46%	46%	84%	1%
Direct Install	PGE210011	Residential Energy Fitness program	1,844,537	24%	Participant	86%	96%		
	PGE21008	Enhance Time Delay Relay	3,596,787	46%	Property Manager	100%			
	PGE21009	Direct Install for Manufactured and Mobile Homes	525,257	7%	Participant	100%			

[41] Precision is reported at 90% confidence level.

Delivery Mechanism	Program ID	Program Name	PA Gross Savings Claims - kWh	Weight	Survey	NTGR			PA Relative Precision[41] +/-
						Program	Type	PA	
Rebate	SCE-13-SW-001B	Plug Load and Appliances Program	935,192	11%	Participant	45%	45%	88%	1%
Direct Install	SCE-13-SW-001C	Multifamily Energy Efficiency Rebate Program	3,224,391	37%	Property Manager	100%	92%		
	SCE-13-SW-001G	Residential Direct Install Program	2,942,268	33%	Participant	83%			
	SCE-13-TP-001	Comprehensive Manufactured Homes	1,717,470	19%	Participant	99%			
Rebate	SCG3702	RES-Residential Energy Efficiency Program	5,093,137	53%	Participant	71%	71%	82%	3%
	SCG3703	RES-Plug Load and Appliances - POS	4,143	0%	Participant	60%			
Direct Install	SCG3762	RES-CLEO	144,970	2%	Participant	86%	94%		
	SCG3820	RES-Direct Install Program	132,061	1%	Participant	82%			
	SCG3763	RES-MF Direct Therm Savings	2,344,912	24%	Participant	97%			
	SCG3765	RES-Manufactured Mobile Home	1,853,572	19%	Participant	92%			
Rebate	SDGE3203	SW-CALS-Plug Load and Appliances-HEER	300,770	18%	Participant	48%	56%	76%	1%
	SDGE3204	SW-CALS-Plug Load and Appliances-POS Rebates	566,735	34%	Property Manager	60%			
Direct Install	SDGE3212	SW-CALS-Residential HVAC-QI/QM	43,134	3%	Participant	78%	98%		
	SDGE3207	SW-CALS-MFEER	306,446	19%	Participant	100%			
	SDGE3211	Local-CALS-Middle Income Direct Install (MIDI)	16,024	1%	Participant	86%			
	SDGE3279	3P-Res-Comprehensive Manufactured-Mobile Home	415,130	25%	Property Manager	98%			

Participant and property manager survey-based free-ridership estimates were also weighted by gas PA gross savings claims to arrive at final gas program attribution estimates (Table 4-5). As expected, the survey reveals a similar pattern of lower levels of free-ridership and higher program attribution of therms savings for direct install programs relative to rebate programs at 92% - 98% versus 45% - 77%, respectively.

Table 4-5. Smart thermostat gas program attribution (NTGR) by PA program, delivery mechanism, and survey

Delivery Mechanism	Program ID	Program Name	PA Gross Savings Claims (therms)	Weight	Survey	NTGR			PA Relative Precision[42] +/-
						Program	Type	PA	
Rebate	PGE21002	Residential Energy Efficiency	312,485	46%	Participant	49%	49%	73%	1%
Direct Install	PGE210011	Residential Energy Fitness program	189,991	28%	Participant	86%	93%		
	PGE21008	Enhance Time Delay Relay	156,887	23%	Property Manager	100%			
	PGE21009	Direct Install for Manufactured and Mobile Homes	27,245	4%	Participant	100%			
Rebate	SCE-13-SW-001B	Plug Load and Appliances Program	55,681	13%	Participant	45%	45%	86%	0%
Direct Install	SCE-13-SW-001C	Multifamily Energy Efficiency Rebate Program	167,260	40%	Property Manager	100%	92%		
	SCE-13-SW-001G	Residential Direct Install Program	153,909	37%	Participant	83%			
	SCE-13-TP-001	Comprehensive Manufactured Homes	40,836	10%	Participant	99%			
Rebate	SCG3702	RES-Residential Energy Efficiency Program	301,380	39%	Participant	77%	77%	82%	4%
	SCG3703	RES-Plug Load and Appliances - POS	200	0%	Participant	60%			
Direct Install	SCG3762	RES-CLEO	8,429	1%	Participant	86%	86%		
	SCG3836	RES-LADWP HVAC	151,339	13%	Participant	83%			
	SCG3820	RES-Direct Install Program	98,383	20%	Participant	75%			
	SCG3763	RES-MF Direct Therm Savings	172,049	22%	Participant	99%			
	SCG3765	RES-Manufactured Mobile Home	37,719	5%	Participant	92%			
Rebate	SDGE3203	SW-CALS-Plug Load and Appliances-HEER	19,781	22%	Participant	50%	58%	73%	2%
	SDGE3204	SW-CALS-Plug Load and Appliances-POS Rebates	35,453	39%	Property Manager	77%			
Direct Install	SDGE3212	SW-CALS-Residential HVAC-QI/QM	2,582	3%	Participant	63%	98%		
	SDGE3207	SW-CALS-MFEER	24,022	27%	Participant	100%			
	SDGE3211	Local-CALS-Middle Income Direct Install (MIDI)	774	1%	Participant	86%			
	SDGE3279	3P-Res-Comprehensive Manufactured-Mobile Home	8,002	9%	Property Manager	99%			

42 Precision is reported at 90% confidence level.

4.2.2 Demographic profile of participants and non-participants

In addition to informing the proportion of savings the program should get credit for, surveys also provide relevant information on customer characteristics related to energy consumption. DNV GL surveyed occupant participants and non-participants (i.e., customers who did not receive program discounted or free smart thermostats). Non-participants were selected as a random sample from the matched comparison group for the direct install sample.

We provide a summary of the sample composition by dwelling type for the non-participant and occupant participant surveys below (Table 4-6). The occupant participant survey sample reflects a lower composition of multifamily properties at 3% for direct-install and 6% for rebate programs compared to the non-participant survey sample at 23%. DNV GL's property manager surveys represent the complement of multifamily participants where the property manager is the decision maker versus the occupant participants represented in the table below.

Table 4-6. Occupant survey sample composition by dwelling type

Dwelling Type	Non-Participants Matched to PY2018 direct install participants (n=5,656)	Direct Install PY 2019 Occupant Participants (n=2,291)	Rebate PY 2019 Participants (n=3,707)
Single family	66%	79%	88%
Multifamily	23%	3%	6%
Mobile home	5%	10%	0%
Other	1%	1%	0%
No response	5%	7%	5%

The property manager surveys mainly inform program attribution presented previously in Section 4.2.1. Property managers do not have visibility into or knowledge of occupant characteristics or behavior impacting energy use. In the following sections we present insights related to occupants such as their demographic profile, changes in the home that may impact energy use, and how participants use their smart thermostats. These aspects are necessarily only knowable by occupants. Given these differences in sample composition by dwelling type, we contrast non-participants and direct install program participants separately by single family and mobile home occupants. We do not include a comparison between multifamily participants and non-participants as the full range of tenant units, including those where the property manager is the decision maker, is not represented by the direct install participant occupant survey.

Table 4-7 below presents a survey-based demographic profile of the non-participants and participants for single family and mobile home occupants. A comparison of direct install participants and matched non-participants by dwelling type shows a reasonably close match along key demographic lines such as homeownership, building vintage, home size, and income which supports the quasi-experimental design that underlies the billing analysis.

Table 4-7. Demographic profile of non-participant and participant survey respondents

Characteristic	Non-Participants Matched to PY2018, Single Family (n=4,202)	PY2019 Direct Install Participants, Single Family (n=1,760)	Non-Participants Matched to PY2018, Mobile Home (n= 202)	PY2019 Direct Install Participants, Mobile Home (n=269)	PY2019 Rebate Participants, Single Family (n=3,222)
	a[43]	b	c	d	e
Home Ownership					
Own	85%[b]	90%[e]	91%[d]	87%	95%
Dwelling Vintage					
Before 1979	40%[b]	45%	44%	48%	45%
1980-1999	31%[b]	28%	32%	30%	30%
2000 and after	22%	23%	13%	17%	23%
Dwelling Size					
Less than 1,000 square feet	7%[b]	4%[e]	15%[d]	8%	3%
1,000 to less than 2,000 square feet	55%[b]	59%[e]	69%[d]	80%	50%
Greater than 2,000 square feet	33%	33%[e]	6%	4%	46%
Main Heating/Cooling System					
Central gas heater furnace with air conditioning	62%[b]	74%	59%[d]	74%	74%
Other or unknown type central heater with air conditioning	16%	14%[e]	15%[d]	9%	8%
Central heat without air conditioning	9%[b]	4%[e]	15%[d]	9%	13%
Central heat pump (air conditioning and heating)	4%	4%[e]	1%	1%	3%
Income					
Less than $50,000	18%[b]	24%[e]	55%	60%	7%
$50,000 - $100,000	22%	21%[e]	19%	16%	14%
Greater than $100,000	31%[b]	26%[e]	5%	4%	46%
Household Composition by Age					
Household includes member less than 5 years old	10%[b]	15%	2%[d]	4%	16%
Household includes member greater than 65 years old	38%	37%[e]	60%[d]	73%	28%
Household includes member under 5 or over 65	47%[b]	50%[e]	61%[d]	76%	43%
Time-of-Use Rate					
Use currently	18%[b]	13%[e]	8%[d]	14%	30%

Survey results indicate the following significant differences:

Single-family rebate program participants versus single-family direct install program participants (column e vs column b). Compared to single-family direct install program participants, higher proportions of single-family rebate program participants tend to be homeowners (95% vs. 90%), reside in larger homes (46% vs. 33%), and have household incomes greater than $100,000 (46% vs. 26%). This is in line with the high free-ridership observed for rebate program participants relative to direct install program participants

[43] Significant differences in reported statistics between pairs of columns are denoted by superscripts as follows: single-family non-participants versus single-family direct install participants – b, single-family direct install participants versus single-family rebate participants – e, and mobile home non-participants versus mobile home direct install participants – d.

(39% vs 10%). Buying a smart thermostat is something most of the single-family rebate participants would have done even without program incentives. Single-family rebate participants are also more likely to currently be on a time-of-use rate versus single family direct install participants (30% vs. 13%). A lower proportion of single-family rebate program participants have seniors or children in the household compared to single-family direct install program participants (43% vs. 50%).

Single-family direct install program participants versus single-family non-participants (column b vs column a). Compared to single-family non-participants, a higher proportion of single-family direct install program participants are homeowners (90% vs. 85%), live in older homes (45% vs. 40%), have central heat with air-conditioning (88% vs. 78%), have household incomes less than $50,000 (24% vs. 18%), and are in homes with household members aged 5 years or less (15% vs 10%). Single-family direct-install program participants are also less likely to be on a time-of-use rate than single-family non-participants (10% vs. 15%).

Mobile home direct install program participants versus mobile home non-participants (column d vs column c). Compared to mobile home non-participants, a lower proportion of mobile home direct install program participants are homeowners (87% vs. 91%) and live in mobile homes under 1000 square feet in area (8% vs. 15%). Mobile home direct-install program participants are more likely to have central heat with air-conditioning (83% vs. 74%), be on a time-of-use rate (14% vs. 8%), and be in homes with household members aged 65 years or more (73% vs 60%) than mobile home non-participants.

Comparisons between rebate participants and the non-participant group are less meaningful, since the non-participant group was selected to match the direct install program participants.

4.2.3 Changes in home that impact energy use

Respondents were asked to indicate whether they had made any changes in their home since 2019. These changes related to EV charging, refrigerator use, household size, living area, pool use, spa use, and lighting use which could have an impact on energy use. Respondents could indicate changes that could have resulted in either an energy use increase or decrease. For example: When asking about refrigerator use, customers could indicate that they were using an additional refrigerator or that they got rid of/recycled/stopped using an additional refrigerator.

A comparison of actions that increase net energy use[44] between non-participants and direct install and rebate program participants is presented below in Table 4-8. Negative percentages reflect answers that indicate a reduction in energy use. For example, the negative percentage for “Using more lighting” indicates that among mobile home non-participants, more people (9 percentage points) said they were decreasing their lighting use than increasing it.

[44] Net increase is derived as the difference in the proportion reporting an action that would increase energy use and the proportion that report doing the opposite which would result in decreased energy use for that action.

Table 4-8. Changes in home impacting energy use

Net Energy Use Increasing Actions	Non-Participants Matched to PY2018, Single Family (n=4,202)	PY2019 Direct Install Participants, Single Family (n=1,760)	Non-Participants matched to PY2018, Mobile Home (n= 202)	PY2019 Direct Install Participants, Mobile Home (n=269)	PY2019 Rebate Participants, Single Family (n=3,222)
	a	b	c	d	e
Added electric vehicle charging to the home	3%	2%[e]	0%[d]	-1%	7%
Using an additional refrigerator	7%	9%	2%[d]	6%	9%
Household size increased	2%	1%	-1%	-1%	3%
Increased living area/square footage of your home	-1%[b]	2%	-2%	-3%	3%
Added a pool/pool pump	0%	0%	0%	-1%	1%
Added a spa	-1%	-2%	0%	-1%	-1%
Using more lighting	-3%	-2%[e]	-9%[d]	-14%	6%
Note: Negative numbers indicate that the proportion reporting an action that would decrease energy use is greater than the proportion that report an action that would increase energy use.					

Single-family direct install program participants versus single-family non-participants (column b vs column a). These results indicate relatively small differences between the direct install program participants and the matched non-participants for single-family residents. Only one category is statistically different (increase square footage) and the remaining categories suggest a mix of increases and decreases of participant consumption.

Mobile home direct install program participants versus mobile home non-participants (column d vs column c). For mobile home respondents, there are a larger number of statistically different changes with counteracting effects. Mobile home participants increased the use of an additional refrigerator, but decreased consumption in every other category. As noted in section 5.1.3, these differences are expected to have a relatively small effect on the results if, in fact, the survey results fully capture the non-program-related changes at participant and comparison group homes.

Single-family rebate program participants versus single-family direct install program participants (column e vs column b). The table also indicates that single family rebate program participants had statistically significantly higher adoption of electric vehicles (7% vs. 2%) and use of lighting compared to single-family direct install participants (6% vs. -2%).[45] These results are consistent with the observations from Table 4-7 that single family rebate program participants tend to have higher incomes and fit the early adopter profile for emerging technologies like electric vehicles more than single family direct install program participants.

Comparisons between rebate participants and the non-participant group are less meaningful, since the non-participant group was selected to match the direct install participants.

4.2.4 Smart thermostat non-participant and participant user profile

Over one-quarter (26%) of all non-participants indicated that they had a smart thermostat. Of these, roughly half installed their thermostat during the evaluation timeframe, which could potentially lower the

[45] DNV GL found similar results based on PY2018 survey responses that indicated rebate participants reporting significantly higher adoption of electric vehicles compared to direct install program participants.

savings estimates produced using the comparison group approach. The evaluated gross savings estimates for smart thermostats presented in this report include an upward adjustment for installations of smart thermostats among non-participants over the program period, as described in Appendix G, section 7.7.2.

A comparison of direct install and rebate program participants and non-participants who installed their own smart thermostats on how they used the device is summarized in Table 4-9. Results indicate that direct install participants have significantly lower engagement with their smart thermostat.

Table 4-9. Smart thermostat non-participant and participant user profile

Characteristic	Non-Participants (with smart thermostats) matched to PY2018, Single Family (n=1,170)	PY2019 Direct Install Participants, Single Family (n=1,752)	Non-participants (with smart thermostats) matched to PY2018, Mobile Home (n= 41)	PY2019 Direct Install Participants, Mobile Home (n=262)	PY2019 Rebate Participants, Single Family (n=3,219)
	a	b	c	d	e
Previous Thermostat Use					
Set it and forget it	18%[b]	28%[e]	8%[d]	21%	22%
Smart Thermostat Use					
Very or somewhat satisfied with smart thermostat	82%[b]	64%[e]	73%[d]	52%	69%
Use the mobile app to access smart thermostat	71%[b]	54%[e]	50%[d]	33%	74%
Remotely adjust home temperature using app	61%[b]	47%[e]	39%	28%	66%
Pre-cool or pre-heat home using app	16%[b]	11%[e]	3%	6%	21%
More comfortable with new smart thermostat vs previous thermostat	53%[b]	60%[e]	38%[d]	55%	70%
Use auto-away feature (to setback thermostat when sensor does not register activity)	23%[b]	13%[e]	7%	10%	27%
Use the smart thermostat to schedule the HVAC system fan	11%[b]	6%[e]	5%	2%	12%
Enrolled in demand response program since installing smart thermostat	24%[b]	20%[e]	15%	19%	26%
Smart Thermostat Settings					
I have provided some setting preferences and minimal programming of my thermostat	23%	21%[e]	19%	21%	19%
I programmed my thermostat settings per my schedule and comfort needs	59%[b]	39%[e]	40%	32%	54%
Contractor/installer programmed the settings	5%[b]	12%[e]	3%[d]	14%	2%
I use factory default settings	5%[b]	9%[e]	14%	8%	7%
Demographics					
Dwelling built in 1980 or after	59%[b]	50%[e]	47%	47%	53%
Income above $100,000	41%[b]	26%[e]	5%	5%	46%
Home size above 2,000 square feet	41%[b]	33%[e]	15%[d]	4%	46%
Own	91%	90%[e]	94%	87%	95%

The results presented below indicate that program participants differed in how they engaged with their smart thermostats, but the effect of this differential engagement on savings is unclear. As expected, results indicate that those who bought smart thermostats themselves, either through rebate programs or outside of

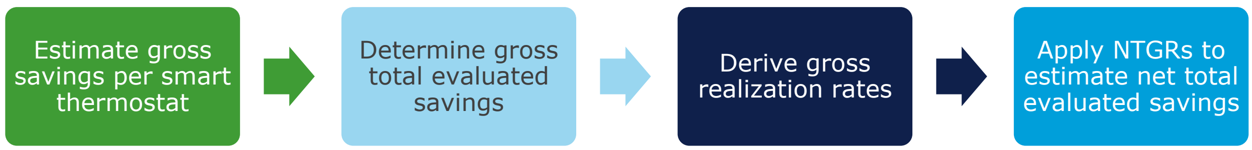
PA programs, were more inclined to do something proactive with the device than those who received smart thermostats through direct install programs.

- Single-family and mobile home direct install program participants describe their previous thermostat use as “set it and forget it” at higher proportions (28% and 21% respectively) compared to single family and mobile home non-participants with smart thermostats (18% and 8% respectively). Furthermore, they describe a more hands-off approach with their new smart thermostat as well with single family and mobile home direct install program participants stating they have programmed their thermostat per their schedule and comfort needs in lower proportions compared to single family and mobile home non-participants with smart thermostats at 39% and 32% versus 59% and 40% respectively.
- Use of the "auto-away” feature is lower at 13% for single family direct install program participants compared to 23% for single family non-participants with smart thermostats and 27% for single family rebate program participants. This feature adjusts temperature setpoints when the smart thermostat sensor does not register activity thus delivering savings. Limited use of this feature reduces this opportunity for savings.
- Use of the mobile app is lower at 47% for single family direct install program participants compared to 61% single family non-participants with smart thermostats and 66% for single family rebate program participants. This lower engagement implies less information for the learning algorithm to draw upon as it continues to optimize the thermostat to deliver energy savings.
- Program participants report greater comfort in the home after installation of the smart thermostat at 60% for single family direct install participants and 70% for single family rebate program participants versus 53% for single family non-participants with smart thermostats. We see a similarly higher proportion of mobile home direct install participants reporting being more comfortable in their homes than mobile home non-participants with smart thermostats at 55% vs. 38%, which could be indicative of takeback among participants.
- Single family direct install program participants report enrollment in demand response programs in lower proportions than single family rebate program participants and single-family non-participants with smart thermostats at 20% compared to 26% and 24% respectively. Demand response programs reduce consumption during times of high demand and are likely to provide a modest contribution to energy savings.

5 IMPACT RESULTS

This section presents estimated electric (kWh) and gas (therm) savings from program smart thermostats by housing type and climate zone. Separate estimates of the effect of a smart thermostat installation are provided for measures delivered by direct install and rebate programs. Savings estimates per unit are used together with tracked installation counts to generate gross evaluated savings and gross realization rates by PA and statewide. Net evaluated savings for each PA are estimated by applying NTGRs to gross evaluated savings (Figure 5-1).

Figure 5-1. Impact evaluation approach



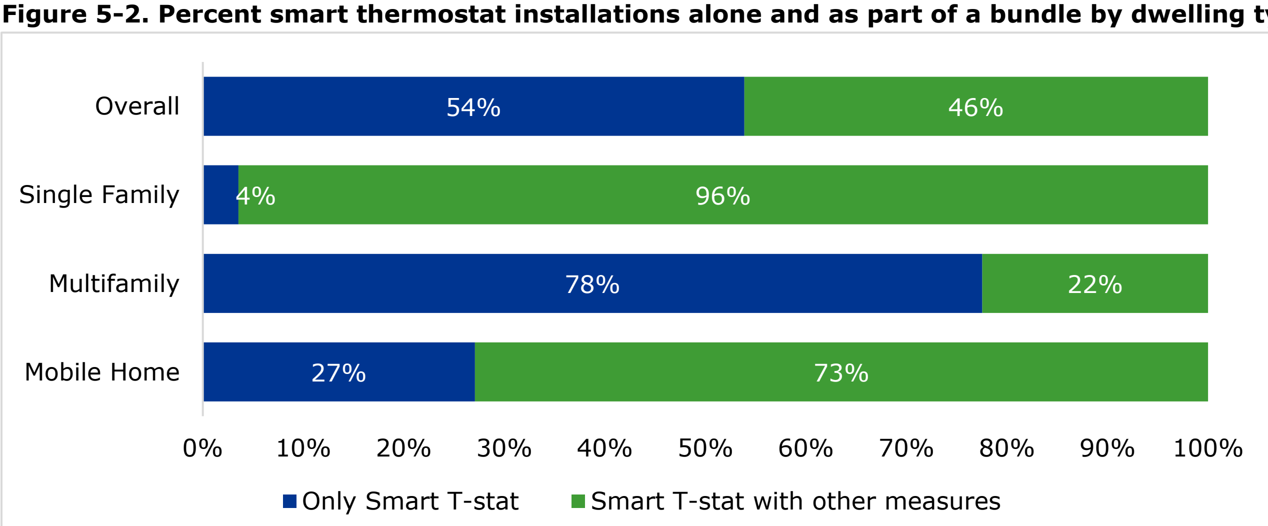
5.1 Direct install results

This section provides results from smart thermostats offered by direct install programs. The programs offered smart thermostats either alone or as part of a bundle for no to low cost to customers.

