PG&E Smart Thermostat Study: Second Year Findings

ET Project Number ET14PGE8661

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Issued: **March 20, 2018**

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ACKNOWLEDGEMENTS

Pacific Gas and Electric Company's Emerging Technologies Program is responsible for this project. It was developed as part of Pacific Gas and Electric Company's Emerging Technology –program under internal project number ET14PGE8661. Applied Energy Group conducted this technology evaluation for Pacific Gas and Electric Company with overall guidance from Lucy Morris and Phil Broaddus. For more information on this project, contact P1B8@pge.com.

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ABBREVIATIONS AND ACRONYMS

DID	Difference in Differences
HVAC	Heating, ventilation and air conditioning
RED	Randomized Encouragement Design
ITT	Intention-to-Treat
LATE	Local Average Treatment Effect
TOT	Treatment-on-the-Treated

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EXECUTIVE SUMMARY – SECOND YEAR FINDINGS

This addendum to Project ET13PGE1461 provides energy savings results from the second year of monitoring as well as the results of an "end-of-project" survey of both the treated and untreated/control group participants, conducted in November 2017. Refer to the first-year report for these sections: **Executive Summary**, **Background**, **Product/Technology**, and **Assessment Objectives**.

PROJECT FINDINGS/RESULTS

After the first year of the study, all three thermostats tested achieved annual electric savings ranging from 4-5%. One of the thermostats tested, Thermostat 3, also achieved annual gas savings. Following these promising findings, PG&E decided to extend the study for a second year to determine if the savings persisted.

The results indicate that savings persisted in the second year, although at a somewhat lower level. The lower level of savings is due in part to the extreme heat in the second year of the study. Also continuing the study for a second year led to sample attrition making the savings more difficult to detect. AEG's interpretation of the data and the results leads us to conclude that customers are likely to save electricity with the Smart Thermostat technology alone, even without any programmatic interventions or customer education efforts.

ES-1. ANNUAL ELECTRIC SAVINGS ESTIMATES BY THERMOSTAT[1]

TREATMENT GROUP		REFERENCE (KWH)	ACTUAL (KWH)	SAVINGS (KWH)	% SAVINGS
Thermostat 1	Year 1	6,170	5,953	217	4%
	Year 2	6,950	6,905	44	1%
Thermostat 2	Year 1	6,401	6,076	324	5%
	Year 2	7,610	7,229	381	5%
Thermostat 3	Year 1	5,853	5,560	293	5%
	Year 2	6,877	6,718	159	2%

Only one thermostat showed natural gas savings and those savings persisted in the second year. In general, the lack of significant gas savings across two of the three thermostats may be a regional effect, given that the sample for this study included warmer climate zones in PG&E's service territory. It may be possible to achieve greater natural gas savings in colder climate zones.

[1] Unless otherwise noted all savings estimates are statistically significant with a p-value of less than 0.10.

TABLE ES-2. ANNUAL GAS SAVINGS ESTIMATES BY THERMOSTAT

TREATMENT GROUP		REFERENCE (THERMS)	ACTUAL (THERMS)	SAVINGS (THERMS)	% SAVINGS
Thermostat 1	Year 1	380	380	0	0%
	Year 2	406	406	0	0%
Thermostat 2	Year 1	386	386	0	0%
	Year 2	415	415	0	0%
Thermostat 3	Year 1	368	352	16	4%
	Year 2	395	378	17	4%

Main findings from an analysis of savings by climate zone include the following:

- Results for both electric and gas savings vary widely by climate zone and study year.
- Customers living in Zones R, S, W are more likely to experience electric savings regardless of the type of thermostat.
- Natural gas savings are achievable for Thermostat 3, regardless of climate zone.

The following conclusions can be drawn from the survey analysis regarding participants' experience during the study:

- Customers are interested in the Smart Thermostat technology and there is naturally occurring adoption of the technology (~15%) within these tech-oriented customer segments in warmer climate zones.
- Customers with Smart Thermostats are very satisfied with the technology and are particularly fond of the remote access features.
- Most customers believe having a Smart Thermostat has resulted in increased comfort in their home and savings on their PG&E bill.
- All brands of Smart Thermostats are not created equal. One of the three thermostats tested received much lower satisfaction ratings than the other two, although the majority of customers with that thermostat still rated their satisfaction high.
- Satisfaction appears to have little to do with savings. The thermostat with the lowest satisfaction ratings, Thermostat 3, still delivered savings. And it was the only thermostat to deliver natural gas savings.
- Some thermostat behaviors such as not lowering the heating temperature during the daytime, and not using the remote monitoring feature of the smart thermostat may lead to lower or negative savings.
- It may be more challenging for larger households, households with someone home during the day during the cooling season, and households with a hot tub or spa to save energy with a smart thermostat.

PROJECT RECOMMENDATIONS/LESSONS LEARNED

The findings of this study show persistent electric savings for all three brands of thermostat and persistent natural gas savings during the heating season for Thermostat 3. The following recommendations/lessons learned should be considered when conducting future research of this technology:

- The savings from this pilot combined with other secondary research could be used to develop ex ante savings estimates for a similar program.
- Given the level of natural market adoption (~15%) among this high-tech segment of the population located in warmer climate zones, PG&E may want to investigate savings for those that purchased their own thermostats.
- PG&E may also want to look at the additional potential savings that could be achieved through programmatic efforts such as educational messaging, or additional features that might be available or "turned on", (such as "green" settings or "away" settings that automate lower usage) for the different thermostats.
- DR potential for customers with smart thermostats should be researched and explored and PG&E could leverage any and all smart thermostats in their territory to participate in DR events in a BYOT thermostat pilot.
- The microdata available from Smart Thermostats was not as useful as anticipated at this time:
    - The microdata available varies greatly across thermostat manufacturers
    - The datasets are very large and considerable time is required to match, clean and aggregate the data.
    - The potential results derived from the data are intuitive and don't provide additional insight into thermostat use or behavior. For example, an analysis could show that individuals who had longer thermostat runtimes saved less energy. This finding does not improve our understanding of customer behavior since it is already assumed that customers who save energy set their thermostats at temperatures that require it to run less often.
    - It is difficult to find meaningful results from an analysis of the Smart Thermostat data without comparable data from the thermostat customers used before the Smart Thermostat was installed. Obtaining this data would require significant planning and expense and would extend the timeline of the study considerably.
- The RED design has both advantages and disadvantages. The advantages are realized mainly during the study implementation (easier recruitment, lower installation costs, etc.) while the disadvantages are mainly realized during the analysis. The disadvantages experienced during this Study included the following:
    - The sample size of the treated customers was a small proportion of the encouraged group (15 – 25% depending on type of thermostat). The sample size of the treated customers with respect to the overall encouraged group significantly diluted the savings estimates making them hard to detect with significance in the impact analysis. For example, if we estimate a savings of 10% annually for the treated customers, and only 25% of the encouraged group received the treatment, that savings translates to only a 2.5% savings at the encouraged group level. Therefore, small savings were difficult to detect at the encouraged group level.
    - The experimental design eroded over time. Over the course of the study, we have lost participants across all groups due to simple churn (e.g. customers moving to another home or out of the territory). As our overall sample size

decreased, we lost statistical power, and it was harder to estimate savings with significance.