5.1.1 Direct install delivery

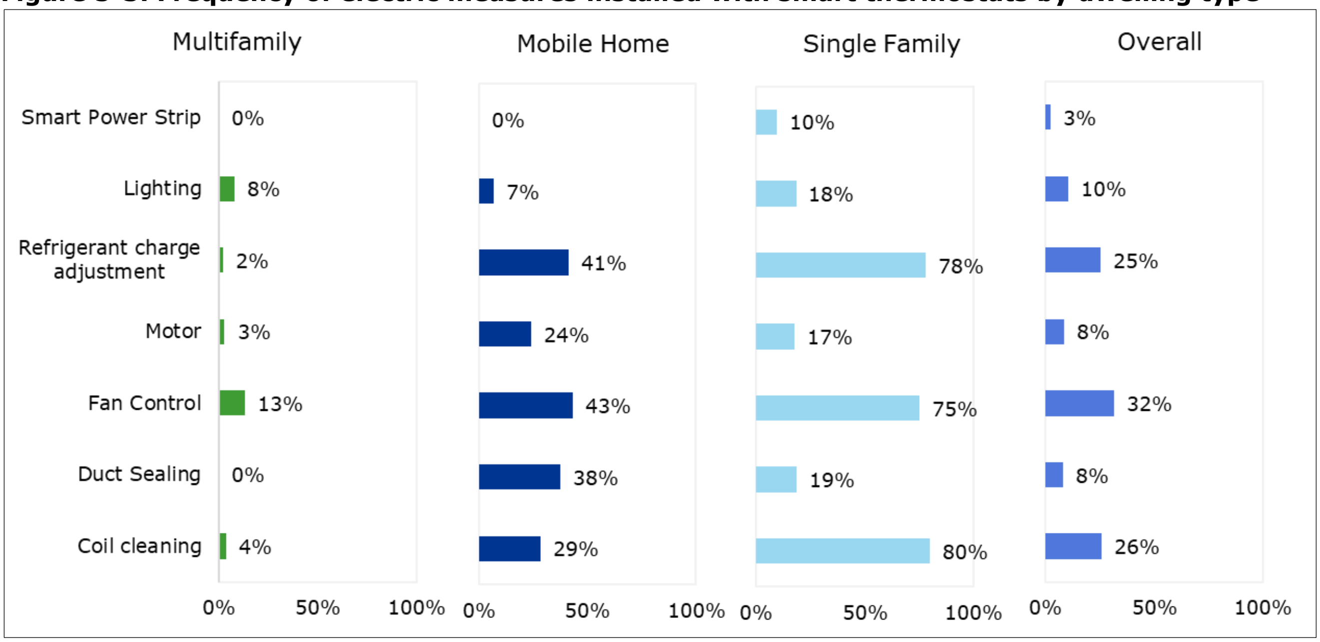
Direct install programs offered smart thermostats as part of a bundle of HVAC and other energy efficiency measures. Some households received smart thermostats in combination with other measures, but a subset received these alone. The frequency with which smart thermostats were installed alone or in combination with other measures varied by dwelling type statewide. Figure 5-2 provides the percent of installations with electric savings claims delivered alone and in combination with other HVAC measures by dwelling type. Statewide, smart thermostats were installed alone in half of the households that direct install programs reached. Smart thermostats were installed as part of other HVAC bundles most commonly in single family homes, while they were delivered alone most commonly among multifamily homes.

Figure 5-2. Percent smart thermostat installations alone and as part of a bundle by dwelling type



The frequency and types of other measures with which smart thermostats were installed also varied by housing type. Overall, smart thermostats were most frequently installed with fan motor controls, which are designed to extract the remaining cooling or heating potential from the HVAC system by delaying the shutdown of the fan motor at the end of an air conditioning or heating cycle. Smart thermostats were also delivered with coil cleaning and refrigerant charge adjustment (maintenance measures that are undertaken to improvement the operation of the HVAC system), duct sealing and high efficiency HVAC motor replacements. Efficient lighting and smart power strips, on the electric side, and small water measures (including aerators and showerheads) and water heaters, on the gas side, were the other non-HVAC measures that were installed with smart thermostats. Figure 5-3 illustrates the frequency of other electric measures installed with smart thermostats by dwelling type.

Figure 5-3. Frequency of electric measures installed with smart thermostats by dwelling type



5.1.2 Engineering estimates

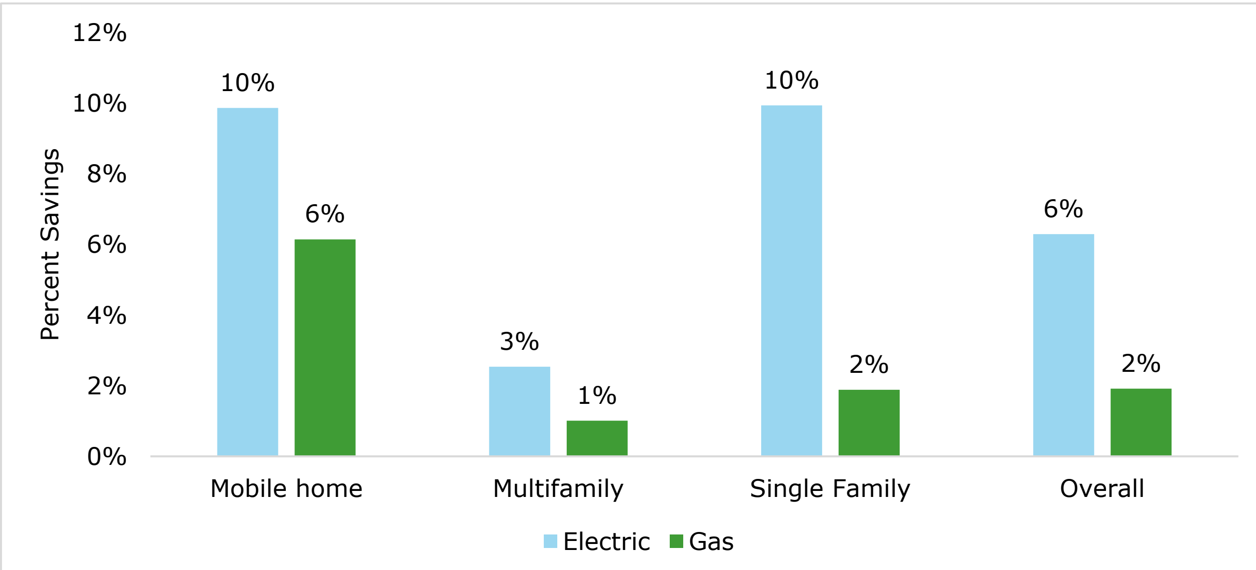
Values from engineering simulation models formed an important foundation of both the models used to estimate whole-home energy use changes and the decomposition of these changes into measure-level estimates. Engineering estimates use a simulation engine to produce prototype models based on certain parameters that reflect multiple scenarios, including dwelling type, climate zone, and retrofits.

The simulation prototype models provide estimates of typical energy consumption and expected consumption changes by climate zone for single family, multifamily and mobile homes that received different combinations of energy efficiency upgrades.

As indicated in section 3.2, the starting point for our evaluation of direct install programs was estimating weather-normalized energy consumption changes among treatment homes that received direct install measures compared to similar homes that had no such intervention. We then modeled weather-normalized whole-home pre-post percent change in consumption as a function of simulated percent savings for the home’s measure bundle. The model also included a general treatment term as a predictor of pre-post energy use change.

The sum of installed measure savings (obtained from engineering prototypes for HVAC measures and tracking data for non-HVAC measures) out of typical consumption of the home used in the prototype are used to calculate percent simulated savings. Figure 5-4 provides the percent electric and gas expected savings obtained from the engineering estimates by dwelling type that were used in whole-home percent savings models.[46] These models were the basis for adjustment factors of the savings realized from the measure installations delivered by the direct install programs.

Figure 5-4. Percent engineering savings per household, PY2019



While total simulated percent savings inform whole-home savings, the engineering measure savings as percent of the bundle of measures installed are used to allocate the estimated whole-home savings to different measures. Table 5-1 provides the smart thermostat savings as percent of all installed measures used to allocate whole-home savings are by dwelling type and climate zone. These percentages vary based on the number of other measures installed. For example, the table indicates that for electricity, 20% of mobile home whole-home savings and 100% of the multifamily whole-home savings were allocated to thermostats based on the engineering estimates in climate zone 2.

Table 5-1. Smart thermostat simulated electric savings allocator by dwelling type and climate zone

Climate zone	Mobile home	Multifamily	Single family
CZ02	20%	100%	0%
CZ03	13%		21%
CZ04	27%		12%
CZ05	36%		0%
CZ06	26%	98%	22%
CZ07	53%	0%	11%
CZ08	19%	97%	20%
CZ09	19%	94%	17%
CZ10	20%	79%	10%
CZ11	21%	43%	20%
CZ12	17%	69%	13%

46 We refer to all the estimates used as inputs to the models, whether from the new simulations or from tracking, as "engineering" estimates of savings.

Climate zone	Mobile home	Multifamily	Single family
CZ13	26%	46%	10%
CZ14	29%	47%	11%
CZ15	21%	69%	15%
CZ16	12%	71%	9%
Average	**21%**	**80%**	**12%**

5.1.3 Smart thermostat electric savings estimates

Discussion of model savings estimates are provided in Appendix G, 7.7.1.[47] In this section we provide estimates of whole-home and smart thermostat electric savings from direct install programs based on the models.

For direct install programs, smart thermostats were often installed as part of a bundle of other HVAC and non-HVAC technologies. Average estimated electric savings per home, which includes the savings for all technologies installed at the same time, are 70 kWh, 115 kWh and 132 kWh or 1% to 2% of total annual electricity use. A portion of these savings are due to smart thermostats (Figure 5-5).

Figure 5-5. Average electric whole-home and smart thermostat savings, PY2019 direct install programs

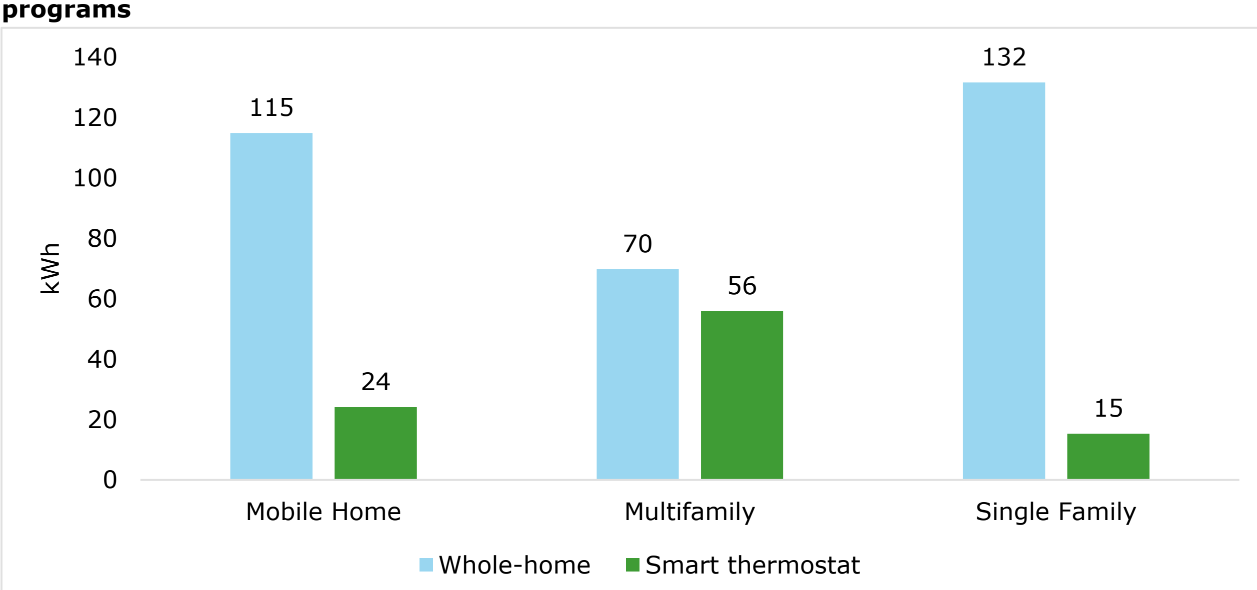


Table 5-2 provides whole-home and smart thermostat savings for direct install programs by climate zone. The results for single family and mobile homes vary by climate zone because the engineering estimates of smart thermostat savings vary by climate zone, and the statistical analysis produces whole-house savings nearly proportional to the bundled engineering estimates. Thus, for example, higher savings are seen in the hot climate zones 13 and 15 for single family and mobile homes. For Multi-family homes, the statistical results show little variation in savings related to the engineering estimates, resulting in relatively flat savings across climate zones.

[47] Average annual electric load and its components are provided in Appendix F.

Table 5-2. Whole-home and smart thermostat electric savings for direct install programs, PY2019

Climate zone	Whole-home Savings (kWh)			Smart Thermostat Savings (kWh)		
	Mobile Home	Multifamily	Single Family	Mobile Home	Multifamily	Single Family
CZ02	75	58	25	15	58	
CZ03	64		41	8		9
CZ04	89		101	24		12
CZ05	36		5	13		
CZ06	70	53	78	18	52	17
CZ07	53	94	53	28		6
CZ08	94	58	57	18	57	11
CZ09	104	69	95	19	65	16
CZ10	113	72	127	22	57	13
CZ11	128	67	106	27	29	21
CZ12	115	60	104	19	41	14
CZ13	123	102	162	32	47	17
CZ14	98	70	167	28	33	18
CZ15	181	93	185	38	64	28
CZ16	138	69	95	17	50	9
Average	115	70	132	24	56	15

The results also reflect a varying mix of measures delivered by the programs across dwelling types and climate zones. The mix of measures installed by the programs has an effect on the realized savings of smart thermostats and is also one of the challenges of evaluating the effect of the device. While our consumption data analysis provided whole-home savings that occurred as a result of the measures put in by the direct install programs, our attempt to disaggregate savings statistically using measure-level consumption regressions did not produce reliable results. We apportioned the estimated whole-home savings to measure savings in proportion to the engineering savings estimates.

While it is uncertain as to how much of the whole-home savings is due to each measure, the total whole-home savings represent a practical cap on the possible smart thermostat savings. Smart thermostat savings could, in principle, be more than the whole-home savings if the other measures combined produce negative savings (increased usage). That would require substantial takeback for the other measures but not for smart thermostats, and there’s no basis for such an assumption.

Survey results in section 4.2 indicate some slight but statistically significant differences between the 2019 direct install participants and their comparison group in actions that might increase energy usage. Analysis in Appendix G (section 7.7.3) shows that even if these non-program effects somewhat reduce the estimated whole-house program savings, their combined effect would not materially change the savings results.[48] We have not formally included these effects as an adjustment to the savings, because the estimates are rough, the differences are small, and the survey results are for 2019 participants not the 2018 participants that are the subject of the consumption analysis. Moreover, results in Appendix E show that the comparison group is

[48] Weighting the differentials in program exogenous changes between participants and non-participants that impact energy use based on RASS 2019 end-use consumption values indicates that the differences in these exogenous factors could account for, at most, a 20% increase in electric savings at the whole-home level. Therm whole-home effects are negligible. Given the proportional break out of savings, only 3 kWh of possible bias related savings would accrue to the smart thermostats.

well matched to the direct install participants across a wide range of characteristics beyond the variables explicitly used for matching.

Thus, the smart thermostat estimates shown represent our best estimates accounting for the contributions to savings of all measures delivered to the homes. Figure 5-3 provides the technologies delivered with smart thermostats by direct install programs among the different dwelling types. It indicates that certain technologies were most commonly installed with smart thermostats in some dwelling types, which might have a bearing on the savings smart thermostats were able to deliver.

In single family homes, smart thermostat installations largely overlapped with the delivery of refrigerant charge adjustment (RCA), coil cleaning, and fan controls. Among mobile homes, smart thermostats installations also overlapped to some degree with duct sealing, high efficiency HVAC motors, and fan controls. These overlaps, particularly with fan controls, could have reduced smart thermostat electric savings.[49]

Most multifamily homes received only smart thermostats, resulting in a savings estimate for this technology that is close to the multifamily whole-home savings estimate. While electric savings for smart thermostats are higher for multifamily than for single and mobile home participants, they are still lower than claimed.

5.1.4 Smart thermostat gas savings

Average estimated gas savings per household for the direct install programs indicate a statistically insignificant change or increase in gas consumption associated with smart thermostats alone or in combination with other technologies. Appendix G, section 7.7.1 provides supplemental results of gas consumption in homes that received only smart thermostats. The results indicate savings were negative (increased consumption), but not statistically significant. The prior evaluation of the rebate program found very low savings for gas, negative for some climate zones. Other studies of smart thermostats have also found minimal gas savings. Thus, a finding of negligible smart thermostat gas savings is reasonable. We therefore assess the gas savings for thermostats as 0 and assign all gas savings from homes that had other measures to those other measures.

5.2 Rebate program results

PAs claimed smart thermostat savings from both direct install (70% of claims) and rebate programs (30% of claims) in PY2019. For rebate program participants, the PY2019 evaluation uses savings per whole-home from the consumption data analysis DNV GL undertook for the PY2018 evaluation, together with 2019 participant counts, by PA, dwelling type, and climate zone. The PY2018 analysis addressed rebate participants only, and the consumption data analysis included only homes that participated in no other program. This approach was taken because the program measure was new, and the single-measure analysis provided the best prospect for developing reliable estimates using consumption data analysis.

The application of 2018 whole-home savings to 2019 rebate installations resulted in 2019 weighted kWh and therm savings for smart thermostats. Table 5-3 provides the distribution of participants and the updated unit savings estimates per smart thermostat in 2019. A majority, almost 75%, of rebate participants were single

[49] Low electricity savings for smart thermostats possibly reflect competing effects of fan controls and smart thermostats, both of which are capable of delaying fan turn-off and were installed together. Similar to what fan controls do, smart thermostats have a feature that uses the fan to spread remaining cool air in the HVAC coils through a home after switching off the air-conditioner compressor.

family residents in 2019 and statewide effective electricity and gas savings per unit were estimated at 54 kWh and almost 3 therms per smart thermostat.

Table 5-3. Effective 2019 savings per unit for rebate participants

Dwelling Type	Percent Participants	Unit Savings kWh	Unit Savings therms
Mobile home	<1%	77.7	8.4
Multifamily	26%	49.8	0.3
Single family	74%	55.8	3.6
Statewide		**54.3**	**2.7**

5.3 Comparison of rebate and direct install savings

Savings per smart thermostat from rebate and direct install programs by PA is summarized in Table 5-4. In all cases, smart thermostat savings from direct install programs are lower than those achieved by rebate programs. This lower performance among direct install participants likely results from several factors. First, the direct install homes tended to be smaller and have lower initial consumption than the rebate homes, reflecting the large numbers of multi-family units. Direct install participants were also less engaged with the smart thermostats, so that the devices may have been less well deployed to produce savings. Direct install customers were also less likely to install a smart thermostat on their own and paid little to nothing for the device they received. Finally, as noted, there is evidence that fan controls installed together with smart thermostats may have resulted in competing controls that reduced their combined effectiveness.

Table 5-4. Final estimated rebate and direct install electric and gas per smart thermostat by PA and statewide

PA	Electric Savings (kWh)			Gas Savings (therms)		
	Single Family Rebate 2018	Single Family Rebate 2019	Direct Install	Single Family Rebate 2018	Single Family Rebate 2019	Direct Install
PG&E	90	64	34	7.7	8.0	0
SCE	80	68	43	0.9	1.9	0
SCG	61	54	51	0.9	0.2	0
SDG&E	36	25	30	2.9	2.4	0
Statewide	**72**	**54**	**43**	**2.1**	**2.7**	**0**

5.4 Total program savings

5.4.1 Electric savings

Table 5-5 provides the number of households with electric service that received a smart thermostat through both direct install and rebate programs, the total gross claimed electric savings, and the total gross evaluated electric savings. Our evaluation found that smart thermostats installed through the program achieved 6.4 GWh of electric savings, which is 23% of expected or claimed savings (gross realization rate). Total gross savings are further adjusted to reflect the portion of savings that can be attributed to program influence. Our evaluation indicates that, statewide, direct install and rebate programs caused electric savings of 5.0 GWh. Our evaluation indicates that overall program attribution is 79% with direct install NTGR that is in line with claimed attribution at 94% and rebate NTGR that is higher than claimed at 60%.

Table 5-5. Total smart thermostat electric savings, 2019

Program Administrator	Program participants (electric)	Total Gross Claimed Savings (kWh)	Total Gross Evaluated Savings (kWh)	Gross Realization Rate	Evaluated NTG Ratio	Total Net Evaluated Savings (kWh)
Direct Install Programs						
MCE	77	8,876	1,234	14%	96%	1,185
PG&E	21,388	5,966,581	734,509	12%	96%	705,128
SCE	34,767	7,884,130	1,487,181	19%	92%	1,368,206
SCG	25,063	4,475,515	1,277,652	29%	94%	1,200,993
SDG&E	2,295	780,735	68,298	9%	98%	66,932
Direct Install Total	*83,590*	*19,115,836*	*3,568,874*	*19%*	*94%*	*3,342,445*
Rebate Programs						
PG&E	13,730	1,784,905	881,880	49%	46%	405,665
SCE	4,357	935,192	295,138	32%	45%	132,812
SCG	27,042	5,097,280	1,465,677	29%	71%	1,040,631
SDG&E	6,581	867,506	164,065	19%	56%	91,877
Rebate Total	*51,710*	*8,684,882*	*2,806,760*	*32%*	*60%*	*1,670,984*
Statewide Total	**135,300**	**27,800,718**	**6,375,634**	**23%**	**79%**	**5,013,429**

Note: The electric savings per smart thermostat that underpin the gross savings are based on estimates by dwelling type and climate zone.

5.4.2 Gas savings

The number of households with gas service that received a smart thermostat through both direct install and rebate programs, the claimed gas savings, and the savings that they achieved is shown in Table 5-6. Our evaluation indicates gas savings of 140,291 therms that are 7% of expected or claimed savings (gross realization rate). Total gross savings are further adjusted to reflect the portion of savings that can be attributed to smart thermostat installations, which indicates that overall program attribution is at 51%.

Table 5-6. Total smart thermostat gas savings, 2019

Program Administrator	Program participants (gas)	Total Gross Claimed Savings (therms)	Total Gross Evaluated Savings (therms)	Gross Realization Rate	Evaluated NTG Ratio	Total Net Evaluated Savings (therms)
Direct Install Programs						
MCE	77	1,687	0	0%	93%	0
PG&E	21,388	374,124	0	0%	93%	0
SCE	34,767	362,005	0	0%	92%	0
SCG	50,460	467,919	0	0%	86%	0
SDG&E	2,294	35,379	0	0%	98%	0
Direct Install Total	*108,986*	*1,241,114*	*0*	*0%*	*90%*	*0*
Rebate Programs						
PG&E	13,770	312,485	110,817	35%	49%	54,300
SCE	4,357	55,681	8,229	15%	45%	3,703
SCG	27,045	301,580	6,585	2%	77%	5,071
SDG&E	6,040	55,234	14,660	27%	58%	8,503
Rebate Total	*51,212*	*724,980*	*140,291*	*19%*	*51%*	*71,577*

Program Administrator	Program participants (gas)	Total Gross Claimed Savings (therms)	Total Gross Evaluated Savings (therms)	Gross Realization Rate	Evaluated NTG Ratio	Total Net Evaluated Savings (therms)
Statewide Total	**160,198**	**1,966,095**	**140,291**	**7%**	**51%**	**71,577**

Note: Gas savings per smart thermostats that underpin the gross evaluations are based on estimates by dwelling type and climate zone.

5.5 Direct install program whole-home and smart thermostat load savings shapes

This section provides summaries of hourly load and savings shapes from homes that installed smart thermostats and other measures offered through direct install programs.[50] The analysis is based on DID estimates using weather normalized hourly (AMI) electricity data. Last year's smart thermostat evaluation report provided similar analysis for smart thermostat measures provided in rebate programs.[51]

We provide summaries of whole-home load and savings shapes that reflect the combined effect of all the residential HVAC measures installed by the programs. The multiple measure installations that made the estimation of direct install program annual impacts difficult are also a challenge for hourly savings shapes. Rather than proportionally distribute whole-home savings shapes to individual measures, we also provide savings shapes that rely on the subset of customers who only installed smart thermostats through the direct install programs.

In the following subsections, we first provide summaries of whole-home hourly load shapes before and after measure installations. This is followed by a presentation of summary savings shapes that reflect the DID estimates of whole-home hourly savings for customers that received direct install smart thermostats in combination with other measures or alone.