- Smart Thermostat adoption increased in the control/untreated groups. This affected the baseline against which the treated customers were measured. For example, if the treated customers saved electricity relative to their own pretreatment usage, their savings relative to the control and encouraged (but untreated groups) appear smaller as more customers in the control/untreated adopt Smart Thermostats.[2]

- These disadvantages may explain why savings were somewhat lower during the second year of the study.

- Due to the RED limitations we recommend the following:
  - Additional research with this sample is not recommended.
  - When using a RED design for future research, effort should be taken during implementation to achieve as high a ratio of treated versus encouraged customers as possible. This could include limiting the outreach to a smaller geographical area, extending the installation period, and using secondary data to estimate a take rate (e.g., the percent of encouraged that accept treatment) to determine the appropriate size of the encouraged group.

[2] Fifteen percent of control/untreated customers purchased a Smart Thermostat during the study period.

STUDY DESIGN

The study was designed using a Randomized Encouragement Design (RED). A RED design is an appropriate alternative to a Randomized Control Trial (RCT) when it is known that not all the treatment customers will accept the treatment, i.e., when treatment is voluntary. In this case, each of the customers in the treatment group was offered a smart thermostat, however, all customers were not expected to accept the thermostat. Furthermore, of those that accepted the thermostat, additional factors would likely prevent the thermostats from being installed. The RED also allows for the alternative scenario where some of the customers in the control group "self-treat" by purchasing a smart thermostat during the study period.

The basic principle behind a RED is identical to a RCT, except for the fact that not all the treatment customers receive treatment. This necessarily gives rise to additional groups, and associated terminology. A RED includes the following:

- Control Group – a randomly assigned group of customers that do not receive any encouragement to accept treatment.
- Encouraged Group – a randomly assigned group of customers that are encouraged to accept treatment, sometimes referred to as the Intention-to-Treat (ITT) group.
- Treated Group – a subset of the encouraged group that includes only the customers that ultimately receive the treatment. The proportion of treated to encouraged customers is referred to as the RED acceptance rate.

The savings calculated using the encouraged group is called the Intent to Treat effect (ITT). The effect of the treatment on those who were actually treated (known as the Local Average Treatment Effect or LATE) is the adjusted savings, dividing ITT by the RED acceptance rate.

The recruitment and assignment process is discussed in detail in the Study's first year report "PG&E Smart Thermostat Study: First Year Findings", along with the statistical validation of each of the groups. This process ultimately resulted in the selection of three encouraged groups (i.e., one for each brand of thermostat) and a single shared control group.

TABLE 1. NUMBER OF CUSTOMERS ENCOURAGED AND TREATED BY TYPE OF THERMOSTAT

TYPE OF THERMOSTAT	ENCOURAGED	TREATED	PROPORTION TREATED
Thermostat 1	4,059	916	23%
Thermostat 2	3,465	881	25%
Thermostat 3	2,814	410	15%

A total of 2,207 smart thermostats were installed in homes, falling short of PG&E's original goal of 3,000. The lower than expected number of installations resulted from the higher than expected walk-away rate. A portion of customers who scheduled an installation could not get a unit installed mainly because of the location of their HVAC system (e.g., on the roof of the house) or because they didn't like the brand of thermostat provided. There was a sufficiently negative reaction from customers to Thermostat 3, resulting in trips by installers to the customer residences that did not result in a successful installation that PG&E decided to discontinue installations of that brand of thermostat mid-way through the installation phase of the study, which also reduced the total number of customers in the treated group.

ENERGY SAVING ESTIMATES

Energy savings were estimated by first using a statistical difference-in-differences (DID) approach, and second, using a fixed-effect regression approach. This two-step process allowed preliminary estimates of savings that are unconstrained by the assumptions of a regression model. Then, those estimates were refined using the regression approach. Both the statistical DID and regression approaches are described below.

STATISTICAL DIFFERENCE-IN-DIFFERENCES

The DID method compares the monthly usage of the encouraged customers to the randomly assigned control group customers, both during the participation period (treatment period) and for a time before participation started (pretreatment period). Comparison during the treatment period gives an unadjusted estimate of the impacts. This estimate is then corrected using the difference during the pretreatment period to adjust for any preexisting differences between the encouraged and control groups.

The DID method consist of the following steps for each of the three thermostat encouraged groups:

- **Input source data** – Start with monthly energy data for the treatment and pretreatment periods for encouraged customers and a control group.
- **Calculate first difference** – Calculate the difference between the encouraged and control group's monthly usage in the treatment and pretreatment period.
- **Calculate second difference** – The result of the difference during the pretreatment period is the pretreatment difference. Subtract pretreatment difference for each month from the unadjusted impact to get the adjusted or corrected impact for each encouraged group. This second difference represents the estimated savings impacts for each month corrected for the pre-participation differences between the encouraged and control groups.
- **Adjust for untreated customers in the encouraged group** – In a RED design the difference between customers in the encouraged and treated groups require an additional adjustment. The second difference described above is inflated by dividing it by the installation rate (RED acceptance rate) for each encouraged group – for example, 23% for thermostat 1, 25% for thermostat 2 and 15% for thermostat 3. Note that the RED acceptance rate differs in each month of the treatment period, increasing as the program rolls out and decreasing if customers move out of the service territory.
- **Determine statistical significance** – Create 90% confidence intervals around the savings estimates. If the difference in consumption is statistically significant, this indicates that there is 90% certainty that the actual savings value for an average treated customer falls within the confidence interval and is not equal to zero.

Equation 1 shows a simplified form of the mathematical calculations used in the DID analysis to estimate energy savings for each month.

$$Savings_{LATE} = (Cntl_{after} - Tx_{after}) - (Cntl_{before} - Tx_{before}) \quad (1)$$

Where

$Cntl_{after}$ is the average control group customer energy use in the treatment (after) period,

Tx_{after} is the average encouraged group customer energy use in the treatment (after) period,

$Cntl_{before}$ is the average control group customer energy use in the pretreatment (before) period, and

Tx_{before} is the average encouraged group customer energy use in the pretreatment (before) period.