We also provide smart thermostat savings shape using data from multifamily customers that received only smart thermostats through the direct install programs. Because this savings shape is based solely on AMI data as opposed to simulation models, it is the most informative smart thermostat-only savings shape available from this analysis. It can also serve as the savings shape for smart thermostats across all cases given the lack of better alternatives, although there are likely differences among the underlying smart thermostat savings shapes by dwelling type.

5.5.1 Whole-home hourly load shapes

Figure 5-6 provides weather normalized average hourly electric load shapes for households that installed smart thermostats under direct install programs in combination with other measures or alone. The plots include both treatment (solid line) and comparison group (dashed line) households in each panel, with separate rows for pre- and post-installation periods. The average hourly load shapes reflect electricity usage from single family (26%), multifamily (65%) and mobile home (9%) participants and their matches.

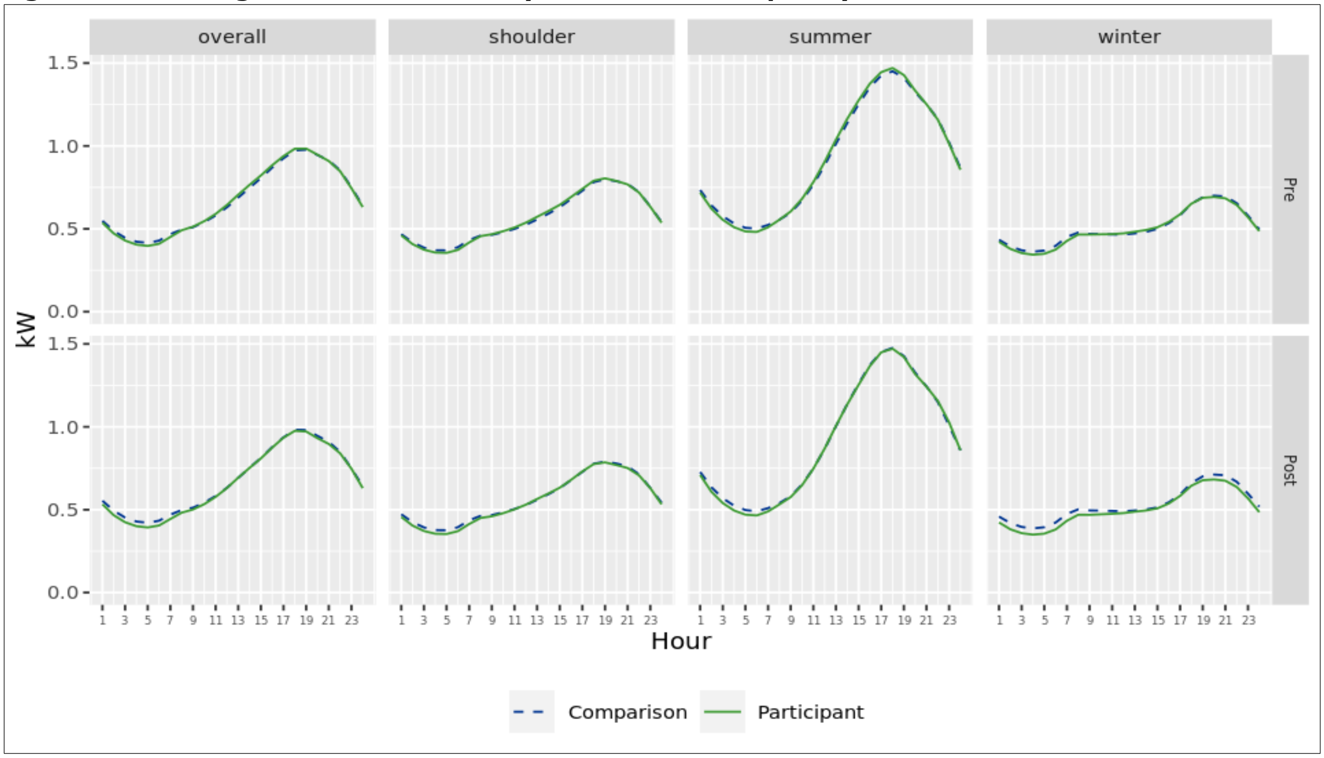
The figure indicates that average daily electric load peaks for both groups and all periods at 6 p.m., with highest usage in the summer (June through September) and lowest in the winter (December through February) seasons. The observed peak hours are in line with the updated DEER 2019 peak period definition of 4 p.m. to 9 p.m.

[50] As we indicate in earlier sections of the report, direct install programs that offered smart thermostats also installed other HVAC (such as efficient HVAC motors) and non-HVAC measures (such as lighting) that contribute to whole-home savings. We include homes that installed smart thermostats alone or in combination with other measures to limit differences across dwelling types as much as possible.

[51] The link to the full report is: http://www.calmac.org/publications/CPUC_Group_A_Report_Smart_Thermostat_PY_2018_CALMAC.pdf

The pre-installation average hourly load shapes indicate energy use that is highly similar between treatment and comparison group households in all seasons. The separation in energy use between treatment and comparison group homes in the post-installation period is also small (but most visible for the winter season) and is the basis of hourly savings shapes we present in the next section.

Figure 5-6. Average whole-home hourly electric load shapes by season



5.5.2 Hourly savings shapes

We use the DID approach presented in section 3.3 to estimate hourly whole-home savings. We produce savings shapes for all dwelling types that installed smart thermostats with other measures and for multifamily homes that installed smart thermostats alone.

Figure 5-7 provides whole-home average hourly savings by season for participants that installed smart thermostats with other measures. The panels indicate:

- Average hourly savings range from approximately -0.03 to 0.03 kW
- Summer savings shapes reflect expected cooling-related energy use reductions that peak early-afternoon and decline, with dissavings in the evening
  - Summer savings are highest in the early afternoon (from 1 p.m. to 4 p.m.)
  - Summer savings are lower but still substantial in late afternoon and early evening hours of 4 p.m. to 8 p.m.
  - Savings drop to zero or become negative until the end of the day as residents appear to be making up for foregone cooling during earlier peak hours where savings are positive. This is consistent with

greater setbacks when homes are unoccupied during the afternoon with associated "recovery" once occupants return.

- Winter period savings are flatter and likely reflect heating-related savings. The modest increase in savings overnight and lack of increased savings during the day make it less likely that savings result from aggressive setbacks while sleeping or away rather than a general lowering of setpoints across all hours.
- Shoulder savings are lower than savings during either summer or winter. These savings may reflect a mix of cooling and heating savings that occurred during the shoulder months or savings from measures with less weather correlated load. The reduction of savings during the late evening hours parallels the cooling savings indicating the likely presence of at least some cooling-related savings.

Figure 5-7. Direct install whole-home average hourly savings by season for all housing types

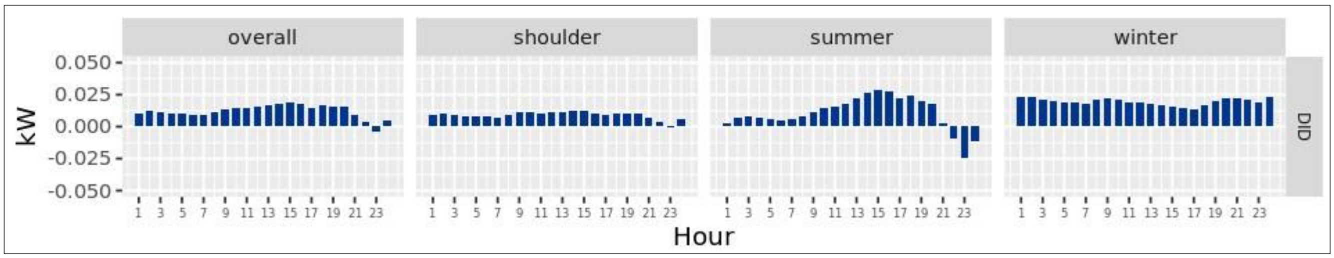


Figure 5-8 through Figure 5-10 provide average hourly savings shapes by season for single family, multifamily and mobile homes that received smart thermostats through direct install programs. There are similarities in the hourly savings shapes among the three dwelling types where smart thermostats and other measures were installed in different combinations.

All the summer shapes in the three dwelling types have peak load reductions between 2 and 3 p.m. with associated dissavings later in the evening. Multifamily dwellings maintain modest savings overnight while single family and mobile homes do not. Single family savings also last longer into the evening. These differences reflect some combination of dwelling type heating and cooling dynamics and the different measure mix delivered to each dwelling type.

Figure 5-8. Direct install whole-home average hourly savings by season for single family homes

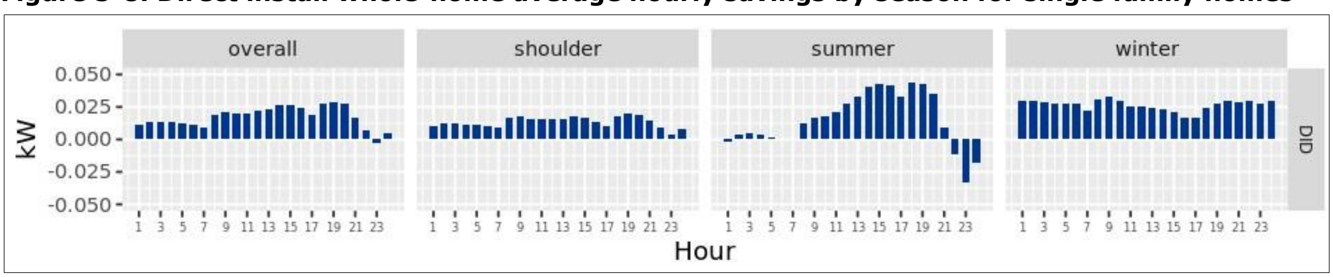


Figure 5-9. Direct install whole-home average hourly savings by season for multifamily homes

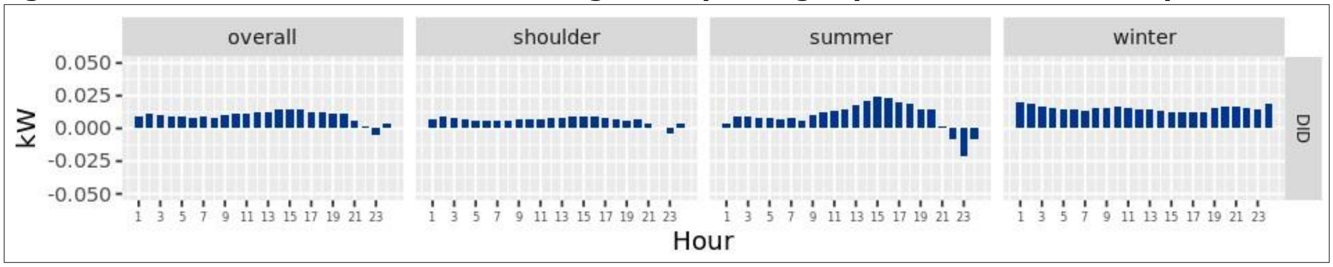
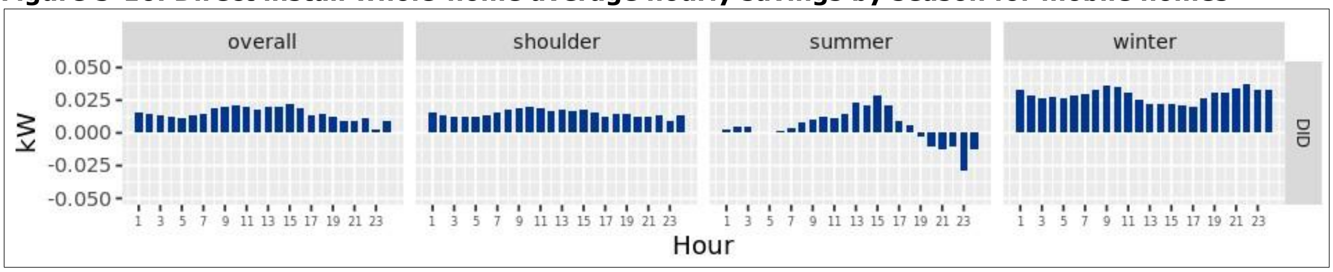


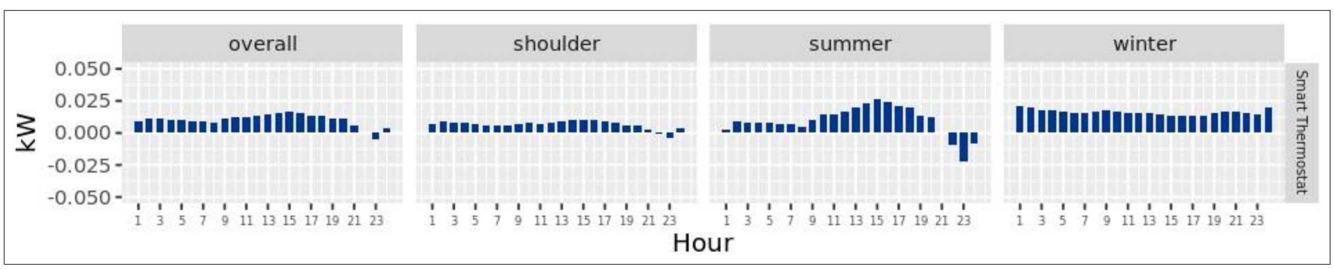
Figure 5-10. Direct install whole-home average hourly savings by season for mobile homes



While the previous figures provide whole-home hourly savings shapes from the installation of smart thermostats with other measures, delivered in different mixes to participating homes, the next set of figures illustrate hourly smart thermostat savings shapes using data from homes that only installed smart thermostats. Data from a large number of multifamily homes that received smart thermostats as the only measure are the basis for these; similar analysis was not practical for mobile and single-family homes because of the much smaller numbers of participants that installed only smart thermostats in these groups.

Figure 5-11 provides summaries of hourly savings by season for multifamily homes that installed only smart thermostats. It indicates hourly savings that are similar to those observed at the whole-home level where smart thermostats are installed with other measures in relatively large numbers.

Figure 5-11. Direct install average hourly savings for multifamily homes with only smart thermostat installations



We also examine differences in smart thermostat savings shapes by location using data from multifamily homes located in coastal and inland regions. Figure 5-12 and Figure 5-13 provide average hourly savings shapes for over 2000 multifamily homes in coastal climate zones and over 12,000 multifamily homes in inland climate zones, respectively, that only installed smart thermostats.[52] The figures indicate that:

- Summer savings shapes are similar for the homes in both locations though afternoon savings for coastal homes are roughly half the magnitude.

[52] Appendix D provides the categorization of California's climate zones into coastal and inland regions.

- By contrast, winter and shoulder savings are greater in all hours among coastal multifamily homes compared to inland homes.
- Full year, coastal homes savings shapes demonstrate more consistent savings across the hours of the day while full year inland homes savings shapes are more dominated by the summer savings shape.

Figure 5-12. Direct install average hourly savings for coastal multifamily homes with only smart thermostat installations

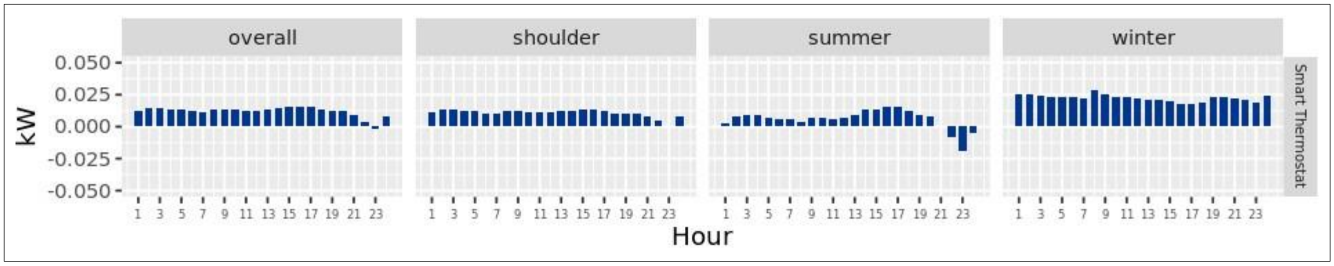
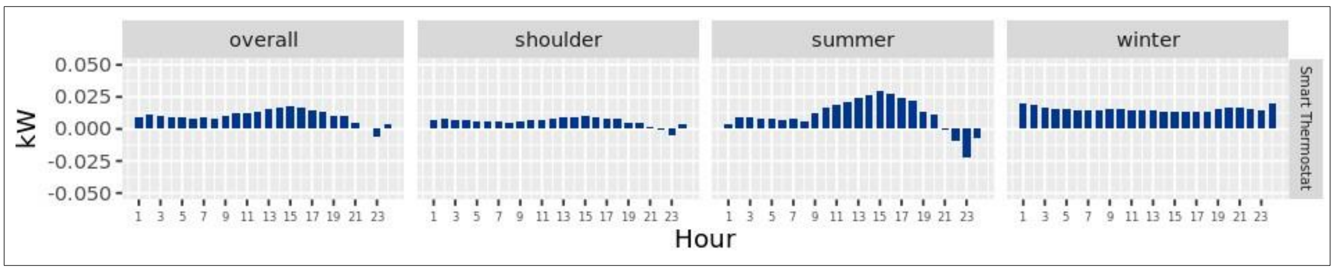


Figure 5-13. Direct install average hourly savings for inland multifamily homes with only smart thermostat installations



5.5.3 DEER peak period hourly load and savings shapes

California's Database for Energy Efficient Resources (DEER) defines peak period demand as one that occurs during a heat wave period. It defines a heat wave as 3 consecutive non-holiday weekdays between June 1 and September 30 with the hottest temperatures within the 9-hour window of 2 p.m. to 5 p.m. This definition considers the average temperature, average afternoon temperature (12 p.m.–6 p.m.), and maximum temperature over the course of 3-day heatwave candidates. It requires that the heat wave definition be based on TMY data.

We used TMY data to determine the applicable peak period and examined hourly load and savings shapes during that period. Figure 5-14 summarizes the hourly load shapes for multifamily participants that only installed smart thermostats and comparison households during the defined peak period.[53] It indicates hourly load that is well matched between the two groups, on the left panel, and reduction in energy use among participants in the post period, on the right panel.

[53] The heat wave periods are June 26-28, August 14-16, and August 28-30 for participants from PG&E's, SCE's, and SDG&E's service territories respectively.

Figure 5-14. DEER peak days average hourly electric load shapes for multifamily homes with only smart thermostat installations

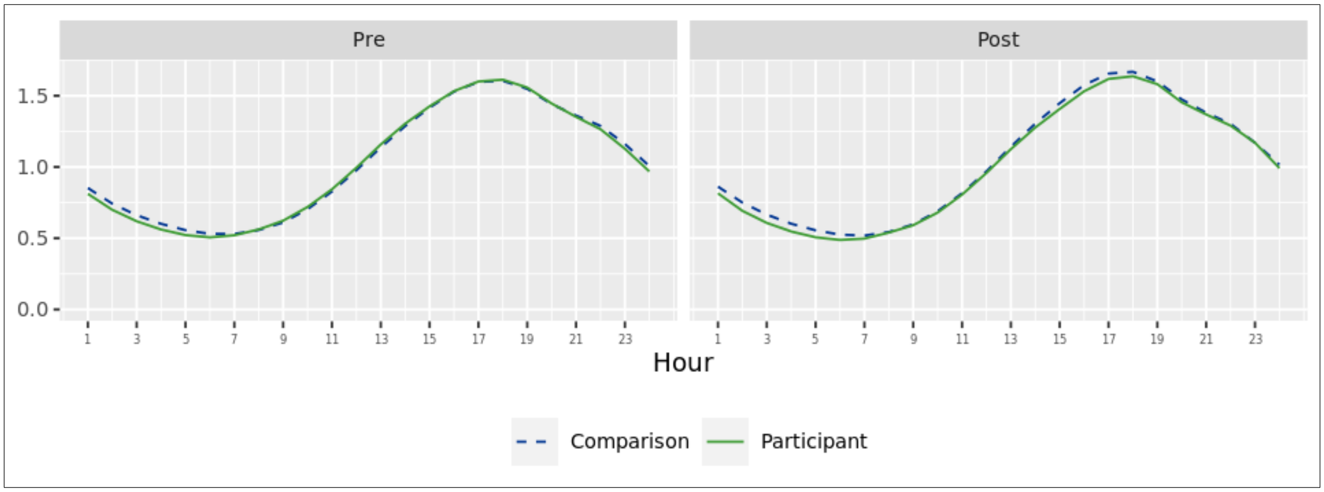


Table 5-7 provides a summary of average hourly load and load reduction (in kW and percent terms) for the DEER peak days and hours of 3 p.m. to 5 p.m. It also provides the reductions during the 4 p.m. to 9 p.m. window of the same days, which will become the new DEER defined window starting in program year 2020 and more closely tracks the actual system peak demand period. The table provides whole-home load and savings for participants that received smart thermostats along with other measures and for those that only installed smart thermostats. Baseline use is lower among smart thermostat only installers since they are largely multifamily homes, whose energy is generally lower than single family and mobile home customers. Average hourly load reduction is greater (2% to 3%) during the current DEER peak hours of 3 to 5 p.m. than during the 4 to 9 p.m. period (1% to 2%) and is greater for the smart thermostat only participant segment.

Table 5-7. DEER peak period average hourly baseline and load reductions

Participant Segment	3 p.m. - 5 p.m.			4 p.m. - 9 p.m.		
	Savings (kW)	Baseline (kW)	Percent savings	Savings (kW)	Baseline (kW)	Percent savings
HVAC whole-home	0.04	2.2	2%	0.03	2.2	1%
Smart thermostat-only	0.05	1.5	3%	0.03	1.5	2%

5.6 Direct install 2020 outcomes

In this section, we present the results of an exploratory analysis that investigates the impact of smart thermostat installations in their second post-installation year. The results we present in this section do not inform final savings and realization rates reported in prior sections.

Given the changes in energy usage due to COVID-19 in 2020, our PY2019 smart thermostat evaluation uses PY2018 smart thermostat direct install installations to estimate savings for PY2019. In order to better understand the smart thermostat savings changes that occurred in 2020 related to the pandemic, we extended the smart thermostat analysis for the direct install households.

For the PY2019 direct install evaluation, the first-year post period covers parts of 2018 and all of 2019. Energy use from this period is unaffected by COVID-19 disruptions, which brought substantial disruption to residential routines. We extended the analysis of smart thermostat savings for direct install programs by examining changes in 2020 (a second post period) among PY2018 direct install participants that did not move and have complete data for the analysis.

Table 5-8 updates the data attrition we presented in section 3 for the 2020 period. The PY2018 counts are all direct install participants with complete data for pre- and post-installation analysis.[54] The 2020 counts reflect the availability of complete data for participants and their matched pairs. Only matched pairs with relevant and sufficient data in 2020 are included for the 2020 analysis in order to maintain balance between treatment and comparison group households.

Table 5-8. Participant counts in 2020 analysis

Participant Data Attrition	Electric	Gas
Customers with data for PY2018 analysis	42,835	25,279
Customers with relevant and sufficient 2020 data used in analysis	25,946	18,492

The 2020 analysis follows the same approach we used to evaluate savings for the original post period presented in section 5.4.1. The 2020 analysis is based on data from January through December 2020, instead of the original post-installation data for participants and their matches. Thus, the 2020 analysis is approximately the second-year savings, relative to the same baseline.

Analysis based on this data indicates that gas savings are qualitatively the same in 2020 as in the original post period with insignificant savings or dissavings for direct install occupants that remained in their homes in 2020. Figure 5-15 provides whole-home and smart thermostat electric savings estimates. These results are provided for the following three conditions:

- **Post period.** This is the original 2018-19 post period result, relative to the 2017-2018 pre-installation period, covered in section 5.
- **Post period for those with 2020 data.** This is the first post period analysis (2018-2019) that uses the subset of PY2018 direct install participants and their matched pairs that did not move and have complete data for the analysis.
- **2020.** This is the second post period analysis (2020) that uses the same PY2018 subset of direct install participants and their matched pairs that did not move and have complete data for the analysis.