Equation 2 shows the adjustment on the savings estimate to account for the untreated customers in the encouraged group.

$$Savings_{TOT} = {Savings_{LATE}}/{RED\ Acceptance\ Rate} \quad (2)$$

Where

$Savings_{LATE}$ is the unadjusted savings, defined above in Equation 1, and

$RED\ Acceptance\ Rate$ is the proportion of the encouraged group with installed thermostats.

REGRESSION MODELING

In a second analysis step, savings were estimated using regression models. In the regression approach, energy use is looked at as a function of other explanatory variables (e.g., weather) that the statistical DID is unable to do. The models include the encouraged and control customers in both the treatment and pre-treatment periods. This type of data is generally referred to as panel data and can be modeled in several different ways. However, it is important to recognize that panel data has some inherent issues:

- Panel data tends to be auto correlated, which simply means that the variables are correlated through time. For example, electricity use during a particular month is likely to be highly correlated with electricity use in the previous month.
- Panel data is also often heteroskedastic, which means that the variances associated with the variables are not constant. For example, customers that use more electricity are likely to have larger variances, and those that use less electricity are likely to have smaller variances.

The presence of these issues introduces additional considerations into the modeling approach. The robust error correction adjusts the standard errors and t-statistics to account for autocorrelation and heteroskedasticity that would otherwise bias these values.

The regression modeling method consists of the following steps for each of the three thermostat encouraged groups:

- **Input source data** – Start with monthly energy and weather data for the treatment and pretreatment periods for encouraged customers and a control group.

- **Create indicator and interaction variables** – Set up indicator variables to distinguish between pretreatment versus treatment periods and encouraged versus control customers. Other indicator variables include seasonal indicators, monthly indicators, and Energy Efficiency (EE) program participation. Then, interactions between different indicator variables and with weather are also prepared.
- **Run regression models** – Test several model specifications using monthly energy use as the dependent variable. Check coefficients of individual independent variables for statistical significance and adjust the model as appropriate, including only variables that actually influence energy use significantly.
- **Estimate final regression model** – Estimate the encouraged group's baseline energy use and savings (ITT) for the treatment period using the finalized regression model.
- **Adjust for untreated customers in the encouraged group and determine statistical significance** – Like in statistical DID, we divide the encouraged group savings by the RED acceptance rate to calculate the savings in the treated group (the LATE). We also determine at 90% certainty if the LATE is statistically different from zero.

Equations 3 and 4 show the two final models used in the year 2 analysis.

$$Usage_{it} = EE_{it} + CDD_t + HDD_t + Year1_t(CDD_t + HDD_t) + Year2_t(CDD_t + HDD_t) + Encrgd_i(CDD_t + HDD_t) + Year1_t x Encrgd_i(CDD_t + HDD_t) + Year2_t x Encrgd_i(CDD_t + HDD_t) \quad (3)$$

$$Usage_{it} = EE_{it} + CDD_t + HDD_t + Year1eriod_t(CDD_t + HDD_t) + Year2_t(CDD_t + HDD_t) + Year1_t x Encrgd_i(CDD_t + HDD_t) + Year2_t x Encrgd_i(CDD_t + HDD_t) + \quad (4)$$

Where

$Usage_{it}$	is the energy use (kWh or thm) of customer i in month t,
EE_{it}	is an indicator variable that takes on the value of one after customer i begins participation in an EE program (only applicable in electric models),
CDD_t, HDD_t	are the cooling and heating degree days in month t,
$Year1_t$	is an indicator variable that takes on the value of one in first year of the treatment period September 2015 to September 2016
$Year2_t$	is an indicator variable that takes on the value of one in second year of the treatment period October 2016 to September 2017
$Encrgd_i$	is an indicator variable that takes on the value of one if customer i belongs to the encouraged group,
$Period_t x Encrgd_i$	is the interaction between the two indicator variables that takes on the value of one for the encouraged customer i during the treatment period,
$ID(CDD_t + HDD_t)$	is the interaction between an indicator variable and weather, the effect of weather to the energy use of a particular group or time period.

Note that the only difference between Equations 3 and 4 is the inclusion/exclusion of $Encrgd_i(CDD_t + HDD_t)$, which is the weather responsiveness unique to the encouraged

group. The inclusion of this explanatory variable does not indicate that there is a significant difference in usage between the encouraged and control groups. The t-tests and goodness of fit tests in the Validation section still hold true. However, there is a significant difference between the two groups in how their usage increases or decreases in response to changes in weather. In other words, the two groups reflect a difference in their sensitivity to weather, even though their average usage is similar.

The same model was used for both Year 1 and Year 2. Because the Year 2 weather was extremely hot, Year 2 savings were modeled separately from Year 1. This preserved the Year 1 savings and accounted for the difference in weather experienced each year.

The energy impacts in the section below present monthly and annual savings. The annual savings represent the sum of each month of significant savings.

Energy Impacts

Table 2 shows annual electric savings by thermostat for each year. The savings estimates used to determine impacts are at the p= .10 level. All three thermostats achieved statistically significant annual electric savings ranging from 1 to 5%.

Table 2 Annual Electric Savings Estimates by Thermostat

Treatment Group		Reference (kWh)	Actual (kWh)	Savings (kWh)	% Savings
Thermostat 1	Year 1	6,170	5,953	217	4%
	Year 2	6,950	6,905	44	1%
Thermostat 2	Year 1	6,401	6,076	324	5%
	Year 2	7,610	7,229	381	5%
Thermostat 3	Year 1	5,853	5,560	293	5%
	Year 2	6,877	6,718	159	2%

Table 3 shows the monthly estimated electric savings achieved for the average customer in the Thermostat 1 group, with significant savings italicized. In the first year, Thermostat 1 achieved significant positive savings, at the p = .10 level, from April through September, indicating cooling savings. In the second year, Thermostat 1 achieved statistically significant savings in October and April.

TABLE 3. MONTHLY ELECTRIC SAVINGS ESTIMATES – THERMOSTAT 1

MONTH	OCT 2015 – SEPT 2016		OCT 2016 – SEPT 2017	
	FIRST YEAR (KWH)	FIRST YEAR (%)	SECOND YEAR (KWH)	SECOND YEAR (%)
October[3]	NA	NA	*21*	*4%*
November	-7	-1%	5	1%
December	-24	-4%	8	1%
January	-17	-3%	8	1%
February	-11	-2%	4	1%
March	-3	-1%	4	1%
April	*1*	*0%*	*24*	*6%*
May	*22*	*5%*	24	5%
June	*46*	*7%*	-28	-4%
July	*59*	*7%*	-15	-2%
August	*54*	*7%*	-13	-2%
September	*35*	*6%*	-4	-1%
Annual Total	217	4%	44	1%

[3] There were not enough Smart Thermostats installed in October 2015 to conduct the analysis.