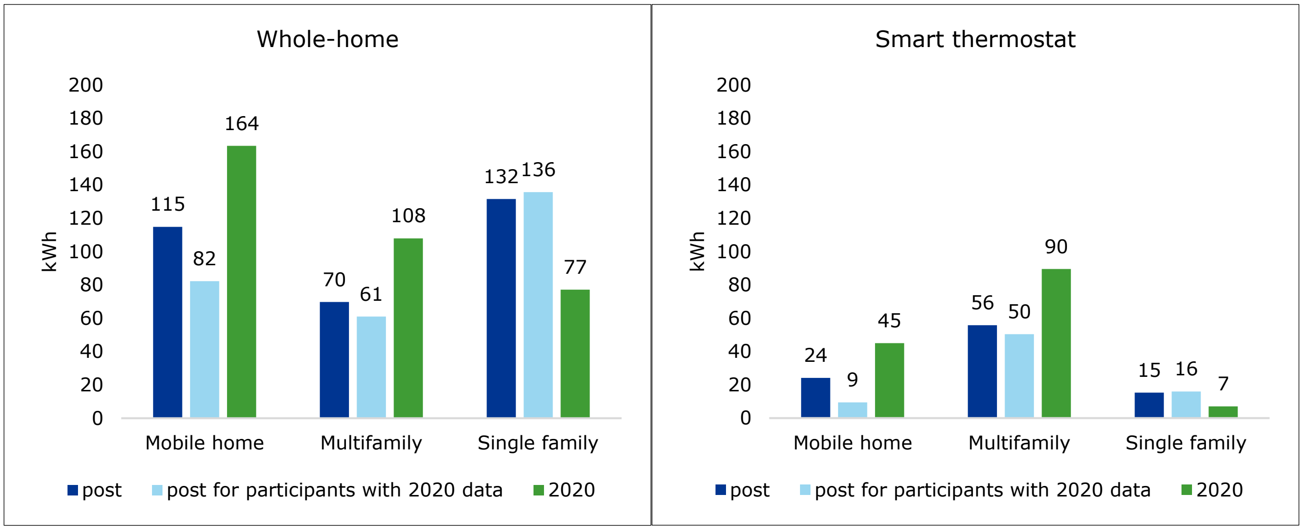
Electric whole-home and smart thermostat savings are similar for the two versions of post. The subset of households with complete 2020 data have post (2018-2019) electric savings estimates that are similar to the original post period savings estimates. Electric savings for 2020 (the second post period) indicate an increase in whole-home and smart thermostat savings for multifamily and mobile homes, and a decrease for single family homes.[55]

The reasons for the differences in the effect of pandemic disruptions across dwelling types are not clear. Survey results in section 4 indicate differences in the demographic and household characteristics of participants from the three dwelling types. Pandemic effects have had different effects on different demographic groups. Understanding how these differences translate into greater or lower savings related to smart thermostats would require further investigation.

[54] The details of the count of customers included in the PY2018 analysis is provided in section 3 of the report.

[55] Model results for 2020 are provided in Appendix G, section 7.7.1.

Figure 5-15. Direct install whole-home and smart thermostat electricity savings post-participation (2018-2019) and in 2020



The figure above provides model-based savings estimates that indicate how much change in usage is associated with program participation either in the post period or in 2020 relative to a 2017-18 baseline. An increase in savings for 2020 relative to the original post period does not necessarily indicate a drop in energy consumption relative to the original post period. Such savings can mean that energy consumption increased less for participants than for the comparison homes.

Table 5-9 shows the change in energy use relative to the post period, for participants and the comparison group homes. The table indicates electricity use was higher in 2020, which largely overlaps with the COVID period, compared to the period prior to COVID for both groups. Electricity use increased by 2% to 4% for matched non-participants and by 1% to 4% for participants in 2020 compared to the post period. The electricity use increase was highest for single family participants; unlike the other dwelling types, single family homes had a reduction in savings in 2020 compared to their original post-period savings. Thus, it appears that residents of the other dwelling types were better able to moderate the increase in their energy consumption during this period of economic disruption.

Table 5-9. Change in matched non-participant and participant electric consumption in 2020

Dwelling Type	Non-Participant Energy Use (kWh) and Energy Use Changes			Participant Energy Use (kWh) and Energy Use Changes		
	Post Period (2018-2019)	Second Post Period (2020)	Percent Change	Post Period (2018-2019)	Second Post Period (2020)	Percent Change
Mobile home	6,314	6,463	2%	6,232	6,299	1%
Multifamily	4,878	5,076	4%	4,817	4,968	3%
Single family	8,331	8,569	3%	8,195	8,492	4%

Further research and analysis are required to understand fully the results presented in this section. While these results indicate outcomes that are different from the first post-installation year, additional analysis is required to understand the extent to which the estimated effects are due to COVID disruptions and/or part of a trend in savings delivered by smart thermostats.

6 CONCLUSIONS AND RECOMMENDATIONS

The findings from this evaluation and resulting recommendations and implications are summarized in Table 6-1.

Table 6-1: Key findings and Recommendations

 **Key findings**	 **Recommendations & Implications**
1. There are no discernible gas savings from direct install programs and low gas savings from rebate programs. These results are consistent with other studies.	Consider eliminating gas savings claims for direct install smart thermostats.
2. Electric savings have low gross realization rates.	Consider reducing utility reporting assumptions for electric thermostat savings, particularly for direct install applications. Review the potential for fan control measures to interfere with savings opportunities from smart thermostats. Consider restricting smart thermostat direct install to homes without fan control measures.
3. Lower engagement among direct-install program participants compared to rebate participants and non-participant installers implies underutilization of the learning algorithm to optimize and save energy, which reduces savings opportunities.	Require direct install programs to include or strengthen contractor training and customer education about settings (auto-away) and device use (pre-heating/pre-cooling) that will help save energy. Consider leveraging contractors and property managers to deliver customer education recommended above.
4. Direct-install program participants report lower rates of enrollment in demand response programs compared with rebate program participants and non-participants with smart thermostats.	Require direct install programs to include or strengthen education of participants receiving smart thermostats on demand response opportunities to achieve their full savings potential.

 **Key findings**	 **Recommendations & Implications**
5. Hourly load shapes for direct install smart thermostat participants indicate that demand peaks in late afternoon hours during the summer, whereas hourly savings shapes show that the greatest summer load reductions occur in the early part of the afternoon.	While substantial smart thermostat related savings occur during the summer peak hours of 4 p.m. to 6 p.m., there are opportunities to shift the greater early afternoon savings through active management. We recommend the use of demand response programs that encourage pre-cooling to achieve additional late afternoon savings when peak demand occurs.
6. There are indications that customers maintained, and some increased, smart thermostat savings during the pandemic affected year of 2020.	We recommend further research and analysis to understand fully the outcomes and mechanisms through which these savings occurred.

7 APPENDICES

7.1 Appendix A: Gross and net lifecycle savings

Gross and net lifecycle savings are in the attached pdf.

7.2 Appendix B: Per unit (quantity) gross and net energy savings

Per unit (quantity) gross and net energy savings are in the attached pdf.

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

Study ID	Study Type	Study Title	CPUC Study Manager
Group A Residential Sector	Impact Evaluation	Impact Evaluation of Smart Thermostats - Program Year 2019	Peter Franzese

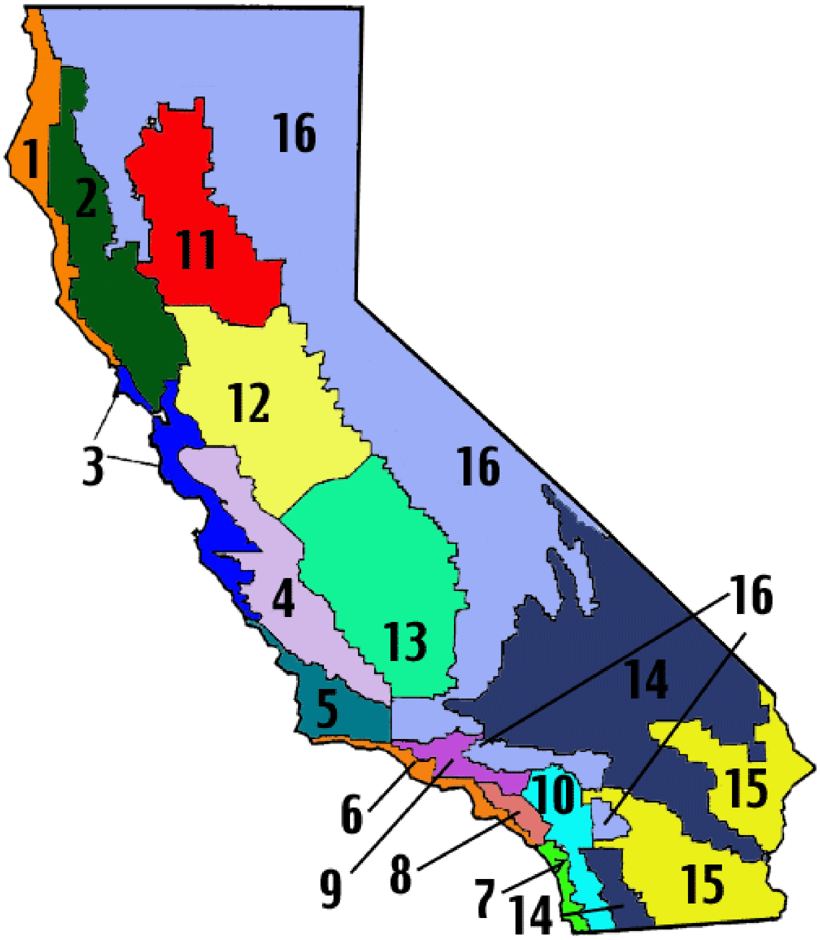
Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
1	Multiple programs delivering smart thermostats	There are no discernible gas savings from direct install programs and low gas savings from rebate programs. These results are consistent with other studies.	Sections 5.1 and 5.4	Consider eliminating gas savings claims for direct install smart thermostats.	CPUC, All PAs	Statewide workpaper
2	Multiple programs delivering smart thermostats	Electric savings have low gross realization rates.	Sections 5.1 and 5.4		CPUC, All PAs	Statewide workpaper
3	Multiple programs delivering smart thermostats	Lower engagement among direct-install program participants compared to rebate participants and non-participant installers implies underutilization of the learning algorithm to optimize and save energy, which reduces savings opportunities.	Section 4.2	Consider reducing utility reporting assumptions for electric thermostat savings, particularly for direct install applications.	CPUC, All PAs	N/A (Program design consideration)
4	Multiple programs delivering smart thermostats	Direct-install program participants report lower rates of enrollment in demand response programs compared with rebate program participants and non-participants with smart thermostats.	Section 4.2	Review the potential for fan control measures to interfere with savings opportunities from smart thermostats. Consider restricting smart thermostat direct install to homes without fan control measures.	CPUC, All PAs	N/A (Program design consideration)

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
5	Multiple programs delivering smart thermostats	Hourly load shapes for direct install smart thermostat participants indicate that demand peaks in late afternoon hours during the summer, whereas hourly savings shapes show that the greatest summer load reductions occur in the early part of the afternoon.	Section 5.5	Require direct install programs to include or strengthen contractor training and customer education about settings (auto-away) and device use (pre-heating/pre-cooling) that will help save energy.	CPUC, All PAs	Statewide workpaper for any future kW claims, Program design consideration
6	Multiple programs delivering smart thermostats	There are indications that customers maintained, and some increased, smart thermostat savings during the pandemic affected year of 2020.	Section 5.6	Consider leveraging contractors and property managers to deliver customer education recommended above.	CPUC, All PAs	N/A (Future CPUC or IOU led studies)

7.4 Appendix D: Climate zones

The California Energy Commission has established 16 climate zones (Title 24 climate zone or CEC CZs) that reflect the diversity of climates in the state (Figure 7-1). Efficiency standards developed and adopted for various building and measure conditions reflect the varying effect of the CEC CZs.

Figure 7-1. California CEC climate zones



For the purpose of developing survey weightings, we have grouped the 16 CEC CZs into three climate regions: coastal, inland, and desert. Table 7-1 provides these groupings along with the percent of electric and gas participants by climate region.

Table 7-1. Climate zone groupings and percent claims by climate region

Climate region	CEC climate zone	Percent program participant				
		MCE	PG&E	SCE	SCG	SDG&E
Coastal/Mild	1,2,3,4,5,6,7,16	100%	57%	7%	21%	65%
Inland	8,9,10,11,12,13	0%	43%	67%	76%	35%
Desert	14,15	0%	0%	27%	3%	0%

7.5 Appendix E: Matching

The quasi-experimental design that DNV GL used in this study involved the identification of comparison group customers that served as matches for smart thermostat participants. This section provides results from the two-phase matching that DNV GL undertook to select such matched comparison households. Tests of balance between participant and selected comparison group customers show improvements in the condition of matching with each phase.

7.5.1 First-phase matching results

Table 7-2 provides values of the metrics used to test balance. These metrics are computed based on annual consumption of participants and selected candidate matches after matching. In general, standardized mean differences and the ratios of variance of annual consumption for the matched groups show that the selected 10:1 matches are relatively well balanced. Standardized differences for the matched groups are all well below 0.2 (are no higher than 0.06) and the ratio of variances are close to 1 and generally indicate the variance of annual usage of the matched groups is similar.

Table 7-2. First-phase matching test of balance metrics

PA	Fuel	Standardized Mean Difference	Variance Ratio
PGE&E	electric	0.00	1.0
	gas	0.00	1.0
SCE	electric	-0.01	1.0
SCG	gas	-0.01	1.0
SDG&E	electric	-0.02	1.1
	gas	-0.06	1.0

7.5.2 Second-phase matching results

The quasi-experimental design we use to model whole-home, and ultimately, smart thermostat savings are based on 1:1 matches of participants and general population non-participants with similar pre-period energy use patterns. We present the state of balance for the second and final stage of matches conducted for this purpose.

Interval data from the 10:1 participant to non-participant matches based on monthly billing data were the basis of the second phase 1:1 matches. These matches led to the selection of non-participant households that were best matches for the participants. These matches provide the conditions for a robust analysis of the effect of smart thermostats on energy consumption changes since they control for non-program related changes effectively.

The metrics used to test the condition of balance indicate that the selected 1:1 matches in this phase of matching are well-balanced (Table 7-3). As in the first-phase matching, total consumption of the matched groups was used to compute the test of balance metrics. Most standardized mean differences are near zero, and no higher than 0.03, and the ratios of variance of total consumption between matched groups are close to 1.

Table 7-3. Second-phase matching test of balance metrics

PA	Fuel	Standardized Mean Difference	Variance Ratio
PGE&E	electric	0.00	1.0
	gas	0.00	1.0
SCE	electric	0.00	1.0
SCG	gas	0.00	1.0
SDG&E	electric	0.03	1.3
	gas	0.00	1.0

Figure 7-2 through Figure 7-7 illustrate the quality of matches for the selected matched samples graphically. Each panel provides the distribution of variables for participant and matched non-participant homes. Each indicates that these distributions are very similar and indicate data that are well balanced.