Table 4 shows the monthly estimated electric savings achieved for the average customer in the Thermostat 2 group. In the first year, Thermostat 2 achieved significant positive savings from April through September, indicating cooling savings. In the second year, Thermostat 2 achieved significant savings from October through May and September. It is interesting to note that the total annual savings are about the same for both years but the savings flipped seasonality in the second year vs. the first year.

TABLE 4. MONTHLY ELECTRIC SAVINGS ESTIMATES – THERMOSTAT 2

Month	Oct 2015 – Sept 2016		Oct 2016 – Sept 2017	
	First Year (kWh)	First Year (%)	Second Year (kWh)	Second Year (%)
October	NA	NA	*25*	*5%*
November	9	2%	*19*	*4%*
December	32	5%	*60*	*9%*
January	23	4%	*64*	*10%*
February	15	3%	*30*	*6%*
March	4	1%	*18*	*4%*
April	*3*	*1%*	*30*	*7%*
May	*33*	*7%*	*51*	*9%*
June	*69*	*10%*	56	7%
July	*87*	*10%*	67	8%
August	*80*	*10%*	62	8%
September	*52*	*8%*	*82*	*9%*
Annual Total	324	5%	381	5%

Table 5 shows the monthly estimated electric savings achieved for the average customer in the Thermostat 3 group. In the first year, Thermostat 3 achieved significant positive savings from April through September, indicating cooling savings. In the second year, Thermostat 3 achieved statistically significant savings in October, April and May.

TABLE 5. MONTHLY ELECTRIC SAVINGS ESTIMATES – THERMOSTAT 3

MONTH	OCT 2015 – SEPT 2016		OCT 2016 – SEPT 2017	
	FIRST YEAR (KWH)	FIRST YEAR (%)	SECOND YEAR (KWH)	SECOND YEAR (%)
October	NA	NA	*41*	*9%*
November	3	1%	16	4%
December	13	2%	43	8%
January	9	2%	46	9%
February	6	1%	22	5%
March	2	0%	14	4%
April	*3*	*1%*	*49*	*12%*
May	*30*	*7%*	*68*	*12%*
June	*62*	*10%*	32	4%
July	*79*	*10%*	56	7%
August	*73*	*10%*	52	7%
September	*47*	*8%*	42	6%
Annual Total	293	5%	159	2%

Tables 6 – 9 show the monthly estimated natural gas savings achieved for the average customer in each treated group. Only Thermostat 3 achieved statistically significant natural gas savings (significant savings italicized).

TABLE 6. MONTHLY NATURAL GAS SAVINGS ESTIMATES – THERMOSTAT 1

Month	Oct 2015 – Sept 2016		Oct 2016 – Sept 2017	
	First Year (Thm)	First Year (%)	Second Year (Thm)	Second Year (%)
October	NA	NA	-0.2	-1%
November	0.0	0%	-0.5	-1%
December	0.1	0%	-1.6	-2%
January	0.1	0%	-1.7	-2%
February	0.0	0%	-0.8	-1%
March	0.0	0%	-0.4	-1%
April	0.0	0%	-0.3	-1%
May	-0.1	0%	-0.7	-5%
June	-0.2	-1%	-1.4	-12%
July	-0.2	-2%	-1.5	-13%
August	-0.2	-1%	-1.4	-12%
September	-0.1	-1%	-1.2	-11%
Annual Total	0.0	0%	0.0	0%

TABLE 7. MONTHLY NATURAL GAS SAVINGS ESTIMATES – THERMOSTAT 2

Month	Oct 2015 – Sept 2016		Oct 2016 – Sept 2017	
	First Year (Thm)	First Year (%)	Second Year (Thm)	Second Year (%)
October	NA	NA	-0.2	-1%
November	-0.7	-1%	0.3	1%
December	-2.2	-3%	1.0	1%
January	-1.5	-2%	1.1	1%
February	-1.0	-2%	0.5	1%
March	-0.3	-1%	0.3	1%
April	0.0	0%	-0.2	-1%
May	-0.1	0%	-0.6	-4%
June	-0.1	-1%	-1.2	-9%
July	-0.2	-2%	-1.2	-10%
August	-0.2	-1%	-1.1	-9%
September	-0.1	-1%	-1.0	-8%
Annual Total	0.0	0%	0.0	0%