Figure 7-2. Distribution of PG&E's matched electric data

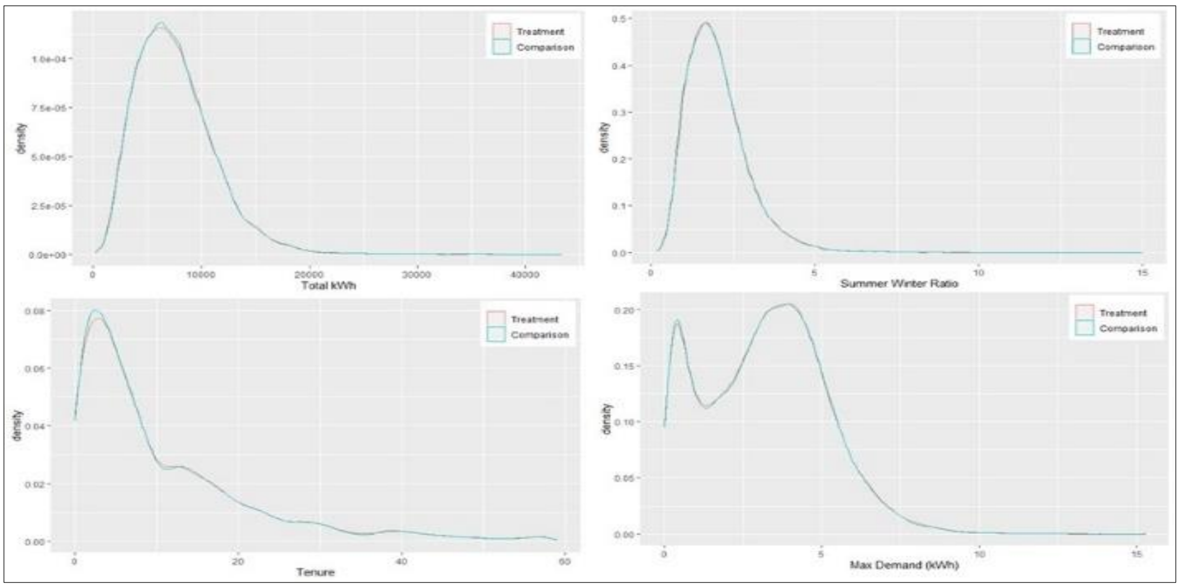


Figure 7-3. Distribution of PG&E's matched gas data

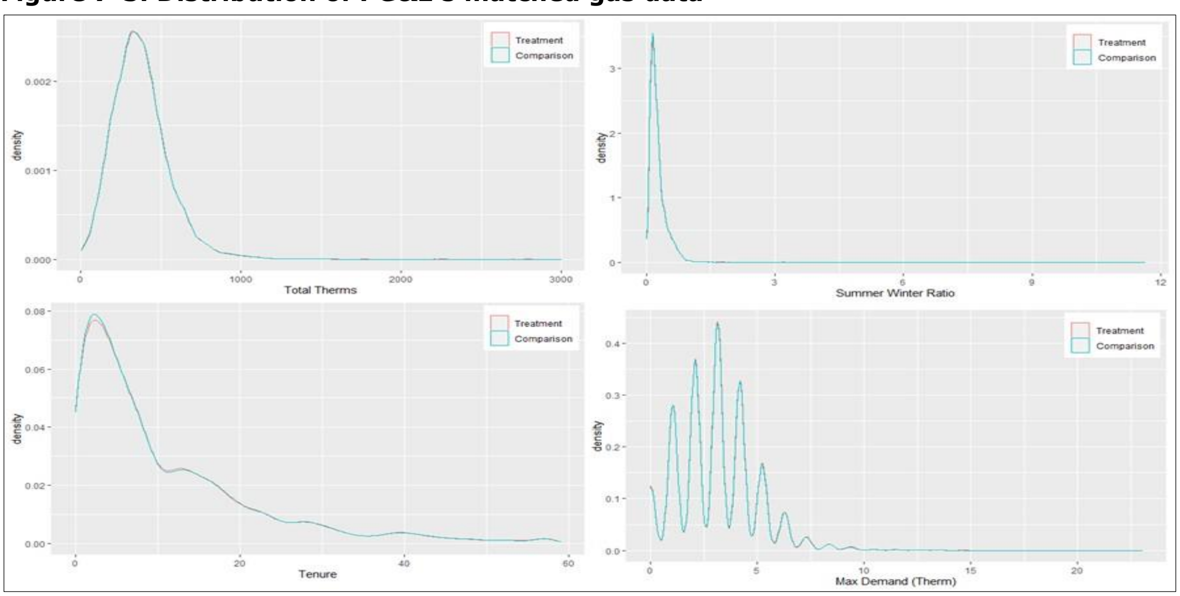


Figure 7-4. Distribution of SCE matched electric data

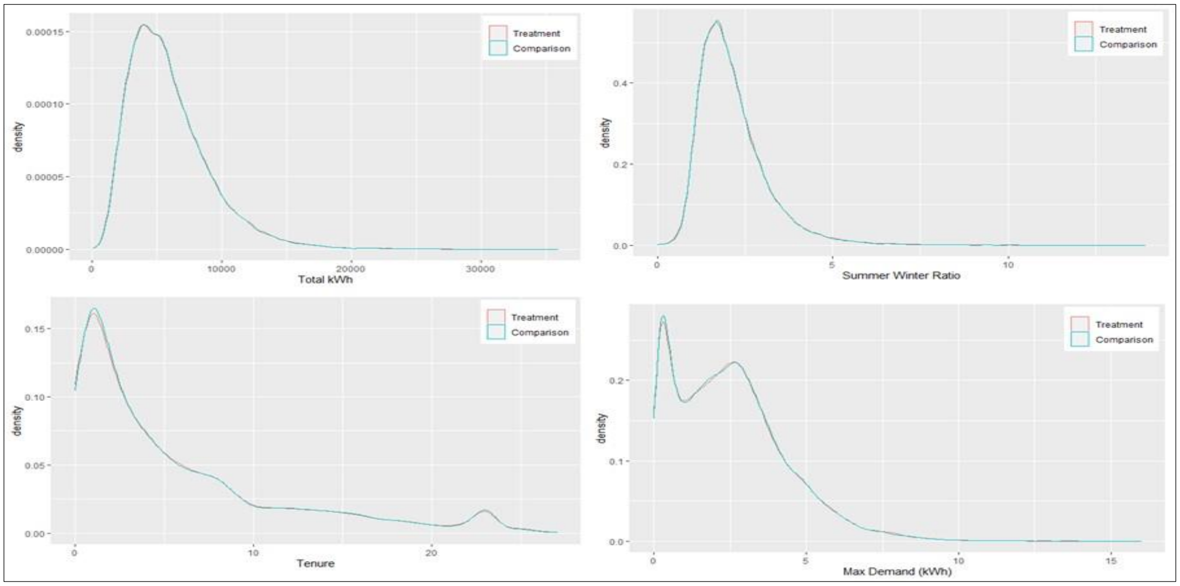


Figure 7-5. Distribution of SCG matched gas data

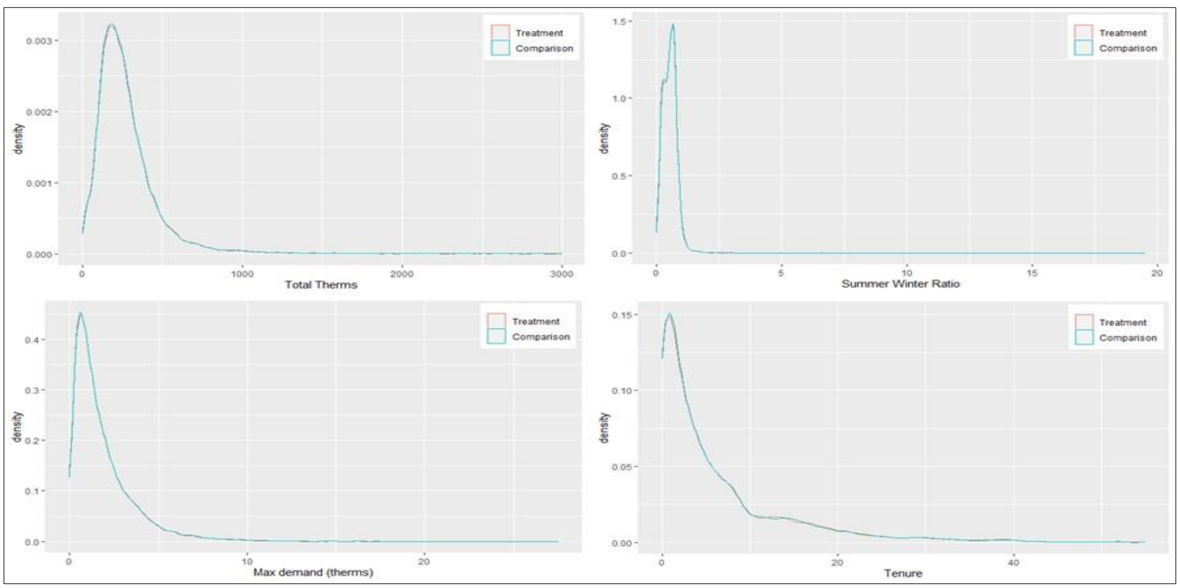


Figure 7-6. Distribution of SDG&E's matched electric data

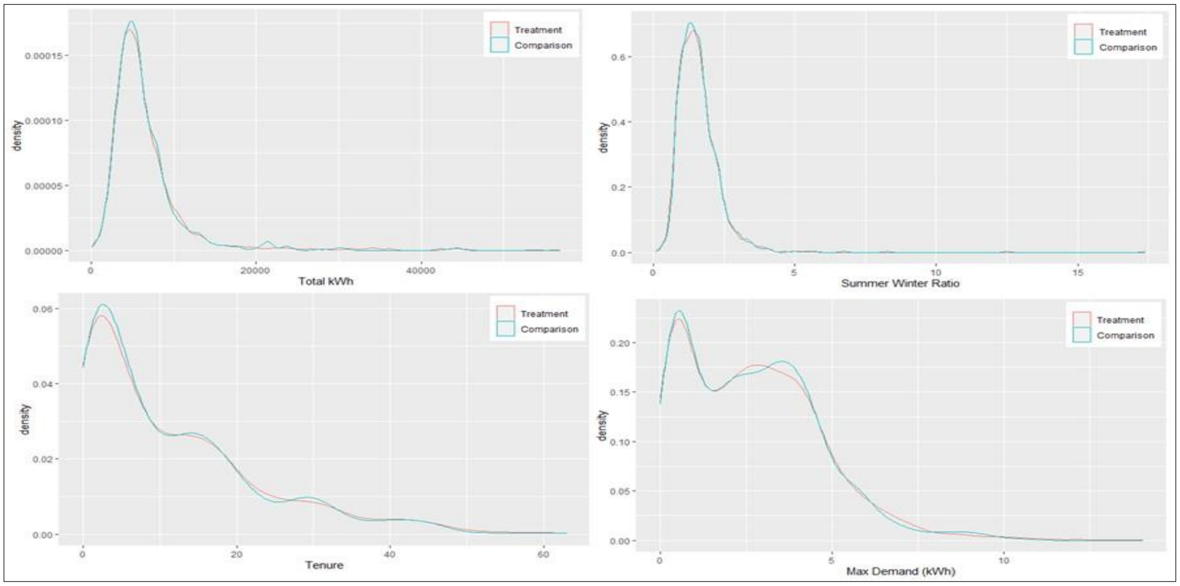
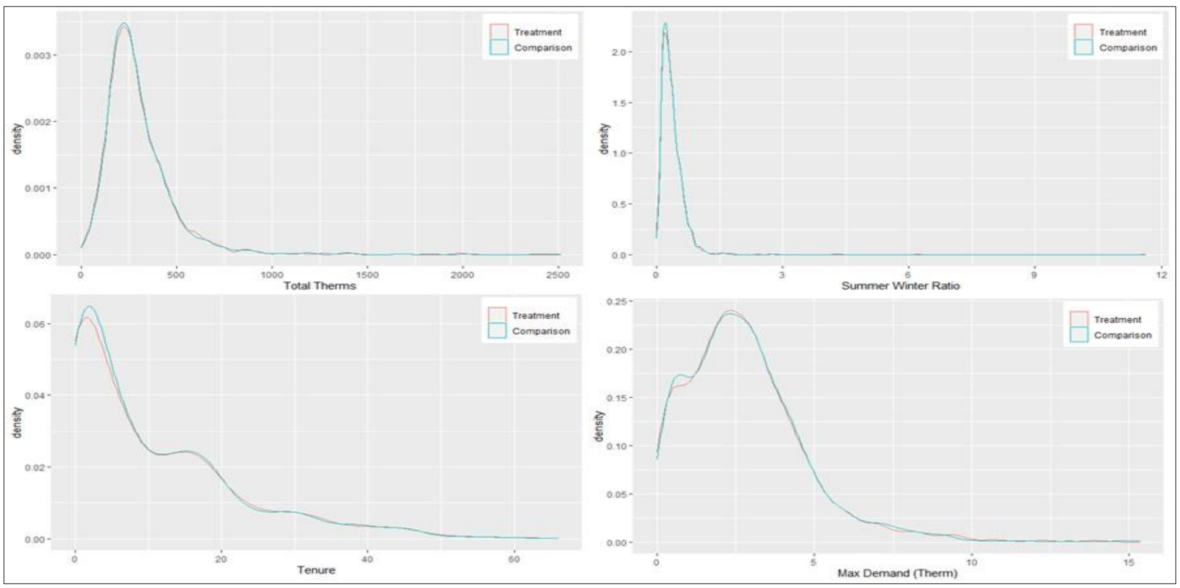


Figure 7-7. Distribution of SDG&E's matched gas data



7.5.3 Quality of matches to additional variables

In addition to the consumption and tenure data used for the basic matching, PG&E and SCE also provided additional household characteristics data. Figure 7-8 and Figure 7-9 show the distributions of these characteristics for PG&E and SCE participants and their matched comparison groups, respectively, where the matches were based on consumption and tenure only. The figures show good correspondence between the participants and matched comparison groups on these additional dimensions.

Figure 7-8. Distribution of PG&E's customer characteristics - matched with energy usage and tenure only

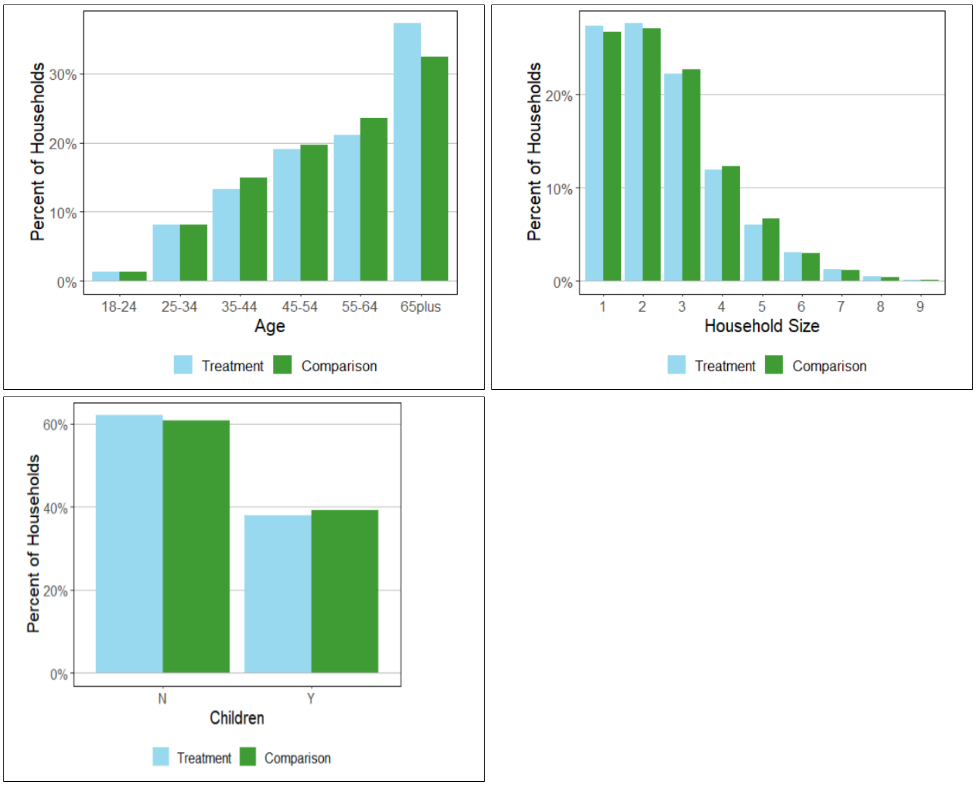
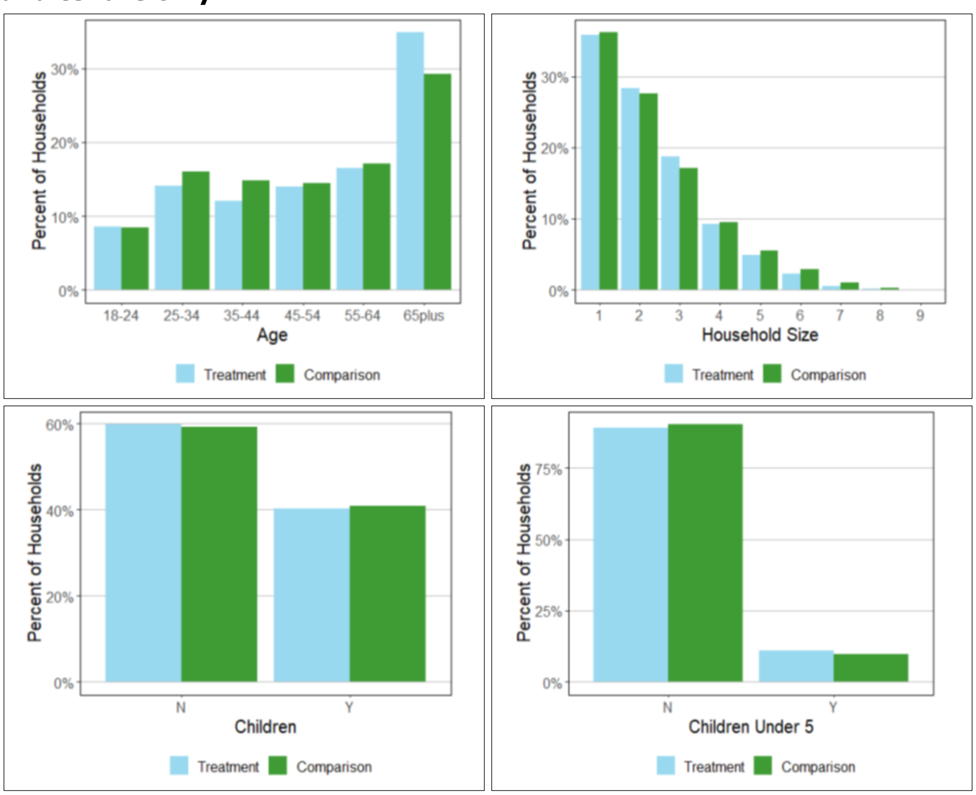
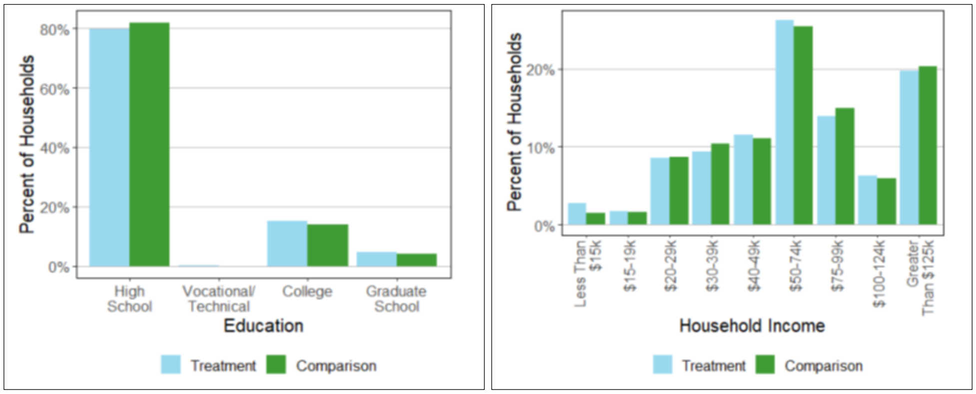


Figure 7-9. Distribution of SCE's customer characteristics - matched with energy usage and tenure only

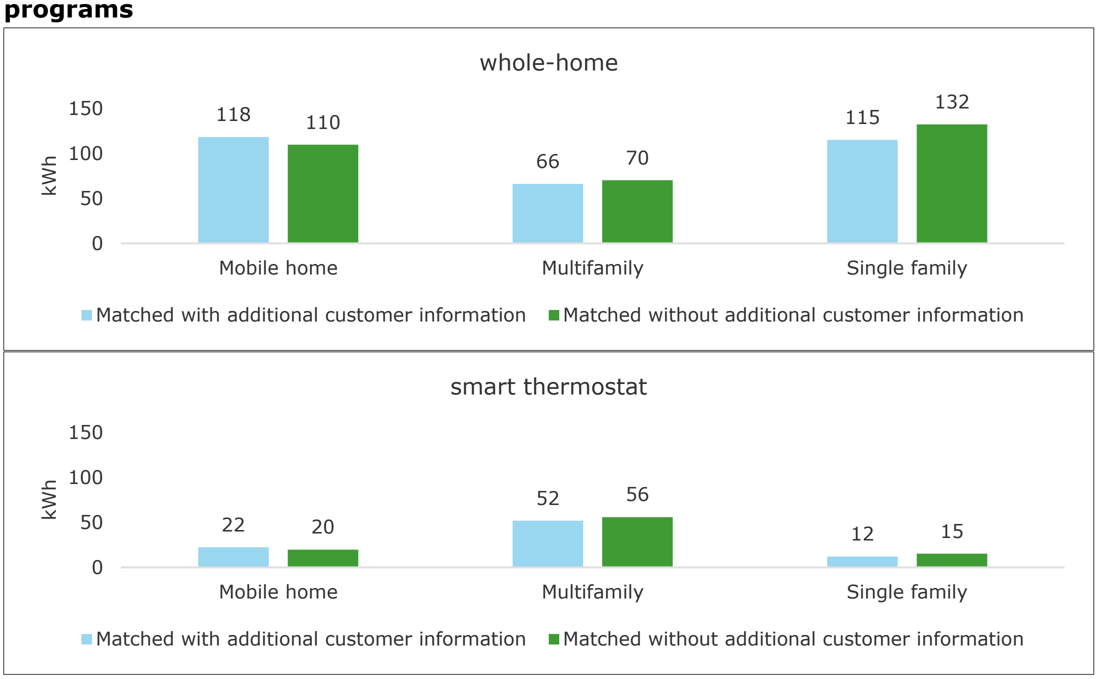




7.5.4 Savings for matches with and without additional customer characteristics

We also undertook matching that include the additional customer characteristics to investigate if estimated energy savings for matches that include these additional information are different. Figure 7-10 provides estimated whole-home and smart thermostat electricity savings for PG&E and SCE participants matched with and without the additional customer characteristics. While including the additional customer characteristics improved balance for those characteristics, changes to estimated savings were relatively small and directionally mixed. This suggests that matches that are well-balanced with respect to energy consumption provide reasonably matched participant and non-participant groups across a wider set of dimensions and the inclusion of remaining demographic differences is unlikely to improve savings estimates substantially.

Figure 7-10. Average SCE and PG&E whole-home and smart thermostat electric savings for matches with and without additional customer characteristics, PY2019 direct install programs



7.6 Appendix F: Electric load by dwelling type and climate zone

Table 7-4 provides estimates of average electric baseload, cooling, and heating load across all participants by dwelling type and climate zone. It also includes NAC, which is the sum of the three components, along with the count of households (N) with data in each dwelling type and climate zone.

Table 7-4. Electric load components by dwelling type and climate zone

Dwelling type	climate zone	N	baseload	cooling load	heating load	NAC
DMO	2	32	3,485	334	316	4,135
	3	89	3,338	205	287	3,829
	4	100	4,386	598	310	5,294
	5	97	3,532	55	296	3,884
	6	28	4,217	800	175	5,192
	7	37	3,551	887	166	4,604
	8	153	4,036	1,201	189	5,427
	9	83	3,670	1,743	166	5,578
	10	1,807	4,196	1,958	110	6,264
	11	124	4,572	2,602	336	7,510
	12	203	3,921	1,815	318	6,054
	13	730	4,357	2,452	225	7,035
	14	115	4,308	1,733	367	6,408
	15	276	4,103	3,971	143	8,217
	16	102	4,270	1,805	220	6,294
MFM	2	39	3,747	507	105	4,358
	3	5	5,720	1,917	138	7,774
	6	2,129	3,142	729	71	3,942
	7	5	4,067	37	154	4,258
	8	3,820	3,280	946	93	4,319
	9	2,058	3,494	1,454	56	5,003
	10	8,142	3,394	1,637	65	5,097
	11	93	3,041	1,512	91	4,645
	12	1,152	3,079	794	202	4,076
	13	1,206	3,662	2,049	168	5,879
	14	443	2,890	1,653	168	4,711
	15	1,462	3,172	2,830	100	6,102
	16	259	2,980	1,937	81	4,998
SFM	2	43	4,304	245	286	4,835
	3	249	4,673	150	438	5,261
	4	4	6,721	488	77	7,285
	5	1	4,277	0	175	4,452
	6	42	8,048	1,479	286	9,813
	7	84	5,162	747	225	6,134
	8	436	5,674	1,301	141	7,116
	9	46	5,865	1,902	215	7,982
	10	4,890	5,599	2,141	113	7,853
	11	938	5,993	2,375	279	8,647
	12	3,739	5,834	1,432	388	7,654
	13	5,386	5,777	3,166	321	9,264
	14	617	5,540	2,448	355	8,344
	15	820	5,607	5,049	76	10,731
	16	219	4,967	2,428	342	7,738

7.7 Appendix G: Second-stage difference-in-difference model results

Site-level, weather-normalized estimates of pre-post consumption difference are summarized in the second-stage model. The simplest version of this model estimates average consumption difference across all climate zones while controlling for comparison group trends using a simple dummy model. Including tracking or simulated savings as an independent variable allows the model to be flexible to the variation in simulated measure bundle savings across climate zones. Both the constant dummy and climate zone-varying values are included, and the regression determines the mix of these effects that best reflects the first-stage site-level data entering the model as the dependent variable.

A further step recognizes that savings, particularly HVAC savings, are likely to vary as a function of the size of a home. To further increase the flexibility of the model to address this, both sides of the regression are divided by consumption to put variables on a percentage basis. The first stage, site-level, weather-normalized estimates of pre-post consumption are divided by pre-period consumption. The engineering simulation values on the right side are divided by simulation model baseline consumption. This allows the model to be flexible to savings as a fixed percentage of baseline consumption across climate zones as well as variable percentage across climate zones. Again, the regression determines the mix of these effects that best reflects the empirical data entering the model in the dependent variable.

Whole-home savings are based on estimates of a general trend in energy use of participants (Bt) and an adjustment factor on the simulated percent savings of the energy savings (B_adj) term. The general trend indicates a decline in electricity use and an increase in gas use among participants post installation, although the majority of these estimates are not statistically different from zero.

The adjustment factor reflects what fraction of expected savings of the installed measures were realized by the mix of measures installed by the direct install programs. The coefficients among all dwelling types and both fuels were positive and largely significant.

7.7.1 Electric and gas model fits and savings estimates

Table 7-5 provides model estimates from annual weather normalized whole-home percent change models by fuel and dwelling type. The intercept value provides the percent change in weather normalized energy use that is not program or measure related. The negative intercept coefficients for both gas and electric models indicate, on average, increases in non-program related energy use.

Table 7-5. Electric and gas models of percent change in annual whole-home consumption

Dwelling Type	*intercept*	*p_val*	*Bt*	*p_val*	*B_adj*	*p_val*
Electric						
Mobile home	-0.002	0.416	0.005	0.276	0.127	0.000
Multifamily	-0.011	0.000	0.013	0.000	0.060	0.176
Single family	-0.006	0.000	0.001	0.660	0.144	0.000
Gas						
Mobile home	-0.056	0.000	-0.042	0.160	0.530	0.077
Multifamily	-0.080	0.000	-0.001	0.940	1.614	0.000
Single family	-0.067	0.000	-0.025	0.000	0.994	0.000

The combined effect of the two treatment coefficients provides an estimate of whole-home energy change due to the installation of measures by direct install programs. These estimates are provided in Table 7-6. They indicate whole-home savings of 1% to 2% for electricity, while gas savings range from dissavings (increases) of about 1% to positive savings of under 2%. They also indicate electric savings estimates are statistically significant and well-determined (based on the implied relative precisions that reflect the relatively low estimated standard errors).

Table 7-6. Estimated whole-home and smart thermostat savings by dwelling type

Dwelling Type	Whole-Home Savings				Smart Thermostat Savings		
	Savings (kWh)	Standard Error	p value	Savings (%)	Savings (kWh)	Standard Error	p value
Mobile home	114.9	23.1	0.00	1.8%	24.1	9.9	0.03
Multifamily	69.8	8.1	0.18	1.4%	55.8	6.9	0.00
Single family	131.6	13.6	0.00	1.5%	15.3	2.6	0.00
Dwelling Type	**Savings (therms)**	**Standard Error**	**p value**	**Savings (%)**	**Savings (therms)**	**Standard Error**	**p value**
Mobile home	-2.8	4.6	0.63	-0.9%	-5.86	4.5	0.15
Multifamily	4.1	3.4	0.22	1.6%	1.31	3.3	0.69
Single family	5.5	2.9	0.07	1.1%	-4.15	2.2	0.09

To further explore the mixed, possibly negative savings for gas, we estimated a whole-home model for participants residing in mobile homes who did *not* install smart thermostats. This model produced statistically discernible positive gas savings. Thus, the negative estimated gas whole-home savings for mobile homes appears to be associated with smart thermostat installations. Negative or insignificant estimated gas savings when thermostats are present, and gas models that were better determined without smart thermostats indicate the absence of gas savings among participants that received smart thermostats through direct install programs.

As a further examination of the gas findings, we fit a model for multifamily homes that received *only* smart thermostats. Similar analysis was not practical for mobile home and single-family participants, because of the much smaller numbers of these dwelling types that had only smart thermostats. The multifamily estimates shown in Table 7-7 indicate gas savings are negative (increased consumption) but are not statistically significant.

Table 7-7. Gas savings for multifamily homes with smart thermostat installations only

Dwelling Type	Intercept	p value	*Bt*	p value	*B_adj*	p value	Savings (therms)	p value	Savings (percent)
Multifamily	-0.05	0.00	-0.03	0.00	5.13	0.00	-1.14	0.37	-0.5%

Thus, from several perspectives the evidence is that direct install smart thermostats did not producing meaningful gas savings. Based on these findings, the gas thermostat savings are set at zero.

Table 7-8 provides estimated whole-home and smart thermostat savings and estimates of their uncertainty in 2020. These estimates are based on the same models used to estimate post period savings with data from accounts that were still active in 2020.

Table 7-8. Estimated whole-home savings by dwelling type in 2020

Dwelling Type	Whole-Home Savings				Smart Thermostat Savings		
	Savings (kWh)	Standard Error	p value	Savings (%)	Savings (kWh)	Standard Error	p value
Mobile home	164	40	0.00	2.5%	45	17	0.01
Multifamily	108	16	0.00	2.2%	90	14	0.00
Single family	77	25	0.00	0.9%	7	5	0.12

7.7.2 Savings adjustment for comparison group smart thermostat installations

Smart thermostat savings estimates are adjusted upward to account for the prevalence of smart thermostats among the comparison group. Results from surveys of comparison group households revealed that 8% to 13% installed smart thermostats in 2018 and 2019. These are periods during which participants installed smart thermostats and the effect of smart thermostats on energy consumption are measured for this group. If comparison group smart thermostat installations are assumed to have the same savings effect in the matched comparison households as program thermostats, then their presence will have the effect of diminishing the magnitude of participant savings estimates coming directly from the model coefficients.

Table 7-9 provides the installation rates of smart thermostats among the comparison group and the multiplicative adjustment factors used to account for these rates by dwelling type. For example, a prevalence of 13.1% smart thermostats among comparison group households requires that savings estimates be divided by (1-0.131 = 0.869) or multiplied by its reciprocal (1.15). This is a modest upward adjustment that assumes that all comparison group installations perfectly correlate with the timing of program participant installations.

Table 7-9. Adjustment factors for the presence of smart thermostats among the comparison groups by dwelling type

Dwelling Type	2018-2019 Installations	Effect on Estimated Savings
Mobile home	8.0	1.10
Multifamily	9.2	1.09
Single family	13.1	1.15

7.7.3 Net energy use increasing actions

The participant and matched non-participant surveys we discussed in section 4.2.3 asked questions regarding changes in the home that affect energy use. Respondents could indicate changes that either lead to an increase or a decrease in energy use with corresponding effects on whole-home savings. We used the survey results to estimate the potential aggregate consumption impacts caused by the reported energy changing actions. The results are presented in Table 7-10 for direct install mobile home participants and in Table 7-11 for single family direct install participants.

We calculated the difference between matched non-participant and participant net change in energy use actions. When the difference is negative, matched non-participants undertook more energy increasing activities than the participants which could increase savings. When the difference is positive, the participants undertook net energy increasing activities than matched non-participants which could decrease savings.

Table 7-10. Changes in home impacting energy use, mobile home

Net Energy Use Increasing Actions	Net Change in Action			Installation Timing Factor	Consumption Added Due to Action (kWh)[56]	Aggregate Consumption Impacts
	Non-participants (n= 202)	Direct Install Participants (n=269)	Difference			
Added electric vehicle charging to the home	0%	-1%	-1.4%	50%	901	-6
Using an additional refrigerator	2%	6%	4.7%	50%	1,034	24
Household size increased	-1%	-1%	-0.5%	50%	580	-1
Increased living area/square footage of your home	-2%	-3%	-1.0%	50%	580	-3
Added a pool/pool pump	0%	-1%	-1.2%	50%	0	0
Added a spa	0%	-1%	-1.0%	50%	106	-1
Using more lighting	-9%	-14%	-5.0%	50%	58	-1

Note: Negative numbers indicate that the proportion reporting an action that would decrease energy use is greater than the proportion that report an action that would increase energy use.

Table 7-11. Changes in home impacting energy use, single family

Net Energy Use Increasing Actions	Net Change in Action			Installation Timing Factor	Consumption Added Due to Action (kWh)[57]	Aggregate Consumption Impacts
	Non-Participants (n=4,202)	Direct Install Participants (n=1,760)	Difference			
Added electric vehicle charging to the home	3%	2%	-0.8%	50%	1,062	-4
Using an additional refrigerator	7%	9%	2.1%	50%	1,209	13
Household size increased	2%	1%	-0.3%	50%	755	-1
Increased living area/square footage of your home	-1%	2%	3.4%	50%	755	13
Added a pool/pool pump	0%	0%	0.6%	50%	2,895	9
Added a spa	-1%	-2%	-1.0%	50%	322	-2
Using more lighting	-3%	-2%	0.8%	50%	76	0

Note: Negative numbers indicate that the proportion reporting an action that would decrease energy use is greater than the proportion that report an action that would increase energy use.

The energy use changing actions could have occurred anytime during the post period. The installation timing factor adjusts for how much of the evaluation period is affected by each energy use changing action. If the energy use changing action occurred at the same time as the smart thermostat and other HVAC measures installations, then the changes would affect the entire analysis period (100%). If the energy changing action occurred immediately after the evaluation post period, it would have no impact (0%).

We used 2019 RASS unit energy consumption values to estimate the aggregate consumption impacts of changes in the households that affect energy use. We calculated the aggregate consumption impact by multiplying the difference between matched non-participant and participant net energy use actions with the installation timing factor, and the consumption added due to the

[56] RASS 2019 Estimates.

[57] RASS 2019 Estimates.

action. For mobile home direct install participants, the total aggregate impacts could be up to 10%[58] of the whole-home savings. For single family direct install participants, the total aggregate impacts could be up to 20%[59] of the whole-home savings.

[58] We calculated this by summing the aggregate impacts and dividing by the mobile home whole-home savings estimate, 12 kWh/115 kWh.

[59] We calculated this by summing the aggregate impacts and dividing by the single-family direct install whole-home savings estimate, 27 kWh/132 kWh.

7.8 Appendix H: NTGR survey scoring

For the smart thermostat evaluation, DNV GL used NTGR scoring methods similar to those used for other residential measures. DNV GL'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 smart thermostats, the survey determined "efficiency" in terms of the type of thermostat that would otherwise have been installed but rated these at only 2 levels—smart (efficient) or not.

Timing and "efficiency" are directly applicable to all smart thermostat program participants. Single-family program participants could only receive a single smart thermostat, so that the quantity dimension is not applicable. However, survey respondents who are multifamily property managers[60] could be responsible for multiple homes and could have decided to install the thermostats in more or fewer units. Thus, the quantity dimension is applicable to multifamily survey respondents. The NTGR survey scoring elements are summarized below in Table 7-12.

Table 7-12. Free-ridership elements by survey respondent type

Survey Respondents	Free-ridership Dimension	Question Wording	Answer	Free-Ridership Score
Participants (occupants)	Timing – (FR_t)	If the program didn't offer a smart thermostat on {installed date}, when would you have purchased and installed it/them…?	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
Property managers	Timing – (FR_t)	If the program didn't offer a smart thermostat on {installed date}, when would you have purchased and installed it/them…?	At the same time or sooner	1
			1 to 48 months later	48 - # of months)/48
			More than 48 months	0
			Never	0
			Don't know	Average of non-Don't know answers
Participants (occupants) Property managers	"Efficiency" (FR_e)	Smart thermostats come in a variety of models, there are BASIC models that cost about $150-$200 dollars (e.g., Nest E and Ecobee 3 lite) and UPGRADED models that cost about $250-$300 which offer additional sensing technology (e.g., Nest 3rd gen and Ecobee 4) and non-programmable thermostat costs range from $20-100. If the program didn't offer a smart thermostat rebate/the smart thermostats in 2019, which model would you have likely purchased?	Would have purchased the BASIC model smart thermostat(s)	1
			Would have purchased the UPGRADED model smart thermostat(s)	1
			Would have purchased standard programmable thermostat(s); (e.g., without smart capabilities)	0
			Would NOT have purchased any thermostat(s)	0

[60] All of the multifamily property managers and contractors participated in programs that used direct install delivery channels. Many of the single-family home residents participated in programs with more traditional, downstream rebate mechanisms.

Survey Respondents	Free-ridership Dimension	Question Wording	Answer	Free-Ridership Score
Property Managers	FR_q	Without {Q4}'s program how many smart thermostats would your company had installed at their expense? As a reminder, {Q4} records show {Q20} were installed. Using the scale below, please specify the percentage you would have installed without the program.	0%, 100%, 1% to 100% in 10% increments	0%, 100%, or mid-point of increment

Using these metrics in combination allowed DNV GL to fully assess the amount of savings that could be attributed to measures that participants would have installed absent program support. DNV GL 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 through 3.

Equation 1: Free-ridership Scoring Algorithm for single-family participants

$$\textit{Free-ridership} = FR_t * FR_e$$

Equation 2: Free-ridership Scoring Algorithm for multifamily participants

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

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

Results from the free-ridership analysis based on the participant (occupants) or property manager surveys are summarized in Section 4.2.1. Program level NTGRs derived from participant and property manager surveys are weighted by claims to compute PA level program attribution estimates which are then applied to gross savings to arrive at net savings.

7.9 Appendix I: Sample weights

DNV GL presents summaries of the sample weights developed for the participant and non-participant surveys in this section. The approach used to compute and assess weights is summarized below.

- Survey samples were post-stratified by PA, CZ group, consumption level.
- For each cell, DNV GL calculated the proportion of the population and the proportion of the sample in each cell.
- The proportional sample weight is calculated as the ratio of the population proportion to the sample proportion.
- DNV GL screened these weights for extremely low or high values.
- While weight trimming is standard to address extreme values for sample weights, DNV GL did not need to make any adjustments to sample weights.

With this approach, the average results for each cell determined from the sample are weighted by the proportion of households in the full program population from that cell.

Participant survey – sample weights. The team applied sample weights, in order to balance the participant survey sample to the population proportions by each PA, fuel, climate zone category, and consumption level combinations. No trimming of weights was required with the maximum weight, minimum weight, and the ratio of the maximum to minimum sample weight at 0.63, 1.76, and 2.79 respectively (Table 7-13). This range indicates a balanced survey sample, with the differential weights providing minor corrections for over and under representation.

Table 7-13. Participant survey sample weights

PA	Climate zone category	Consumption level	Sample frame - Frequency	Sample frame - percent	Survey sample – frequency	Survey sample - percent	Proportional sample weight
SCE	coastal	1	200	0.4%	33	0.5%	0.65
SCE	coastal	2	199	0.4%	29	0.5%	0.73
SCE	coastal	3	205	0.4%	33	0.5%	0.66
SCE	desert	1	737	1.3%	84	1.4%	0.94
SCE	desert	2	737	1.3%	68	1.1%	1.16
SCE	desert	3	759	1.4%	46	0.8%	1.76
SCE	inland	1	2,226	4.0%	301	5.0%	0.79
SCE	inland	2	2,226	4.0%	254	4.2%	0.94
SCE	inland	3	2,291	4.1%	202	3.4%	1.21
SCG	coastal	1	896	1.6%	133	2.2%	0.72
SCG	coastal	2	893	1.6%	98	1.6%	0.97
SCG	coastal	3	921	1.6%	84	1.4%	1.17
SCG	desert	1	744	1.3%	84	1.4%	0.95
SCG	desert	2	731	1.3%	75	1.2%	1.04
SCG	desert	3	758	1.3%	73	1.2%	1.11
SCG	inland	1	6,518	11.6%	728	12.1%	0.96
SCG	inland	2	6,519	11.6%	630	10.5%	1.10
SCG	inland	3	6,685	11.9%	544	9.1%	1.31
SDG&E	coastal	1	1,157	2.1%	168	2.8%	0.74
SDG&E	coastal	2	1,157	2.1%	161	2.7%	0.77
SDG&E	coastal	3	1,191	2.1%	155	2.6%	0.82
SDG&E	inland	1	906	1.6%	154	2.6%	0.63
SDG&E	inland	2	906	1.6%	141	2.3%	0.69
SDG&E	inland	3	932	1.7%	101	1.7%	0.99
PG&E	coastal	1	1,901	3.4%	232	3.9%	0.87
PG&E	coastal	2	1,900	3.4%	216	3.6%	0.94
PG&E	coastal	3	1,957	3.5%	229	3.8%	0.91

PA	Climate zone category	Consumption level	Sample frame - Frequency	Sample frame - percent	Survey sample – frequency	Survey sample - percent	Proportional sample weight
PG&E	inland	1	3,282	5.8%	326	5.4%	1.08
PG&E	inland	2	3,282	5.8%	310	5.2%	1.13
PG&E	inland	3	3,381	6.0%	309	5.1%	1.17

Non-participant survey - sample weights. The team applied sample weights, in order to balance the non-participant survey sample to the population proportions by each PA, fuel, climate zone category, and consumption-level combinations. No trimming of weights was required with the maximum weight, minimum weight, and the ratio of the maximum to minimum sample weight at 0.2, 2.7, and 15.7 respectively (Table 7-14). This indicates a balanced survey sample with the differential weights providing minor corrections for over and under representation.

Table 7-14. Non-participant survey sample weights

PA	Climate Region	Consumption Level	Sample frame - frequency	Sample frame - percent	Survey sample - frequency	Survey sample - percent	Proportional sample weight
SCE	coastal	1	3,978	1.3%	39	0.7%	1.94
SCE	coastal	2	3,979	1.3%	28	0.5%	2.71
SCE	coastal	3	4,095	1.4%	40	0.7%	1.95
SCE	desert	1	4,564	1.5%	57	1.0%	1.52
SCE	desert	2	4,563	1.5%	62	1.1%	1.40
SCE	desert	3	4,701	1.6%	59	1.0%	1.52
SCE	inland	1	24,386	8.2%	239	4.2%	1.94
SCE	inland	2	24,395	8.2%	221	3.9%	2.10
SCE	inland	3	25,113	8.5%	217	3.8%	2.20
SCG	coastal	1	5,600	1.9%	78	1.4%	1.37
SCG	coastal	2	5,532	1.9%	85	1.5%	1.24
SCG	coastal	3	5,717	1.9%	89	1.6%	1.22
SCG	desert	1	2,065	0.7%	41	0.7%	0.96
SCG	desert	2	2,033	0.7%	30	0.5%	1.29
SCG	desert	3	2,105	0.7%	34	0.6%	1.18
SCG	inland	1	21,978	7.4%	274	4.8%	1.53
SCG	inland	2	22,016	7.4%	261	4.6%	1.61
SCG	inland	3	22,499	7.6%	258	4.6%	1.66
SDG&E	coastal	1	1,943	0.7%	197	3.5%	0.19
SDG&E	coastal	2	1,942	0.7%	215	3.8%	0.17
SDG&E	coastal	3	2,002	0.7%	203	3.6%	0.19
SDG&E	inland	1	3,998	1.3%	433	7.7%	0.18
SDG&E	inland	2	3,998	1.3%	414	7.3%	0.18
SDG&E	inland	3	4,119	1.4%	420	7.4%	0.19
PG&E	coastal	1	1,081	0.4%	16	0.3%	1.29
PG&E	coastal	2	1,080	0.4%	23	0.4%	0.89
PG&E	coastal	3	1,113	0.4%	30	0.5%	0.71
PG&E	inland	1	28,507	9.6%	537	9.5%	1.01
PG&E	inland	2	28,507	9.6%	534	9.4%	1.02
PG&E	inland	3	29,371	9.9%	522	9.2%	1.07

Property manager - sample weights. Property manager surveys were post-stratified by PA and savings magnitude. For each cell, the weight was calculated as the ratio of number of thermostats in the program population to the number in the responding sample for that cell. With this approach, the average responses for a cell are weighted by the total number of thermostats the program delivered in that cell. Therefore, property managers who installed a greater number of smart thermostats count commensurately toward the final property manager free-ridership score. No trimming of weights was required with the maximum weight, minimum weight, and ratio of the maximum to minimum sample weight at 9.2, 1.8, and 5.1 respectively (Table 7-15). This range indicates a balanced survey sample with the differential weights providing minor corrections for over and under representation.

Table 7-15. Property manager sample weights

PA	Savings level	Survey sample - frequency	Survey frame - Frequency	Survey Weight
PG&E	1	38	351	9.24
PG&E	2	13	59	4.54
PG&E	3	3	20	6.67
SCE	1	59	289	4.90
SCE	2	13	25	1.92
SCE	3	4	9	2.25
SCE-SCG	1	4	23	5.75
SCE-SCG	2	3	8	2.67
SDG&E	1	44	210	4.77
SDG&E	2	6	23	3.83
SDG&E	3	4	12	3.00
SCG	1	49	217	4.43
SCG	2	18	34	1.89
SCG	3	8	14	1.75

7.10 Appendix J: Surveys

7.10.1 Occupant surveys – Program participants and non-participants

Below are links to survey instruments used in the evaluation.

7.10.1.1 Program participant survey

Participant survey instruments used in the evaluation are included as pdf attachments.

7.10.1.2 Non-participant survey

Non-participant survey instruments used in the evaluation are included as pdf attachments.

7.10.2 Property manager survey

Property manager survey instruments used in the evaluation are included as pdf attachments.

7.11 Appendix I: Response to comments

Comment #	Commenter	Document Page	Comment	Response
1	ecobee	General	Thank you for the opportunity to comment on the Impact Evaluation of Smart Thermostats – Draft Residential Sector - Program Year 2019. ecobee is providing comments as a leading developer of smart thermostats. Overall, ecobee is concerned with the results that have been presented due to the fact that the **<u>comments that ecobee provided to DNV GL on this study on 6.22.20 and 11.13.20 have not been incorporated or addressed.</u>** The main issues that ecobee has identified with the draft report are: 1) It does not include Thermostat Optimization Savings - Comment 2 2) It uses a quasi-experimental design method which is subject to selection bias - Comment 3 3) It does not include other relevant data points such as state-specific ENERGY STAR results - Comment 4 4) It does not properly value energy savings during peak periods which is highly relevant in California with all customers being moved to time-of-use rates as it results in greater bill savings for customers and greater benefits to the grid - Comment 5 ecobee respectfully requests that the following items be included in the next draft of this report:	Please see response to detailed comments (#2 to #6) provided for each of the points raised in this introductory paragraph.
2	ecobee	General	**1. Inclusion of Thermostat Optimization Savings** In 2019, leading smart thermostat technology vendors began to offer free thermostat optimization which results in incremental energy savings beyond a smart thermostat baseline. ecobee launched a new thermostat optimization platform called eco+ that has been released to all of its thermostats in the form of a free software upgrade, and Google Nest made its seasonal savings platform free to consumers. California's current energy efficiency evaluation methodology looks exclusively at outdated past periods before these capabilities were deployed, and therefore fails to account for the incremental energy savings specific to these devices in California through new thermostat optimization features that have been provided to customers through over-the-air software updates. This flawed approach will stand in the way of accurately assessing the cost-effectiveness of smart thermostat deployment absent changes to capture increased benefits from automation software improvements. Leading up to the release of eco+, ecobee contracted Demand Side Analytics, a third-party measurement and verification firm, to	DNV prepared the study plan at the start of lockdowns due to the COVID outbreak. Although the extent and duration of the effect of the pandemic on residential energy use was not fully evident, DNV made the decision to use data from 2018 participants to evaluate all of 2019 residential HVAC installations to avoid confounding unknown COVID effects with program effects. This decision, which DNV reflected in its workplan, was made available for public review and implemented following this review. The timeframe of the analysis and the study undertaken based on it cannot be changed at this point. That said, 2019 data represent a substantial portion of the post-installation data of 2018 participants. To the extent that thermostat optimization was present, then those savings would have been captured in the analysis. Thus, it is not the case that the "current energy efficiency evaluation methodology looks exclusively at outdated [post] periods before these capabilities were deployed."

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<tr><th>Comment #</th><th>Commenter</th><th>Document Page</th><th>Comment</th><th>Response</th></tr>
<tr><td></td><td></td><td></td><td>measure the climate-specific additional energy and demand savings impacts of this software upgrade through a robust randomized encouragement design using nearly 250,000 ecobee devices.

The executive summary of the full measurement and verification report is accessible at ecobee.com/ecoplusEMV. The California-specific results are presented in the figure below.
<table>
<tr><th>Region</th><th>June Per-Device kWh</th><th>July Per-Device kWh</th><th>August Per-Device kWh</th><th>Total Per-Device kWh</th><th>Peak kW Savings (Weekdays 2-6pm)</th></tr>
<tr><td>Hot-Dry/Mixed-Dry</td><td>21.7 ± 9.8</td><td>36.3 ± 11.7</td><td>39.0 ± 12.9</td><td>96.9 ± 20.0</td><td>0.10</td></tr>
<tr><td>Marine</td><td>16.0 ± 7.5</td><td>16.9 ± 8.6</td><td>22.4 ± 11.2</td><td>55.3 ± 16.0</td><td>0.08</td></tr>
</table>

As being done in several other states/regions, including but not limited to - Oregon, Illinois, Michigan, Minnesota, New Jersey, Vermont, Georgia, Washington DC - the additional savings attributable to thermostat optimization savings that now exist but were not present during this evaluation period should be valued in this study. In fact, Energy Trust of Oregon has determined that the additional savings offered from these free thermostat optimization solutions should be valued both for devices that were incented through utility programs, and that the incremental savings are claimable for all devices within the utility territory outside of those programs due to the market transformational aspect of utility energy efficiency programs which led to these vendor decisions and innovations in enhanced energy efficiency.1 This is vital information that needs to be incorporated to accurately assess the current energy efficiency benefits of smart thermostats in California.

1 See https://www.energytrust.org/wp-content/uploads/2020/11/Thermostat-Optimization-MTMemoFinal_20AUG2020_wSR-1.pdf</td><td></td></tr>
</table>

Comment #	Commenter	Document Page	Comment	Response
3	ecobee	23	**2. Addressing Selection Bias By Including Other Relevant Data Points such as ENERGY STAR** Due to selection bias issues inherent in quasi-experimental design, ecobee does not believe that quasi-experimental methods are a suitable alternative on their own to randomized experiments for smart thermostat evaluation, and that the use of quasi-experimental methods for smart thermostat evaluation should be strongly discouraged for policymaking purposes. In this case where a quasi-experimental design has already been utilized, ecobee believes that the best approach to address selection bias more directly and effectively is to run the ENERGY STAR metric on the devices used in the study and adjust for setback behavior. ENERGY STAR uses telemetry data and measures only HVAC changes, while whole-house data measures all changes made to HVAC and non-HVAC related end-uses alike. By comparing and averaging the two methods, DNV GL could better assess the true savings value. This approach has been recommended by the Northeast Energy Efficiency Partnerships (NEEP) as depicted in the figure below. 	The EPA rating is not designed as an evaluation method. Its application by NEEP as shown in the figure provided with the comment is an example of how the ENERGY STAR methodology is used for claiming savings, not evaluating them. Moreover, the use of HVAC runtime in place of whole-home energy consumption to ascertain the effect of smart thermostats is not practical given that such data is not typically available prior to smart thermostat installations for participants nor at any time for comparison non-participants. The use of RCTs to evaluate program smart thermostats, as suggested by the comment, is also not practical. While RCTs are the gold standard for evaluating the effectiveness of treatment interventions, most energy efficiency programs are not and cannot be run on a randomized experimental basis. For example, the residential HVAC measures (including smart thermostats) evaluated in program year 2019 are offered to eligible customers that can benefit from improving the energy efficiency of their homes and are not rolled out in any randomized manner. The quasi-experimental method is the best alternative approach available for evaluating the effects of measures rolled out in this manner. It affords ways of controlling the effect of weather and exogenous factors, and thereby isolates the effect of programs and measures on energy consumption. The quasi-experimental design used in the two-stage modeling framework of the current the evaluation is a well-established and accepted methodology that is appropriate for the assessment of energy changes at the home level after an energy efficiency intervention. The methodology is consistent with the approach laid out in the Uniform Methods Project (UMP) Chapter 8 modeling approach, which provides estimation protocols for energy efficiency interventions that have whole-home impacts like smart thermostats. The modeling approach is closely related to all other forms of program analysis that use energy consumption data including time-series, cross-section approaches. It is also consistent with CalTRACK, the recent effort to develop agreed upon steps for site-level modeling. Please also note that DNV received additional customer characteristics data from two utilities and found comparison groups created and, more importantly, savings estimates with

Comment #	Commenter	Document Page	Comment	Response
				and without those data to be highly similar. The findings related to this issue are discussed in section 7.5.4 (Savings for matches with and without additional customer characteristics). The use of the additional customer characteristics helped us conclude that matches that are well-balanced with respect to energy consumption provide reasonably matched participant and non-participant groups across a wider set of dimensions and the inclusion of additional demographic variables in matching is unlikely to change or improve savings estimates.
4	ecobee	50	**3. Appropriately Valuing Peak Savings and Load Flexibility** This report does not properly value energy savings during peak periods which is highly relevant in California with all customers being moved to time-of-use rates as it results in greater bill savings for customers and greater benefits to the grid. The Commission has recognized the importance of developing flexible load resources in its recently-issued joint SB 100 report with the California Energy Commission, which states that "load flexibility — the ability to shift electricity use to other parts of the day — is critical to maintaining a reliable and affordable supply of electricity," and recognizes that "the growth of load flexibility" is constrained by the "limited mechanisms to compensate for load flexibility in current utility programs and rate designs."[2] While ecobee recognizes that the parameters of the cost- effectiveness framework may be beyond the scope of this study, ecobee agrees with comments that other parties have provided in this docket that, "resource energy efficiency programs need to be measured for their full value of benefits they provide. This means that a metric that accounts for the energy, carbon reduction, capacity, and other energy system benefits of energy efficiency needs to be used to measure and track these programs instead of using the average annual value of kilowatt hours to guide investment. Existing goal setting and tracking metric, annual energy savings, does not capture the full value or need of the system. Energy efficiency should be valued in terms of its total monetary benefit in dollars or the sum of its lifetime avoided costs that are established by the CPUC. This total value metric incentivizes implementers and program administrators to save energy when it is most valuable and promotes those energy savings that best meet system needs (such as providing energy savings during summer evenings to avoid future power shortages)."[3]	The evaluators agree with the statement that peak period savings are important. A full benefit accounting of smart thermostats including their demand response potential is important but was beyond the scope of the evaluation; DNV was tasked with measuring gross and net savings of the measure and programs offering the measure. However, we do provide savings shapes in section 5.6 of the report despite the substantial technical challenges of doing so in the context of multiple installed measures. We include the load and saving shapes of households that installed smart thermostats along with other HVAC measures, and in cases where practical, alone to indicate when smart thermostats deliver their greatest energy savings. We also investigated and include savings during the DEER defined peak period (2 - 5 p.m. heatwave weekdays). The findings make it clear that smart thermostats deliver the greatest level of savings in early afternoons of summer. Although smart thermostats provided lower savings (and in some cases dis-savings) in late afternoon and early evening peak usage hours during this season, their notable savings during midafternoon summer hours, particularly among homes located inland, indicates that they have the ability to provide load flexibility that could be a valuable grid resource as indicated in the comment.