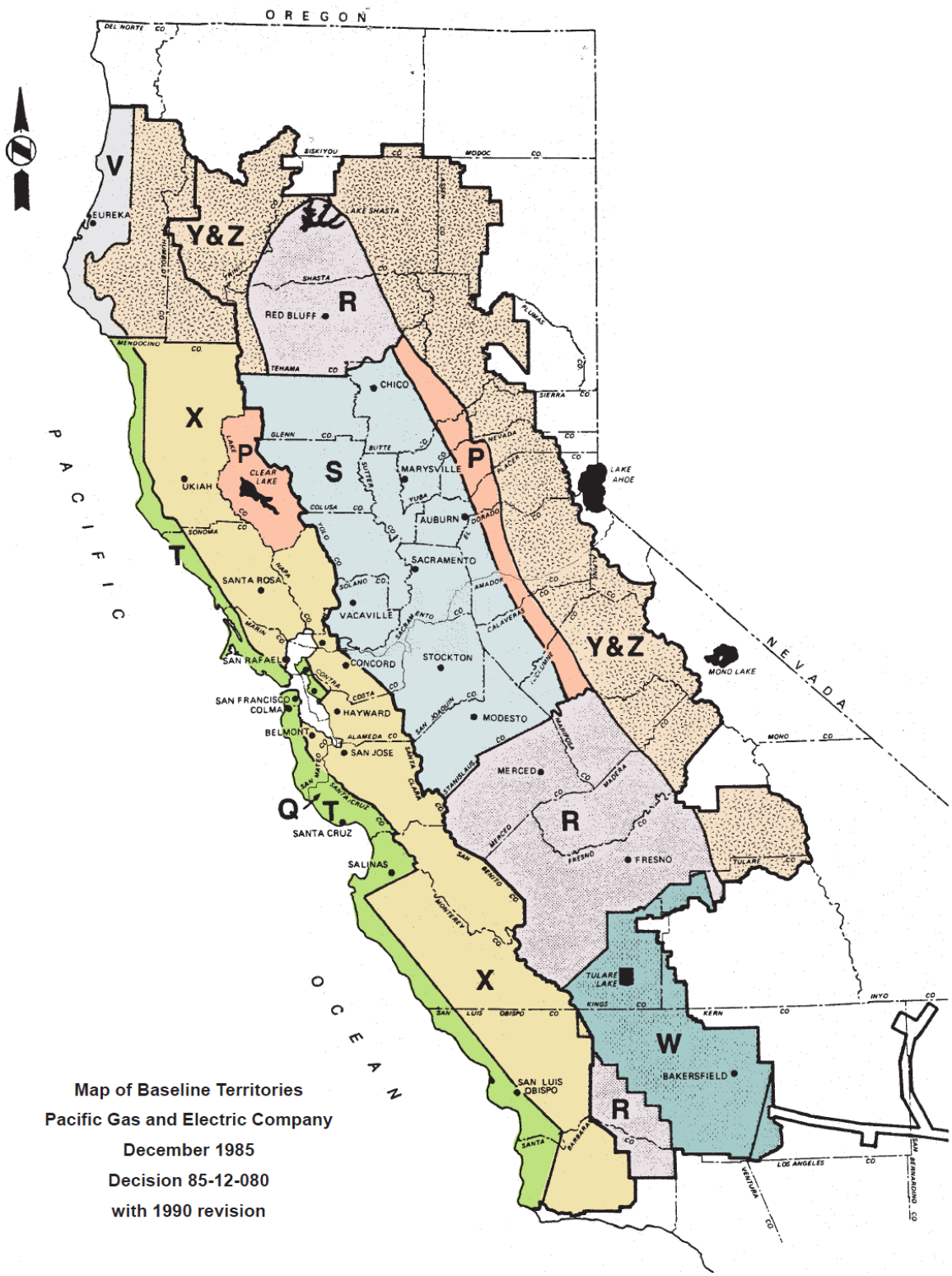
TABLE 8. MONTHLY NATURAL GAS SAVINGS ESTIMATES – THERMOSTAT 3

MONTH	OCT 2015 – SEPT 2016		OCT 2016 – SEPT3 2017	
	FIRST YEAR (THM)	FIRST YEAR (%)	SECOND YEAR (THM)	SECOND YEAR (%)
October	NA	NA	*0.3*	*2%*
November	*1.5*	*3%*	*5.5*	*14%*
December	*6.1*	*8%*	1.1	1%
January	*4.5*	*6%*	0.3	0%
February	*2.9*	*6%*	*6.6*	*10%*
March	*0.8*	*2%*	*3.8*	*9%*
April	*0.2*	*1%*	*0.9*	*4%*
May	1.1	7%	0.6	5%
June	2.3	19%	1.1	10%
July	2.9	27%	1.1	11%
August	2.7	25%	1.1	10%
September	1.7	14%	0.8	7%
Annual Total	16.0	4%	17.2	4%

SAVINGS BY CLIMATE ZONE

In addition to the monthly savings by thermostat, the results were also analyzed by climate zone for each thermostat. PG&E Baseline Zones were used in this analysis for two main reasons:

1. PG&E's Baseline Zones are larger than traditional climate zones. Traditional climate zones would have had to be grouped together in order to detect significant savings.
2. PG&E's Baseline Zones group customers with similar usage together by design making them particularly useful for this type of study.


OREGON
NEVADA
PACIFIC
OCEAN
V
Y&Z
R
X
P
S
T
Q
W
EUREKA
RED BLUFF
CHICO
UKIAH
MARYSVILLE
AUBURN
SACRAMENTO
VACAVILLE
SANTA ROSA
SAN RAFAEL
CONCORD
STOCKTON
HAYWARD
MODESTO
SAN JOSE
MERCED
FRESNO
SANTA CRUZ
SALINAS
SAN LUIS OBISPO
BAKERSFIELD
LAKE AHDE
MONO LAKE
TULARE LAKE
Map of Baseline Territories
Pacific Gas and Electric Company
December 1985
Decision 85-12-080
with 1990 revision

Annual electric savings by climate zone and thermostat are presented in the tables below. Thermostat 1 savings varied greatly by climate zone and year. Zone P had considerable savings in Year 1, but negative savings in Year 2 (electricity use increased). Zones R and W had no savings in Year 1 but substantial savings in Year 2, while Zone S had 7% savings in Year 1 but no savings in Year 2. Finally, Zone X had negative savings in both Years of the study.

TABLE 9 ANNUAL ELECTRIC SAVINGS ESTIMATES BY CLIMATE ZONE – THERMOSTAT 1

CLIMATE ZONE[4]		REFERENCE (KWH)	ACTUAL (KWH)	SAVINGS (KWH)	% SAVINGS
P (n = 9)	Year 1	9,165	7,198	1,967	21%
	Year 2	6,310	8,235	-1,925	-31%
R (n = 108)	Year 1	6,771	6,771	0	0%
	Year 2	8,907	7,768	1,139	13%
S (n = 399)	Year 1	6,340	5,902	439	7%
	Year 2	6,990	6,990	0	0%
W (n = 31)	Year 1	6,742	6,742	0	0%
	Year 2	11,376	8,194	3,182	28%
X (n = 357)	Year 1	5,446	5,685	-240	-4%
	Year 2	5,845	6,363	-519	-9%

[4]The climate zone analysis regression models are largely based off of the population level models. Climate zone specific variables were added to the models to measure incremental changes in savings by climate zone. The savings estimates by climate zone then are made up of the population level savings and the incremental effect of being in a specific climate zone. This approach allowed us to detect differences in savings among customers even when the groups were small.

Thermostat 2 also varied by climate zone and Year, but not as radically as Thermostat 1. Similar to Thermostat 1, Zone P had positive savings in Year 1 and negative savings in year 2 for Thermostat 2. Zones R and W saw an increase in savings from Year 1 to Year 2, while Zone S saw a decrease in savings. Zone X savings were consistent with modest savings each year.

TABLE 10 ANNUAL ELECTRIC SAVINGS ESTIMATES BY CLIMATE ZONE – THERMOSTAT 2

CLIMATE ZONE		REFERENCE (KWH)	ACTUAL (KWH)	SAVINGS (KWH)	% SAVINGS
P (n = 10)	Year 1	7,545	7,039	506	7%
	Year 2	7,553	8,942	-1,390	-18%
R (n = 114)	Year 1	8,059	7,172	886	11%
	Year 2	10,543	9,078	1,465	14%
S (n = 385)	Year 1	6,614	6,007	607	9%
	Year 2	7,192	6,935	257	4%
W (n = 34)	Year 1	8,217	7,147	1,071	13%
	Year 2	12,295	8,123	4,172	34%
X (n = 331)	Year 1	5,818	5,650	168	3%
	Year 2	6,988	6,798	190	3%

Thermostat 3 has negative savings in Climate Zone P for both Years. Climate Zone R and W have greater savings in Year 2 than Year 1. Climate Zone S has decreased savings in Year 2 and Climate Zone X has slight savings in Year 2.

TABLE 11 ANNUAL ELECTRIC SAVINGS ESTIMATES BY CLIMATE ZONE – THERMOSTAT 3

CLIMATE ZONE		REFERENCE (KWH)	ACTUAL (KWH)	SAVINGS (KWH)	% SAVINGS
P (n = 8)	Year 1	6,135	6,277	-142	-2%
	Year 2	5,485	6,243	-758	-14%
R (n = 47)	Year 1	6,756	6,316	439	7%
	Year 2	9,426	8,118	1,308	14%
S (n = 206)	Year 1	6,292	5,792	500	8%
	Year 2	7,340	7,088	252	3%
W (n = 11)	Year 1	7,619	6,706	913	12%
	Year 2	10,127	6,091	4,036	40%
X (n = 134)	Year 1	4,763	4,826	-63	-1%
	Year 2	5,839	5,756	83	1%

Annual natural gas savings by climate zone and thermostat are presented in the following three tables. Similar to the electric results, Thermostat 1 gas savings varied greatly by climate zone and year. Zone P had small savings in Year 1, but negative savings in Year 2 (natural gas use increased). Zones R and W had no savings in Year 1 but substantial savings in Year 2, while Zone S had 5% savings in Year 1 but negative savings in Year 2. Finally, Zone X had negative savings in both Years of the study.

TABLE 12 ANNUAL GAS SAVINGS ESTIMATES BY CLIMATE ZONE – THERMOSTAT 1

CLIMATE ZONE		REFERENCE (THM)	ACTUAL (THM)	SAVINGS (THM)	% SAVINGS
P (n = 9)	Year 1	591	582	9	2%
	Year 2	417	541	-123	-30%
R (n = 108)	Year 1	286	365	-79	-28%
	Year 2	480	374	106	22%
S (n = 399)	Year 1	375	358	18	5%
	Year 2	322	390	-68	-21%
W (n = 31)	Year 1	272	332	-60	-22%
	Year 2	515	330	184	36%
X (n = 357)	Year 1	341	410	-70	-20%
	Year 2	338	436	-97	-29%

Thermostat 2 also varied by climate zone and Year, but again, similar to the electric savings not as radically as Thermostat 1. Zone P and Zone S had positive natural gas savings in Year 1 and negative savings in Year 2 for Thermostat 2. Zone R has negative savings in Year 1 but substantial savings in Year 2. Zone W saw a substantial increase in savings from Year 1 to Year 2, while Zone X savings were consistent with negative savings each year.

TABLE 13 ANNUAL GAS SAVINGS ESTIMATES BY CLIMATE ZONE – THERMOSTAT 2

CLIMATE ZONE		REFERENCE (THM)	ACTUAL (THM)	SAVINGS (THM)	% SAVINGS
P (n = 10)	Year 1	568	491	77	14%
	Year 2	521	552	-30	-6%
R (n = 114)	Year 1	327	356	-30	-9%
	Year 2	506	353	153	30%
S (n = 385)	Year 1	413	372	40	10%
	Year 2	370	400	-31	-8%
W (n = 34)	Year 1	345	310	35	10%
	Year 2	489	300	189	39%
X (n = 331)	Year 1	368	418	-50	-14%
	Year 2	401	462	-61	-15%

Thermostat 3, the only thermostat that showed significant gas savings at the thermostat level, has more consistent natural gas results. Climate Zone P, R, W and X all show no gas savings for the first year, but have significant savings ranging from 1 – 8% for the 2nd year. Climate Zone S has savings in both years.

TABLE 14 ANNUAL GAS SAVINGS ESTIMATES BY CLIMATE ZONE – THERMOSTAT 3

CLIMATE ZONE		REFERENCE (THM)	ACTUAL (THM)	SAVINGS (THM)	% SAVINGS
P (n = 8)	Year 1	420	419	1	0%
	Year 2	429	425	4	1%
R (n = 47)	Year 1	377	377	0	0%
	Year 2	413	391	22	5%
S (n = 206)	Year 1	344	341	3	1%
	Year 2	390	376	15	4%
W (n = 11)	Year 1	364	364	0	0%
	Year 2	391	361	31	8%
X (n = 134)	Year 1	356	356	0	0%
	Year 2	390	376	14	4%

Main findings from the analysis of savings by climate zone include the following:

- Results for both electric and gas savings vary widely by climate zone and year.
- Customers living in Zones R, S, W are more likely to experience electric savings regardless of the type of thermostat.
- Natural gas savings are achievable for Thermostat 3 regardless of the climate zone.

END OF STUDY SURVEYS

In addition to the energy analysis, treated customers and control and untreated[5] customers were surveyed. Treated customers were surveyed following the installation of the Smart Thermostat and near the end of the two-year study period. The post installation survey results are included in the Year 1 report. Topics covered in the End of the Study survey included status and use of the Smart Thermostat, satisfaction with the Smart Thermostat, energy efficiency actions and attitudes, and basic household demographics.

Control/Untreated customers were surveyed at the same time as treated customers, near the end of the two-year study period. The main purpose of this survey was to determine if customers in the control and untreated groups installed Smart Thermostats on their own. Topics covered in the survey included type of thermostat in use, energy efficiency actions and attitudes, and if customers had a Smart Thermostat, a series of questions including satisfaction with the Smart Thermostat and use of the Smart Thermostat features. Copies of the survey instruments can be found in Appendix A.

END OF STUDY TREATED CUSTOMER SURVEY RESULTS

The 2,207 treated customers were sent an email invitation to take the end of the study survey. Treated customers received an email reminder two days later and a third email reminder two days after the first reminder.

A total of 1,309 treated customers responded to the survey. Table 15 shows the breakdown of treated customer surveys by thermostat.

TABLE 15. SURVEY RESPONSE RATE

TYPE OF THERMOSTAT	NUMBER IN TREATED GROUP	COMPLETED SURVEY	RESPONSE RATE
Thermostat 1	916	537	59%
Thermostat 2	881	547	62%
Thermostat 3	410	225	55%

Treated customers were asked about the status and use of their Smart Thermostat, their satisfaction with the Smart Thermostat, their energy efficiency actions and attitudes, and some basic demographic questions about their household. The questions were asked generally and were not specific to year 1 or year 2 of the study.

SMART THERMOSTAT STATUS AND USE

As shown in Figure 1, ninety-three percent of treated customers said their Smart Thermostat was still installed. More than twice as many treated customers with Thermostat 3 said the Smart Thermostat was no longer installed; thirteen percent of Thermostat 3

[5] Untreated customers are a subset of the encouraged group that includes those customers who ultimately did not receive the thermostats.

customers no longer had their Smart Thermostat installed compared to only 6% of customers with Thermostat 1 or 2.

Ninety seven percent of treated customers who said their thermostat was installed said it was connected by WiFi. This also differed by thermostats. Only 1% of customers with Thermostat 1 said it was not connected to WiFi compared to 3% of Thermostat 2 and 6% of Thermostat 3 customers.