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<tr><td></td><td></td><td></td><td>With regards to better valuing peak savings and the ability to facilitate load flexibility, through the eco+ platform, ecobee devices offer time-of-use optimization. The evaluated California- specific incremental savings offered from time-of-use optimization are presented in the figure below.

Table 2: TOU High Level Results
<table>
<tr><th>Rate</th><th>Price Ratio (Peak: Off-Peak)</th><th>Climate Region</th><th>Average kW Savings During Peak Period</th><th>Peak Duration (hours)</th><th>Average On-Peak Percent Savings (kWh)</th><th>Average Total Energy Savings (kWh)</th><th>Percent Savings On Cooling Energy ($)</th></tr>
<tr><td>SMUD Res TOD</td><td>2.4</td><td>Hot Dry</td><td>0.25</td><td>3</td><td>23%</td><td>3.5%</td><td>8%</td></tr>
<tr><td>PG&E EV-A</td><td>3.7</td><td>Mixed Dry</td><td>0.18</td><td>6</td><td>28%</td><td>8.8%</td><td>19%</td></tr>
<tr><td>PG&E EV-A</td><td>3.7</td><td>Marine</td><td>0.10</td><td>6</td><td>20%</td><td>4.0%</td><td>11%</td></tr>
</table>

3 See https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M362/K898/362898671.PDF</td><td></td></tr>
<tr><td>5</td><td>ecobee</td><td>51</td><td>4. It does not properly value energy savings during peak periods which is highly relevant in California with all customers being moved to time-of-use rates as it results in greater bill savings for customers and greater benefits to the grid</td><td>See response to comment 4.</td></tr>
</table>

Comment #	Commenter	Document Page	Comment	Response
6	Google	General	Thank you for the opportunity to comment on this report. Google understands that it is difficult to effectively isolate the energy impacts of smart thermostats given the issues with selection bias, multiple measures per home, heterogeneous climates and housing types, Covid-19, and the general variability of residential energy use that may be large relative to expected savings in mild climates. We therefore appreciate attempts to minimize these potential sources of bias and noise via examining load shapes, demographics/surveys and timing considerations. Unfortunately, how these factors are mitigated becomes the subjective choice of the evaluators and in this repot we have concerns that these choices all lead to lower reported savings. A different set of choices, more consistent with the available data, could easily result in estimated savings impacts of smart thermostats at a rate of 2-3 times higher overall and even greater for single family homes. To avoid substantially underestimating the impact of smart thermostats, which could significantly roll back their uptake in California at a time when reliability is at an all-time need, it is imperative to understand the full implication of these choices when working on the 2022 work paper update for smart thermostats. We've identified three main categories of issues that resulted in the undercounting of savings, which we will detail further in this letter: ● Lack of inclusion of thermostat optimization savings: software changes by Google Nest and ecobee in 2019 added additional savings that are not evaluated in this paper. - Comment 7 ● Comparison group bias: survey data identified a net bias toward understating the savings, but no effort was made to adjust for this bias, leading to a potentially significant undercounting of savings. - Comment 8 ● Allocation of savings of thermostats vs other measures: evaluators allocated savings to measures based on engineering estimates, but the resulting allocation leads to savings results that are inconsistent with the data and with common sense. - Comments 9 - 13	Please see response to detailed comments (#7 to #13) provided for each of the points raised in this introductory paragraph.

Comment #	Commenter	Document Page	Comment	Response
7	Google	General	**Lack of Inclusion of Thermostat Optimization** The smart thermostat market in California has changed significantly since 2018. The two largest manufacturers, Google Nest and ecobee, now offer thermostat optimization (TO) programs free to all customers.[1] TO programs provide meaningful, incremental savings that are not fully included in this evaluation. In the summer of 2020, more than 300,000 Google Nest thermostats in California opted into Google Nest's TO program, "Seasonal Savings". This past winter has seen more than 400,000 California thermostats enroll in Seasonal Savings. Given this new feature that became part of smart thermostats stating in 2020, the entire premise of this evaluation -- that savings from PY2018 participants with a 2019 post period can be used to estimate PY2019 participant savings -- is called into question. The first-year savings for PY2019 participants should be based on the actual pre/post data for that group of participants and not based on prior year analyses. Furthermore, the TO feature should lead to further increases in measure savings after the first post year. The HVAC savings provided by Seasonal Savings in California has been studied in the past through randomized control trials. Savings average about 6 therms of natural gas (and a comparable number of kWh from furnace fans) over the winter and about 30 kWh over the summer, varying with climate and timing. Opt-in rates average about 40% of the total population[2]. Overall, fleet-wide savings can be conservatively expected to average a little more than 2 therms and 14 kWh (12 kWh over summer + 2 kWh over winter). Savings from a second year are expected to increase on these savings by about 1.5x due to a combination of persistence, incremental savings, and new opt-ins among prior opt-outs. Google Nest is actively working on further optimizing these thermostat adjustments to increase the impacts in the future. Google Nest deployed Seasonal Savings in the summer of 2019 in a limited capacity with Marin Clean Energy (MCE) and about 10,000 thermostats opted in. In January 2019, Seasonal Savings was deployed to SoCalGas and MCE territories with a total of 117k opt-ins in SoCalGas territory and 10k in MCE territory. We could perform further analysis to estimate the fraction of all 2018 thermostats activations that participated (by climate zone if desired). The DNV report found, surprisingly, that kWh savings averaged about 50% larger when 2020 was used as the post treatment period rather than 2019. This finding was unexpected since COVID-19 should result in fewer unoccupied hours in homes which would reduce savings from smart thermostats. But one explanation not mentioned in the repot is that Seasonal Savings was deployed	DNV designed its publicly reviewed study plan in the spring of 2020. During that time, the full effect of COVID on energy use was not clear, but the research team realized that estimating changes for a post period affected by both program intervention and pandemic precipitated disruptions in residential routines could result in cofounding the two effects. The team, thus, opted to use data from 2018 participants for the evaluation. Still, there is overlap between part of the post-period of 2018 participants and thermostat optimization (TO) programs, and estimated savings reflect the influence of these programs. Estimating the availability of additional savings from TO beyond the first-post year requires sufficient data from those periods, and these are not usually available for program activities that have only been in existence for a year prior to the evaluation. However, DNV conducted exploratory research to investigate the energy use impact of 2018 smart thermostat installations in 2020, which is past the first-post year for all evaluated installations. On average, estimated 2020 savings were higher for mobile home and multifamily participants by about 40% to 50%, but they were lower by 50% for single family participants. TO programs cannot be credited for the estimated increases, which could be due to differences in economic conditions faced by mobile home and multifamily compared to single family participants. A full investigation of the many changes in consumption behavior in 2020 need to be undertaken to determine whether an increase in savings is due to the TO initiatives or something else. See also response to related comment 2.

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			statewide in the summer of 2020 which could explain some of this increase -- offsetting the reduction in savings caused by the pandemic. In summary, TO programs provide incremental savings that are not fully included in this evaluation, but which should be in any future smart thermostat saving claims in California. The incremental savings may be larger than many of the overall impact estimates in this report.	
8	Google	General	**Comparison Group Bias** The report noted that survey data found bias in the comparison group which would be expected to lead to underestimation of energy savings from smart thermostats. While this fact is acknowledged, no attempt was made to adjust the savings for the bias. In fact, the narrative downplayed the impact from the bias. The main report states that savings could be up to 25% larger based on how different responses to survey questions might impact changes in energy use (footnote 42 says 20% and footnote 43 says 25%). But the appendix includes more detailed calculations showing a 12 kWh/year bias in mobile homes and 27 kWh/year in single family homes. These estimates were described as too small and uncertain to use. But it's worth pointing out that the reported single family (SF) savings are just 15 kWh and so an increase of 27 kWh nearly triples the savings. We agree that these kWh estimates are highly uncertain, but ignoring them is the same as setting them to zero -- which is not consistent with the data. It's also important to note that the estimated bias does not provide a true upper bound since the survey only covered a few sources of bias. The lack of any questions about the addition of other smart home devices (speakers, displays, webcams, doorbells, etc.) is especially notable since those technologies are seeing substantial market growth and are more common among households that have smart thermostats[3]. Each of these devices can be expected to consume 20-40 kWh/yr. These and other items omitted from the survey means that the bias may be much larger than reported. The larger issue here is that when the potential bias is large compared to the impacts being evaluated then the resulting savings estimates are not reliable enough to use for policy making.	Former footnote 42 has been removed (it repeats the information in footnote 43 (now 46) that has the relevant value of 20%). The magnitudes of potential bias reported are the household level (whole-home) savings estimates. The possible 27 kWh increase for single family participants should not be compared to the final smart thermostat savings estimate of 15 kWh but to the household savings estimate of 132. Given the proportional break out of savings, just 3 of those 27 kWh of possible bias related savings would accrue to the smart thermostats. The intent of this analysis is to provide rough support that the savings estimates are of approximately the right magnitude. No set of survey questions can assess the full range of potential biases. There are plenty of scenarios that would decrease savings rather than increase it (for example, newer ACs installed by participants). As calculated, the results would have led to an increase from 15 to 18 kWh of smart thermostat savings and a negligible change in overall realization rate for direct install programs offering smart thermostats. Please also note that DNV received additional customer characteristics data from two utilities and compared comparison groups created and savings estimates with and without those data and found almost no differences in results. The findings related to this issue are discussed in section 7.5.4 (Savings for matches with and without additional customer characteristics). We found matches that are well-balanced with respect to energy consumption provide reasonably matched participant and non-participant groups across a wider set of dimensions and the inclusion of additional demographic variables in matching does not change or improve savings estimates. Direct install participants for the most part would not have

Comment #	Commenter	Document Page	Comment	Response
				installed smart thermostats on their own; our research indicates high program attribution for these customers. Thus, it is unlikely they would adopt other high technology devices with the suggested level of energy consumption effects.
9	Google	52	**Allocation of Savings to Thermostats vs Other Measures** The whole home kWh savings from the billing analysis were allocated to measures based on engineering estimates of savings. This approach led to allocating 89% of the single-family savings, 79% of the mobile home savings and 20% of the multifamily savings to other measures. The thermostat impact estimates are almost entirely driven by this allocation process and the results are not consistent with the data in multiple ways: 1. *<u>Load Shapes:</u>* Smart thermostats' cooling savings are expected to be largest in the afternoon when unoccupied homes can have more efficient set points and then savings turn negative in the evening as air conditioners run to recover the comfort set points. The other HVAC measures (coil cleaning, RCA, fan controller, duct sealing, fan replacement) should show a different pattern, with savings proportional to cooling use and no evening period of negative savings. If the savings allocation in the repot was accurate (thermostats are 11% of SF savings and 80% of MF savings), then the load shape impacts should look very different between these housing types. If accurate, savings for SF homes at 1PM should be	The available savings shapes do not provide enough information to substantiate a particular perspective on the savings allocation process. The analysis only provides one smart thermostat savings shape, which is for multifamily sites that installed only a smart thermostat. Smart thermostat savings shapes for other dwelling types are unknown. In comparing household level savings shapes that reflect the effect of different mixes of other measures, there are too many unknowns to be able to support hypotheses with respect to savings allocation. In particular, it is essential to understand that unlike the non-thermostat measures that may produce low but not negative savings, smart thermostats have the potential to produce negative savings at any time of the day depending on behavior in the evaluation period relative to baseline behavior. The multifamily smart thermostat shape shows evidence of negative savings during some hours and the single-family shape could

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			about the same as at 9PM because cooling loads are about equal at those times. But the load shape analysis (p.52) shows very different patterns -- ones that are consistent with significant thermostat impacts for all housing types. If thermostats only provided 11% of the single-family savings, the load shape should not reflect the thermostat savings pattern so clearly.	have considerably more negative savings, both explaining the combined load shape and the allocation of savings that Google considers small.
10	Google	54	2. *<u>Peak Demand Impacts:</u>* The report shows (p.54) that peak impacts were larger in both absolute and percent terms among homes that only received a thermostat vs. homes that received multiple measures. It's hard to reconcile this finding with the large allocation of savings to these other measures.	The smart thermostat only savings reported in Table 5-7 largely reflect multifamily savings since most of these installations happened in multifamily homes. These savings are thus only indicative of multifamily savings and savings for a subset of participants that only needed/wanted smart thermostats. Comparisons would have to be made within multifamily participant groups or smart thermostat only installers and not across households that installed different mixes of HVAC measures. Also, Table 5-7 indicates savings during the DEER defined peak period that covers the afternoon hours of 3-5 p.m. Smart thermostat savings are relatively high during those hours but fall or are even negative during evening hours. This does not translate to higher smart thermostat savings across all hours and the whole year.
11	Google		3. *<u>Fan Controllers:</u>* Savings claims for the fan controller are larger than for smart thermostats, which makes little sense because the smart thermostat includes the same fan-overrun feature in addition to other energy savings features. Yet the evaluation surprisingly attributes three times as much savings to a fan controller as a smart thermostat in SF homes -- 48 kWh vs 15 kWh.	While we did not conduct analysis to compare savings of these two measures (since it was not part of the scope of the evaluation), DNV's informal analysis of savings from homes that only installed smart thermostats compared to homes that only installed fan controllers in the same housing type and climate zone indicate the latter to have larger savings than the former. This could be because fan controllers are generally only installed on older less efficient HVAC units that do not already have that

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				functionality on board. Fan controllers may thus be reducing condenser action only on older less efficient units while smart thermostats are installed and likely redundant to technology that may already be part of more efficient HVAC units, which use less energy and lower smart thermostat savings opportunities.
12	Google	44 (figure 5-5) & 47 (table 5-3)	4. *Direct Install vs Rebate Savings:* The reported savings in Single Family homes are 15 kWh for direct install (DI) but 56 kWh for rebate. But, we should expect larger savings in SF DI than rebate because we know that 100% of the thermostats were installed at the expected time. This savings anomaly would largely disappear if just the fan controller savings were set to 0 which then would more than triple thermostat savings to 51 kWh in SF (and 58 kWh overall).	First, this is an evaluation of the program and there would be no more justification for zeroing out fan control savings than there is for zeroing out smart thermostat savings. Second, there could be many reasons for the difference between the direct install and rebate savings, such as lower baseline consumption, less heating or cooling, and lower engagement with the smart thermostat among direct install participants. It is also plausible that rebate participants that opt to install smart thermostats on their own volition may use the measure to save more than direct install participants that install it in response to implementer offers.
13	Google	56	5. *Multifamily vs Single Family Savings:* The reported thermostat savings are almost 4x larger in MF than SF even though the MF loads are much smaller and customers in MF DI are expected to be less engaged with the energy savings features of the thermostat. The whole home savings are lower in MF and so this savings disparity is entirely driven by the savings allocation method. These are just a few examples that indicate that the savings allocation approach appears to have substantially under-allocated savings to smart thermostats. The report mentions in several places that the whole home savings provide an upper limit to the thermostat savings. But given the survey findings about a biased comparison group and the larger peak savings among thermostat only homes, thermostat savings could be even higher than the whole home results reported.	Whole-home savings are lower for multifamily participants because they have lower load and fewer measures installed (they installed largely smart thermostats alone). There is no evidence they engage less with the energy saving feature of smart thermostats compared to single-family or mobile home Direct Install participants. Apart from size and load levels, single family and mobile homes may differ in structure, HVAC equipment, and resident behavior. As a result, there could be many reasons the generally higher consuming homes still had smaller thermostat-related savings. While a plausible argument can be made that smart thermostat savings could be higher if all of the potential concerns listed were to line up and all point in the same direction, all of these concerns are hypothetical and contingent on assumptions that are not necessarily supported by the data or for which there are reasonable counter hypotheses that are equally feasible. The comparison group analysis indicates that the comparison group is well matched and biases related to it are slight. See also response to comment #9.

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14	Google	General	**Requests for More Details** In addition to these methodology issues, the report does not appear to include many details that would help in interpreting the results -- especially the estimated breakout of heating, cooling and baseload energy use and the sample sizes by subgroup (climate X housing type). HVAC load estimates and the savings as a percent of those loads are especially valuable in understanding realization rates. The claimed savings averaged 229 kWh/year -- which might be reasonable if cooling loads averaged 2,000 kWh but would indicate a clear problem if loads averaged 1,000 kWh. Without information of the HVAC loads it's hard to put the results in context or assess how much of the savings shortfall is due to over-estimated cooling loads in the target populations vs over-estimated percent savings. An evaluation is most useful if it can help identify the reasons for the results.	Edits made to the report to include heating, cooling and baseload energy use and participant population counts by climate zone and dwelling type (Table 7-4 in Appendix F). Footnote 45 is included to cross reference this table in section 5.1.3.
15	Google	43-44	We also have a question about the allocation of savings to thermostats by climate and housing type shown in table 5-1. The numbers don't appear to be consistent with Table 5-2. For example, 5-1 shows 42% of savings in CZ2 attributed to thermostats in mobile homes. But Table 5-2 shows just 15 kWh out of 75 kWh attributed to the thermostat -- just 20%. We would ask for confirmation of whether this is an issue of interpretation or if there are typos.	We have updated the values in Table 5-1 that reflect the effective percent allocators used to derive smart thermostat savings from the estimated whole-home savings by dwelling type and climate zone. These updated percentages are savings weighted versus the straight averages we provided in the report of the percent allocators used to disaggregate whole-home savings to measure savings at each site.
16	PG&E	2	Pacific Gas and Electric Company (PG&E) acknowledges the collective efforts of the DNV team overseen by the California Public Utilities Commission (CPUC) in completing this draft evaluation for the smart thermostat measures offered by the Investor- Owned Utilities (IOUs) and other Program Administrators (PAs) in the 2019 Program Year (PY). We appreciate the challenges—and tradeoffs—that the pandemic placed on the evaluation team when designing the evaluation methodology. In the ensuing paragraphs PG&E provides a few of its questions and comments to this draft. More are included in an Excel table sent separately. Section 1.3 of the report explains the energy consumption data analysis, which is based primarily on a pre/post design, in combination with an engineering analysis. The explanation is dense, however. Does the table below accurately represent the key design elements of the consumption analysis, and if not, could the evaluators please provide the necessary corrections?	The descriptions provided in table (also provided in accompanying PG&E worksheet2) accurately represent the key design elements of the consumption data analysis.

<table>
<tr><th>Comment #</th><th>Commenter</th><th>Document Page</th><th>Comment</th><th>Response</th></tr>
<tr><td></td><td></td><td></td><td>
<table>
<tr><th colspan="3">2019 Smart Thermostat Impact Evaluation - Evaluation Design</th></tr>
<tr><th></th><th>PRIMARY DATA SOURCE FOR ENERGY SAVINGS</th><th>ADDITIONAL DATA TO DERIVE MEASURE SAVINGS</th></tr>
<tr><td>REBATE PROGRAMS</td><td>Per whole-house t-stat average savings as determined in 2018 t-stat impact evaluation of rebate programs</td><td>2019 participant counts by PA from 2019 PA CEDARs t-stat claims</td></tr>
<tr><td>DIRECT INSTALL PROGRAMS</td><td>Energy use of customer homes receiving retrofits in CY 2018 that included t-stat measures (monitoring periods in 2019), as compared to similar customers not having participated.</td><td>Two-step disaggregation process: First, total whole house savings estimated for the whole house using regression analysis. Next savings were allocated to individual installed measures using engineering analysis, using information from recent evaluations and 2019 RASS Study. Analyses conducted by housing type (single family, multifamily, and manufactured homes)</td></tr>
</table>
</td><td></td></tr>
<tr><td>17</td><td>PG&E</td><td>47</td><td>In comparing the results from the 2018 and 2019 impact evaluations (see table below) no gas savings were found for the direct install program in the PG&E service territory (or statewide), as shown in the table below. To what extent do the evaluators attribute this finding to the change in the evaluation methodology employed between the two studies?
<table>
<tr><th colspan="7">Comparison of 2018 and 2019 Smart Thermostat Evaluation Results-SW and PG&E</th></tr>
<tr><th></th><th>Participants</th><th>Gross Claimed (MTherms)</th><th>Evaluated (MTherms)</th><th>GRR</th><th>NTGR</th><th>Net Evaluated (MTherms)</th></tr>
<tr><td>SW, 2018</td><td>222,457</td><td>3.00</td><td>459.9</td><td>0.15</td><td>0.76</td><td>348.2</td></tr>
<tr><td>PG&E, 2018</td><td>35,543</td><td>743.21</td><td>273.93</td><td>0.37</td><td>0.70</td><td>192.49</td></tr>
<tr><td>SW-Rebate, 2019</td><td>51,212</td><td>725</td><td>140.3</td><td>0.19</td><td>0.51</td><td>71.6</td></tr>
<tr><td>SW-Direct Install, 2019</td><td>108,986</td><td>1.241</td><td>0</td><td>0</td><td>0.93</td><td>0</td></tr>
<tr><td>PG&E-Direct Install, 2019</td><td>21,388</td><td>374.124</td><td>0</td><td>0</td><td>0.90</td><td>0</td></tr>
</table>
</td><td>The rebate program evaluation found no gas savings prior to the adjustment for self-selection. The adjustment for self-selection was pursued as a result of the specific population in question and the nature of the electric results, primarily cooling and baseload. While the claims of self-selection were largely anecdotal and the model results could have been explained in other ways, the relatively small adjustment for self-selection was deemed reasonable given the otherwise severe hit to expected savings. Gas savings were adjusted in a parallel fashion and these adjustments produced the relatively small savings that were reported.