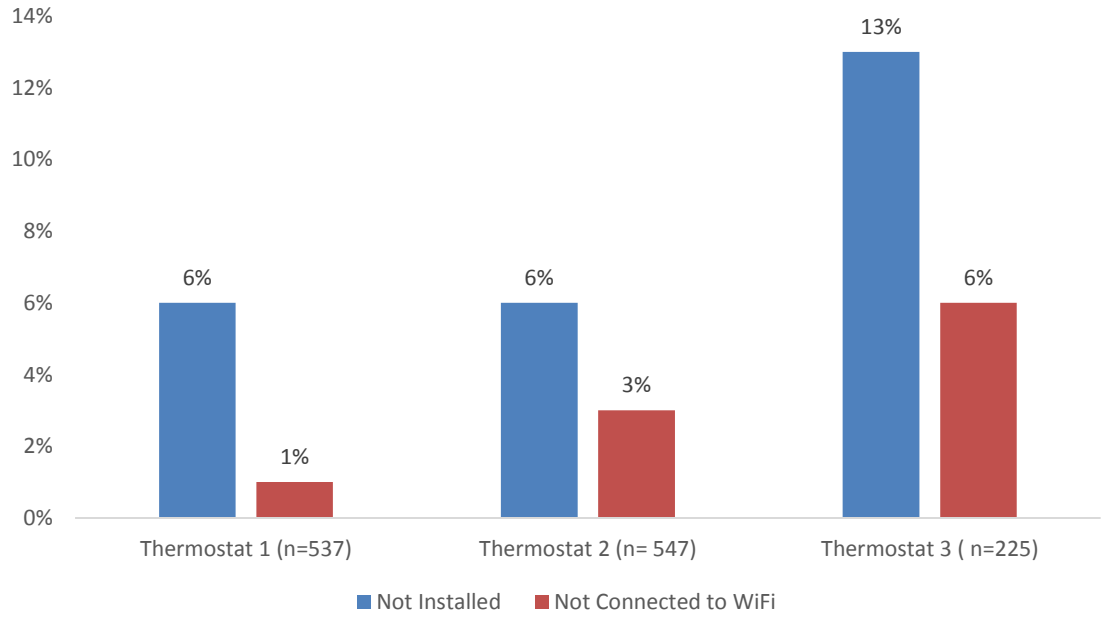


FIGURE 1. PROPORTION OF UNINSTALLS AND NOT CONNECTED TO WIFI BY THERMOSTAT

The majority of treated customers say they lose WiFi connectivity to their Smart Thermostat at least occasionally. Eleven percent of treated customers with Thermostat 3 say they lose WiFi connectivity frequently compared to only 2% and 3% of customers with Thermostat 1 or 2. It also takes Thermostat 3 treated customers longer to get their WiFi restored (Table 16).

TABLE 16. WIFI CONNECTIVITY AND RESTORATION

WIFI STATUS	THERMOSTAT 1 (N=537)	THERMOSTAT 2 (N=547)	THERMOSTAT 3 (N=225)
Lose connectivity occasionally	51%	42%	52%
Lose connectivity frequently	2%	3%	11%
Restored within minutes	73%	71%	43%
Restored within hours	16%	15%	23%
Restored same day	8%	10%	15%
Restored within a few days	1%	2%	7%
Longer	2%	3%	13%

Regulating thermostats is often a balancing act between maximizing comfort and minimizing cost. Most treated customers are neutral regarding whether comfort or cost dictated their thermostat usage (Figure 2). But more treated customers value reducing cost over comfort.

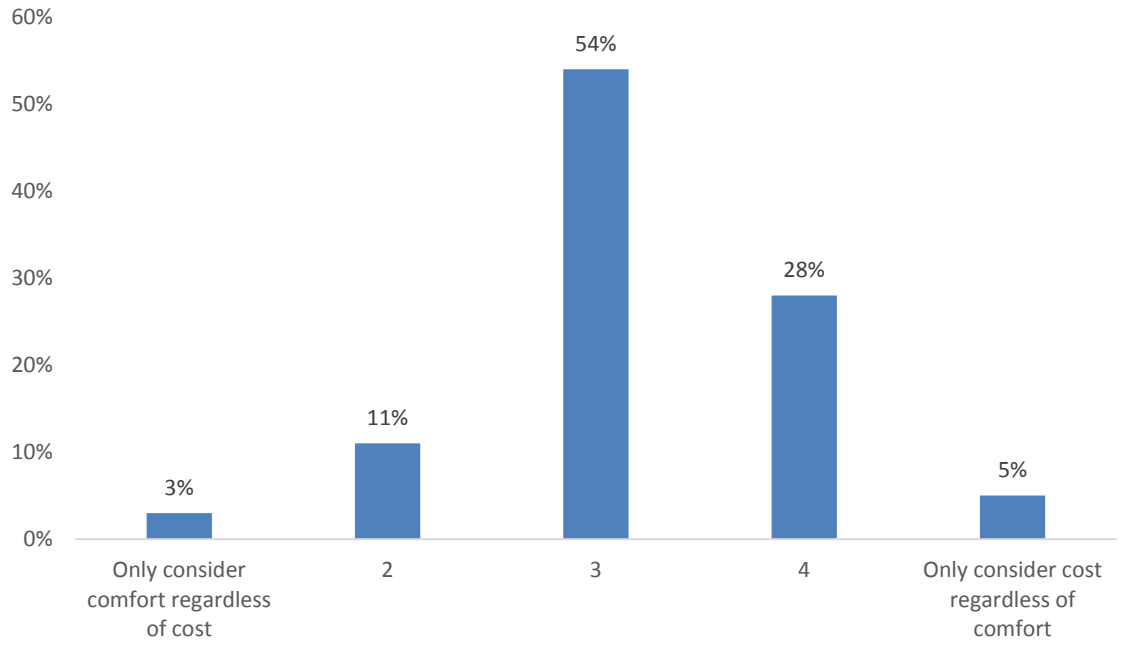


FIGURE 2. MAIN DRIVER OF THERMOSTAT USAGE – COMFORT VS. COST (N =1,309)

To get a better understanding of the thermostat settings, treated customers were asked their heating and cooling set points during different portions of a typical weekday for the heating season (Figure 3) and the cooling season (Figure 4).