The direct install evaluation, where no reasonable expectation of self-selection was in place, found no savings. As we point out in the report, this is consistent with the prior PG&E and SoCalGas reports that also found no gas savings.</td></tr>
<tr><td>18</td><td>PG&E</td><td>44</td><td>As discussed in Section 5.1.3 of the report, smart thermostats were installed as part of a bundle of other HVAC and other non-HVAC technologies. In the modeled savings estimates on electric consumption, the finding was that per-household savings ranged between 70 kWh and 132 kWh, which represents between 1% and 2% of total household consumption. Could DNV comment on the uncertainty bounds around estimates when attributing these savings to individual measures?</td><td>As stated in Section 1.3, the total savings estimate across all measures is well grounded, but there is some uncertainty in the allocation of this total among the measures. At the same time, the allocations are based on simulation estimates for individual measures, each of which was calibrated based on recent empirical studies. Thus, the engineering analysis provides a reasonable savings estimate based on what is known about California homes and about the measures, while the consumption data analysis calibrates the engineering estimates to observed usage and changes in usage.</td></tr>
</table>

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				Taking the allocation proportions as correct, we provide the standard errors and p-values of all savings estimates by dwelling type in Table 7-6. Almost all estimated savings are statistically significant at least at the 95% confidence level. Most of the estimates are also well-determined with relative precision of 0.3 or lower.
19	PG&E	General	How would the different participant decision drivers of direct install programs, such as landlords electing to improve buildings, be accounted for when disaggregating household savings to apportion savings to smart thermostat measures in rebate programs? We are appreciative of the CPUC's and evaluators' efforts in crafting a comprehensive evaluation report. Moreover, Pacific Gas and Electric Company appreciates the opportunity to submit these questions and comments.	Whole-home savings estimates are disaggregated into measure level savings based on engineering simulation modeled shares. The simulation models provide estimates of measure savings by housing type and climate zone. The decision maker type does not affect whole-home savings disaggregation.
20	PG&E	2	Could DNV please confirm or correct PG&E's understanding of the top-level methodology used to generate the savings estimates for smart thermostats for the rebate and direct install channels as provided in the table in Worksheet 2? (see comment #16)	See response to comment 16.
21	PG&E	5	In the key findings section, the report states that "our attempt to disaggregate savings statistically using measure-level consumption regressions did not produce reliable results." Could DNV please provide a layman's explanation of the challenges that were encountered, and whether it was a result of too many different combinations of measures installed across households throughout the service territories?	We did not get reliable estimates of measure savings when we fit models with separate coefficients for each measure or even for some natural groups of measures; many of the coefficients had very wide error bars or unrealistic values. This challenge was primarily due to having a large number of measures whose effects we were trying to separate. Given the number of measures, the more different combinations of measures installed the better, because it would have helped with the identification of individual measure effects. However, having certain combination occurring a high fraction of the time, made it hard to isolate the separate effect of each measure.
22	PG&E	6	Did DNV consider that this differential impact of savings be related to building shell characteristics, rather than to occupant behavior?	The consumption data analysis results account for both.
23	PG&E	8	Given the findings that direct install participants have significantly lower engagement with their smart thermostats, and DNV's observation that "the differences….shed light on the lower than expected savings estimates for these program participants" lead the evaluators to reconsider whether the evaluation methodology to use direct install participants as a proxy for rebate participants for generating per-household savings estimates was a good approach?	DNV did not use direct install participants as a proxy for rebate participants (i.e. direct install per household savings were not used to evaluate rebate programs). We applied the PY2018 rebate per-household savings estimates to the PY2019 rebate participants.

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24	PG&E	20	Could DNV speculate as to why refrigerant charge and coil cleaning measures are associated with negative gas savings?	The tracking data reports gas dissavings for refrigerant charge and coil cleaning. However, the supporting workpapers do not provide any explanation for these and the evaluation team cannot discern any physical reason why refrigerant charge and coil cleaning would directly affect (increase) gas consumption. As a result, customers with negative coil cleaning and/or refrigerant charge claims, and no other gas savings measures were excluded from gas models used to estimate whole-home gas savings.
25	PG&E	24	In Section 3.2.2. DID modeling, third paragraph, the definition of a blackout period uses the word "intervention" rather than "blackout"	Noted. Edits made.
26	PG&E	26	Could DNV explain how adjusting t-stat setpoints/degrees of setback "so that cooling and heating savings is 2% to 3%, in line with PA workpaper estimates" doesn't limit the potential savings contribution for smart thermostats in the model?	The potential savings of all measures is ultimately driven by whole-home change in energy consumption pre- to post-installation. This is why we use consumption data analysis to evaluate measure impacts. The allocation of whole-home savings to specific measures is extremely difficult where multiple measures are installed. Engineering simulations model end use savings to help disaggregate whole-home savings to specific measures. Allocating savings to smart thermostats is particularly challenging because these devices have a much wider degree of savings variability compared to the other measures installed; behavioral elements and replaced thermostats' set points make it possible for smart thermostats to actually increase energy consumption or motivate savings. We used 2018 impact evaluation results for smart thermostats to inform engineering simulated savings. Empirical data from recent studies was similarly used to ground the simulations of the other measures.
27	PG&E	Section 5.1.3	As discussed in Section 5.1.3 of the report, smart thermostats were installed as part of a bundle of other HVAC and other non-HVAC technologies. In the billing analysis conducted by DNV on electric consumption, the finding was that per-household savings ranged between 70 kWh and 132 kWh, which represents between 1% and 2% of total household consumption. Could DNV comment on how different decision drivers of participation in direct install programs, such as landlords electing to improve buildings, may result in different occupant behaviors that drive energy savings? Additionally, could DNV comment on whether receiving a rebate might impact savings performance?	Given that the number and type of installations differed between multifamily and single family/mobile home participants (with about 80% of the former installing only smart thermostats compared to a relatively small proportion installing only smart thermostats for the latter two) and that our research surveyed occupants only in single family and mobile homes, we are not able to say definitively how and if decision maker type affects savings. Whether a receiving a rebate affects savings performance is essentially a takeback question, which wasn't probed in our surveys.

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28	SCE	4	SCE thanks Energy Division and DNV-GL for allowing an opportunity for public review and comment on the Draft Impact Evaluation Report of Smart Thermostats (PY2019). SCE comments are below: 1. Table 1-2. Total smart thermostat electric savings, 2019 There is a critical need to understand specific recommended measure savings per building type (for all Residential Building Types) and climate zone type (for all 16 CZs) to further evaluate and understand cost effectiveness potential from measure per specific building type and climate zone. Study referenced Appendix A: Gross and net lifecycle savings and Appendix B: Per unit (quantity) gross and net energy savings which are currently not available for review. Based on review data, it is not clear if realization rate varies per climate zone, e.g., per cooling (cooling degree day) and heating (heating degree day) and/or building type. It is expected that these will vary.	Appendix A and Appendix B are included as attachments in the report posted to the PDA site. Readers need to open the pdf file to find the appendices that can be accessed through links on the left hand side of the report. Moreover, Table 5-2 from this report posted on the PDA site (https://pda.energydataweb.com/#!/documents/2487/view) provides savings estimates for direct install programs by climate zone and building/dwelling type. The DNV March 2020 report has the analogous rebate program savings estimate by climate zone and building/dwelling type (see http://www.calmac.org/publications/CPUC_Group_A_Report_Smart_Thermostat_PY_2018_CALMAC.pdf). Rebate estimates are also provided at the PA level by climate zone and building/dwelling type in the March 2020 report. Based on stakeholder comments received then, the direct install savings for the current report were estimated by climate zone and building/dwelling type so that the same estimates are applicable across PA programs within the same climate zone and building/dwelling type.
29	SCE	4	2. Table 1-3. Total smart thermostat gas savings, 2019 (same review comments as those for Table 1-2 total smart thermostat electric savings)	See response to comment #28. Also note that DNV found no gas savings for direct install smart thermostats. The details are provided in the sections 5 and 7.7 of the report.
30	SCE	7	3. (Page 7) Both direct install and rebate program participants exhibit some differences in household characteristics compared to non-participants. In addition to informing the proportion of savings for which the programs should receive credit, surveys also provide relevant information on customer characteristics and behavior related to energy consumption and savings. It is not clear from the study if demographic within both the control and treatment groups was considered and aligned and accounted with measure savings methodology – e.g., based on demographic human behavior on technology operation may differ specially between (younger) affluent and (older) non-affluent customers.	The demographic and customer behavior related data collected from surveys were used to see if possible differences exist between participants and matched comparison households that might influence estimated savings. While the select data collected indicate some small differences between the groups, these were shown to have minimal possible effects on energy consumption. Moreover, the purpose of the matching process is to address these issues as best as possible. The analysis DNV used in the evaluation takes advantage of all site-level data that are available, and the considerable research performed last summer to determine how best to use those data. DNV received additional customer characteristics data from two utilities and compared comparison groups created and savings estimates with and without those data and found almost no differences in results. Finally, the largely unsupported assumptions stated around the

<table>
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<tr><td></td><td></td><td></td><td></td><td>2018 evaluation about rebate program adopters, their age and affluence, and likely increases in consumption correlated with the purchase of smart thermostats, are even less relevant for the direct install customers who are the focus of this year's analysis.</td></tr>
<tr><td>31</td><td>SCE</td><td>9</td><td>4. (Page 9) Key findings - low gross realization rates for electric savings – Recommendations and Implications – "Review the potential for fan control measures to interfere with savings opportunities from smart thermostats. Consider restricting smart thermostat direct install to homes without fan control measures."
Impact evaluation study does not provide any evidence (and/or statistically significant data) demonstrating that NEST's fan delayed feature (not available with other SCT technology) has any significant energy savings realization. SCE recommendation is to ignore impact evaluation recommendation (and speculation on energy savings contributions) until energy savings potentials specifically from NEST's "fan delayed" feature is demonstrated. Based on information provided in "Figure 1-2. Average electric whole-home and smart thermostat savings, PY2019 direct install programs" (for single family), any potential measure savings attribution from NEST's fan delayed feature are expected to be marginal, if any.</td><td>DNV noted that some SCTs have functionality that overlaps with fan controls. Google comments (see comment #11) has effectively confirmed this. This feature is also included in ecobee brands although over 95% of direct install program smart thermostats were Nest.

The issue we point out is that if there are redundant capabilities, then the same amount of savings will be distributed to more measures thereby lowering savings across all measures. The intent was not to use this to explain the low savings estimates but to point to a flaw in program design, which no one seems to refute.</td></tr>
<tr><td>32</td><td>SCE</td><td>61</td><td>5. 2021.03.19 RES_SmTstat_IESR_Appendix B

Per Unit (Quantity) Gross Energy Savings (kWh)
<table>
<tr><th>PA</th><th>Standard Report Group</th><th>Pass Through</th><th>% ER Ex-Ante</th><th>% ER Ex-Post</th><th>Average EUL (yr)</th><th>Ex-Post Lifecycle</th><th>Ex-Post First Year</th><th>Ex-Post Annualized</th></tr>
<tr><td>PGE</td><td>Residential Smart Thermostat</td><td>0</td><td>30.5%</td><td>30.5%</td><td>10.4</td><td>479.3</td><td>45.5</td><td>45.0</td></tr>
<tr><td>SCE</td><td>Residential Smart Thermostat</td><td>0</td><td>30.3%</td><td>30.3%</td><td>10.3</td><td>441.4</td><td>43.5</td><td>43.0</td></tr>
<tr><td>SCG</td><td>Residential Smart Thermostat</td><td>0</td><td>74.0%</td><td>74.0%</td><td>10.4</td><td>362.2</td><td>35.1</td><td>34.0</td></tr>
<tr><td>SDGE</td><td>Residential Smart Thermostat</td><td>0</td><td>20.5%</td><td>20.5%</td><td>11.0</td><td>209.4</td><td>19.2</td><td>19.0</td></tr>
<tr><td>MCE</td><td>Residential Smart Thermostat</td><td>0</td><td>0.0%</td><td>0.0%</td><td>9.1</td><td>69.3</td><td>7.6</td><td>7.6</td></tr>
</table>
Average EUL documented in Appendix B (for some of the IOUs) is not consistent with that directed by commission staff in previous workpaper updates and retain in latest version of the workpaper (e.g., 9.1). Are there additional studies conducted on EUL supporting higher EULs (e.g., 10.3 for SCE) that IOUs should be aware of? Please clarify.</td><td>The values reported in Appendix B are taken directly from the tracking data provided by the utilities to the CPUC. The EUL value transitioned from 11 to 9.1 starting 7/6/2019 as reflected in the DEER database and in 2019Q3 of the tracking data.</td></tr>
<tr><td>33</td><td>SCE</td><td>65</td><td>6. Does the report recognize that SCE targets are in hotter zones than the other IOUs (p.65)? Disaggregating the savings beyond ATE would have been more useful for the future of the measure as well as operations standpoint.</td><td>The modeling approach directly accounts for varying climate. Results are estimated and provided at the climate zone level which is relatively granular with respect to climate.</td></tr>
<tr><td>34</td><td>SCE</td><td></td><td>7. The report puts an emphasis on Mobile homes vs. Other dwelling types of where mobile homes have fewer participation. Wouldn't that be also useful investigate CARE vs. Non-CARE customers?</td><td>Savings claims differ among mobile home, multifamily, and single-family homes, which is why we took this approach. It could also be helpful to investigate the difference between CARE</td></tr>
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				and non-CARE customers within these housing types, but that was out of scope for this evaluation.
35	SCE	36	8. In the survey tables it would have been useful to see overall differences between participant survey characteristics vs. Non-participants survey characteristics, and whether those differences are statistically significant.	In the report, we do provide comparisons between direct install participants and matched non-participants including indications on whether these differences are statistically significant. The aspects covered in these comparisons include demographic characteristics, the manner in which smart thermostats are used, and energy use behaviors. See sections 4.2.2, 4.2.3 and 4.2.4 of the report.
36	SCE	4	9. What should be the primary takeaway from low Gross Realization Rate and very high NTG ratio? Is this issue due to the survey or program design? This is particularly the case for Direct Install Programs.	The question implies that low GRR and high NTGR are unexpected or illogical. NTGR is about program influence whereas GRR is about measure efficacy (i.e. actual savings achieved). The high NTGR is simply due to the fact that customers received these measures under circumstances where they were unlikely to have been actively searching them out. As a result, the program gets credit for influencing the installation. The low GRR stems from savings that are lower than expected for the measure.
37	SCE	General	10. In the report it was not stated clearly but did you merge observed data (usage) with the survey data? Otherwise, it is difficult to determine what experiences those survey participants (increase or decrease in kWh) actually had with Smart Thermostats. Linking survey data and actual usage data can offer better understanding of the consumer behavior and observe whether households' revealed preferences match with observed behavior. Can we consider this methodology for the final analysis or the next program year impact evaluations?	This is an interesting analytical approach that DNV has undertaken in other evaluations and will consider doing so in the future. It was not possible to implement the approach for the current evaluation since the consumption data analysis was based on data from 2018 participants while the survey was conducted among 2019 participants.
38	SDG&E	19	It is understandable why the analysis of hourly electric data would exclude households with solar, but why were customers with onsite solar production removed from the daily gas data analysis dataset?	Footnote added to Table 3-3 to clarify that gas data was not excluded from the analysis for customers with onsite solar.
39	SDG&E	19	Did the evaluation team address attrition due to move-out? If so, please explain how.	Yes, the team did address attrition due to move-outs. Only customers with 12 months of pre- and post-installation data were included in that analysis. Please see Table 3-3 and text related to it.
40	SDG&E	32-34	Section 4.2.1 Free-ridership and program attribution tables 4-4 and 4-5 reference NTGR by PA and program delivery. Is the study suggesting that findings should trigger an update to existing NTGR for smart communicating thermostats? If so, then it should be listed in section 6 conclusion and recommendations section as reflected on tables 1-2 and 1-3, please clarify.	The NTGRs are point estimates for PY2019 which are applied to adjust PY2019 gross savings estimates. We are not recommending adjustments to ex ante NTGRs since we do not have the multiple years indicating a trend that warrants a change to ex-ante NTGRs.

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41	SDG&E	58	Recommendation 1: "No discernible gas savings from direct install programs, and low gas savings from rebate programs. These results are consistent with other studies." Please provide the references for these studies.	PG&E Smart Thermostat Study: First Year Findings. Applied Energy Group. December 21, 2016. Emerging Technologies Program Project Number ET14PGE8661. PG&E Smart Thermostat Study: Second Year Findings. Applied Energy Group. March 20, 2018. Emerging Technologies Program Project Number ET14PGE8661. Update: Developing Ex-Ante Statewide Estimates of Savings Based on PG&E's Smart Thermostat Study. Applied Energy Group. January 22, 2019. Southern California Gas Residential Smart Thermostat Impact Evaluation Research. Navigant. January 25, 2019 Smart Thermostat Energy Savings. Nexant. July 26, 2019
42	SDG&E	76	In tables 7-9 and 7-10, an installation timing factor of 50% was applied. What is the source of this value?	It is a DNV assumed value based on the following logic. If an unrelated measure is installed at exactly the same time as the smart thermostat, then it will have a 100% conflation factor. If that measure was installed 6 months prior to or after the smart thermostat, then its effect is roughly 50%. If it is installed 12 months prior to or after the smart thermostat, then its effect will be between 1/12th and zero. Across the two-year window for any customer in either treatment or comparison group, if the probability of installation of unrelated measures is approximately uniform, then the overall expectation of the impact of the timing of the installation is approximately 50%. Since there is some probability that the installation fell fully outside of the evaluation window, this could be an overestimate of the effect.
43	SoCalGas	3	Southern California Gas Company ("SoCalGas") appreciates the opportunity to submit its responses to the Impact Evaluation of Smart Thermostats – Residential Sector – Program Year 2019 – Draft Report. SoCalGas thanks DNV GL for their efforts and the report. SoCalGas offers comments and suggestions below. 1. Methodology and Analysis The limitation of allocating savings in proportion to the engineering estimates in Direct Install (DI) programs (page 3) raises the question of the accuracy of the net evaluated savings results. While there are other measures and technologies installed in the households that would create uncertainty in deriving savings for each measure, with the smart thermostat, there is not enough evidence to conclude a zero savings value for smart thermostats. This ignores the impact of other non-evaluated measures, which likely alter the whole-home savings results.	All measures installed at the house as part of the direct install program were accounted for in the evaluation. The household level savings are a robust estimate of the change in consumption due to the full set of measures. Allocating the savings proportionally does assume that all measures contributed in proportion to their simulated engineering savings share. In addition to estimating savings for participants that installed smart thermostats with other HVAC measures, we also estimated gas savings for multifamily direct install homes with smart thermostat installations only; see section 7.7 in the report. In both cases we found no gas savings.

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44	SoCalGas	15	For this Impact Evaluation, savings are calculated based on consumption data analysis. However, this method was not used in the Water Heating Measures Impact Evaluation. How did DNV GL decide which method is appropriate for any evaluated measure?	The PY2019 water heater evaluation did not include ex-post analysis of gross savings and focused on net adjustments to reported gross savings only, whereas the smart thermostat study includes both gross and net savings evaluation in PY2019. Smart thermostats are a new program measure without established gross savings whereas water heater measures have ex ante savings that have been established as well as several ex post evaluations that have provided gross realization rates.
45	SoCalGas	General	Why would a survey-based approach be not suited for smart thermostat, especially when this measure is often installed with others in a DI program?	A population (participants) level billing analysis provides robust results and is the accepted methodology for several programs including ESA, which is also a direct install program.
46	SoCalGas	6	On page 6, it is mentioned: "As we indicate earlier, our analysis also suggests that savings from fan controls compete with savings from smart thermostats, resulting in lower total savings than if they were installed separately." • Would the best approach be to install one instead of the other, and which one should be more encouraged? SoCalGas program administrators (PAs) are interested in learning more about this.	Smart thermostats provide fan control along with other features. If a smart thermostat is installed, then no fan control should be installed. Please also note that newer HVAC units have built in fan controls, and all HVAC program designs should take this into consideration.
47	SoCalGas	8	Page 8 says, "A comparison of direct install and rebate program participants, and non- participants who installed their own smart thermostats on how they used the device reveals that direct install participants have significantly lower engagement with their smart thermostat." • This is an interesting point to be aware of. PAs will take this observation into account as PAs oversee 3rd party implementers who offer smart thermostats in their lineup of measures to determine the best ways to keep participants engaged with utilizing all helpful features provided by the smart thermostat.	Noted. Thank you.
48	SoCalGas	41	On page 41, it shows 46% of all household types having a smart thermostat installed with other measures (Figure 5-2), which does not include households with gas savings claims. How can this support a conclusion of no savings for gas in a DI program? Since there is no exact method to estimate gas savings for smart thermostat due to statistically insignificant consumption results and the mix of other technologies in the households, a conclusion of zero savings for smart thermostat is apparently subjective. It also dismisses smart thermostats as a measure in DI programs, especially in SoCalGas' multi-family (MF) DI programs – the largest portion of SoCalGas' DI. Given that the smart thermostats in the SoCalGas MF DI program was at no cost to the customers (property owners), tenants did not experience any cost burden; the DI approach has been effective in overcoming the split incentive issue which is unique to MF programs. SoCalGas PAs acknowledge that	Gas household level savings are a robust estimate of savings for the full set of measures installed. It is true that some measures could have positive savings and others negative. However, of all the gas measures, the smart thermostat is the most capable of causing an increase in consumption as it is primarily a behavioral measure. There is no reason to believe that other measures are causing an increase in gas consumption and obscuring real savings from smart thermostats. In addition to estimating savings for participants that installed smart thermostats with other HVAC measures, we also estimated gas savings for multifamily direct install homes with smart thermostat installations only; see section 7.7 in the report. In both cases we found no gas savings.

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			savings from smart thermostats are low, however, customer feedback suggests smart thermostats are considered an effective measure to make customers engage in energy saving practices. SoCalGas PAs oppose the zero savings claim for DI smart thermostats and propose that the evaluator take a closer look at the dynamics within MF DI to truly assess the influence of the program upon the decision maker.	
49	SoCalGas	46	Although Rebates consists of only 30% of smart thermostats installed, the analysis in the report (page 46) does not include as much detail as the DI program results, such as climate zones and housing types. How can readers have a clear comparison between the two types of programs when information provided in the analysis is not presented in a similar fashion, especially when Rebate programs yield a positive savings value, compared to zero savings in DI programs, as recommended? There is no indication that data is not available in the report.	The 2018 impact evaluation focused on rebated smart thermostats. All of the methods and results for smart thermostats offered via rebate programs were discussed there; the report is posted on CALMAC and can be found at http://www.calmac.org/publications/CPUC_Group_A_Report_Smart_Thermostat_PY_2018_CALMAC.pdf. Savings estimates from that report were applied to 2019 tracking data for this report.
50	SoCalGas	58	2. Findings and Recommendations It is recommended to require DI programs to include or strengthen contractor training and customer education to help save energy. For Comprehensive Manufactured Homes DI programs, SoCalGas' contractors provided education and training on the smart thermostats. The training provided to technicians included how to educate the customers on the value that the smart thermostat provides, namely how the technology works to save energy and improve the user experience with HVAC equipment. For MF DI programs, SoCalGas PAs will present this to 3rd party program implementers offering smart thermostats, starting in 2021 program year. SoCalGas suggests that future evaluations distinguish between programs that differ in implementation methods to provide more accurate conclusions to a specific program or measure.	Noted. Thank you. The findings presented here are based on an analysis that cuts across PAs and programs and looks at customer types (i.e. mobile home + single family customers). An independent process evaluation is needed for insights related to customer education and contractor training for specific PA programs.
51	SoCalGas	24	3. Minor Errors/Formatting Section 3.2.2, fourth paragraph, second sentence: "All the sites used in this evaluation indicated no more than two installation months for the mx of measures they delivered." We assume the word should be "mix."	Noted and edits made. Thank you.

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52	SoCalGas	35	Section 4.2.2, leftover redline changes	Noted and edits made. Thank you.
53	SoCalGas	36	Table 4-7: should each column under the Dwelling Vintage, Dwelling Size, and Income sections sum to 100%?	The tables exclude the percent 'Don't Knows' and no response, thus, the reported numbers in the table do not always sum to 100%.