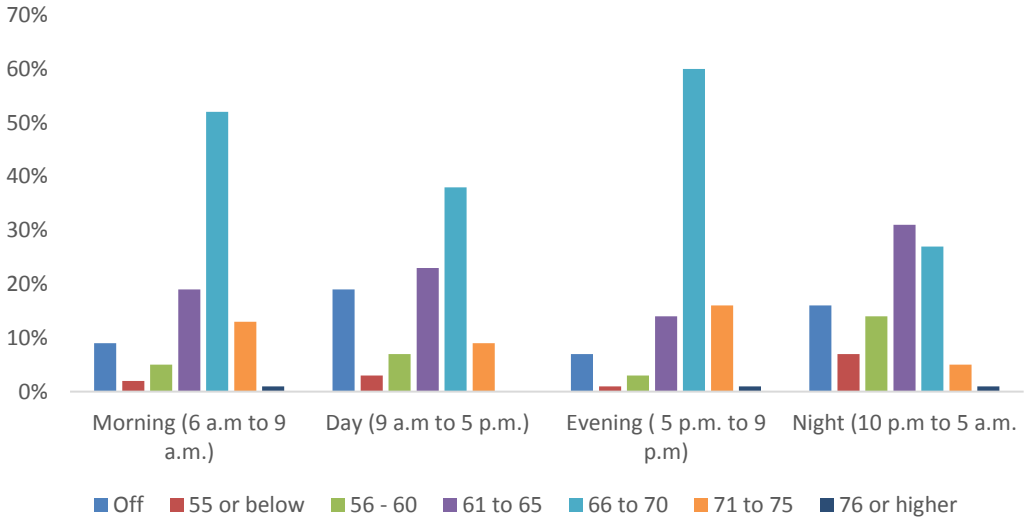


FIGURE 3. HEATING TEMPERATURE SETTING PREFERENCES (N = 1,309)

Many treated customers have their thermostat set between 66-70 degrees throughout the day during the heating season. More than half lower their set point below 66 degrees at night between 9 p.m. and 6 a.m.

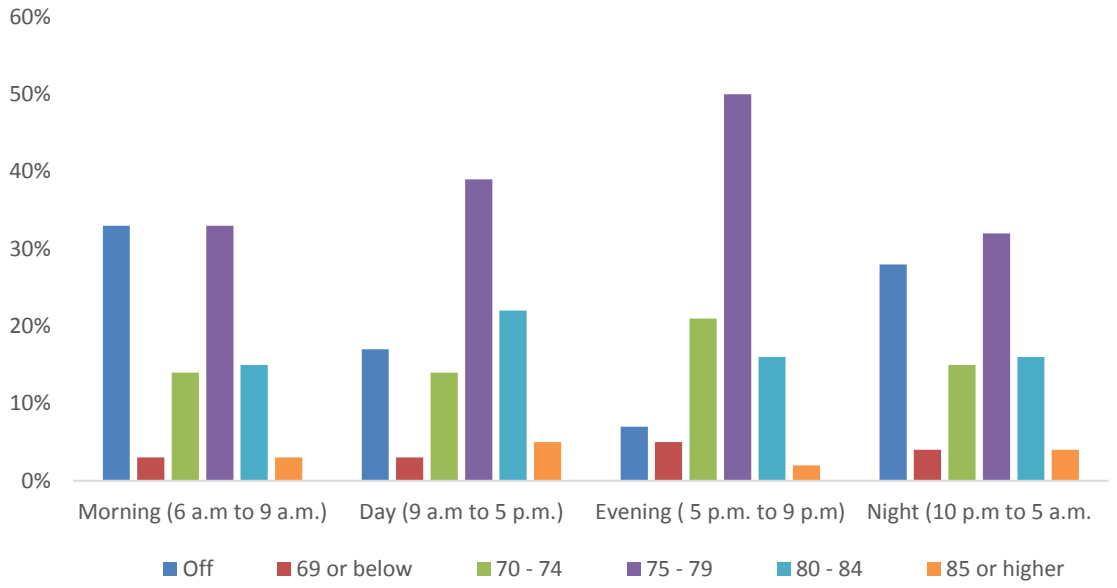


FIGURE 4. COOLING TEMPERATURE SETTING PREFERENCES (N = 1,309)

Most treated customers have their thermostat turned off or set above 75 degrees throughout the day during the cooling season. Though still a minority, more treated customers (26%) set their thermostats below 75 degrees in the evening than at any other time of day.

Treated customers were asked how frequently they used various features of the Smart Thermostats. Monitoring and controlling the Smart Thermostat remotely was used at least occasionally by the majority of treated customers and use of the remote features did not differ significantly by thermostat type (Figure 5).

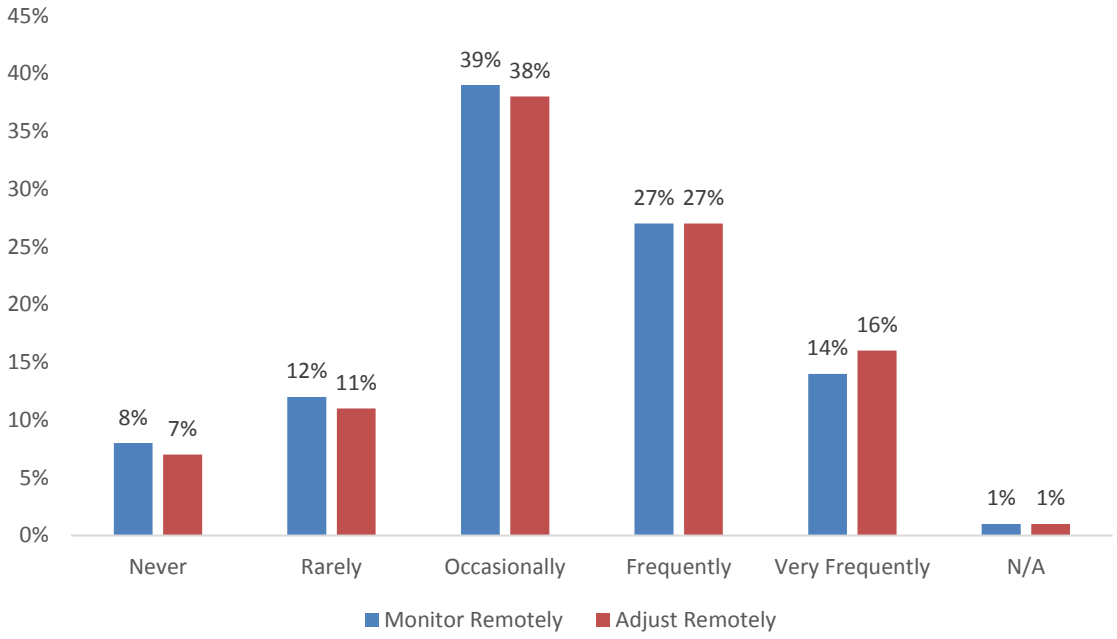


FIGURE 5. USE OF SMART THERMOSTAT REMOTE FEATURES (N = 1,309)

The majority of treated customers at least occasionally adjust or change their thermostat settings, although more than a quarter say they rarely or never adjust their Smart Thermostat. The majority also at least occasionally use the pre-programmed settings such as auto-away, but more than forty percent rarely or never use this feature (Figure 6). Again, the use of these features does not differ greatly by thermostat type.

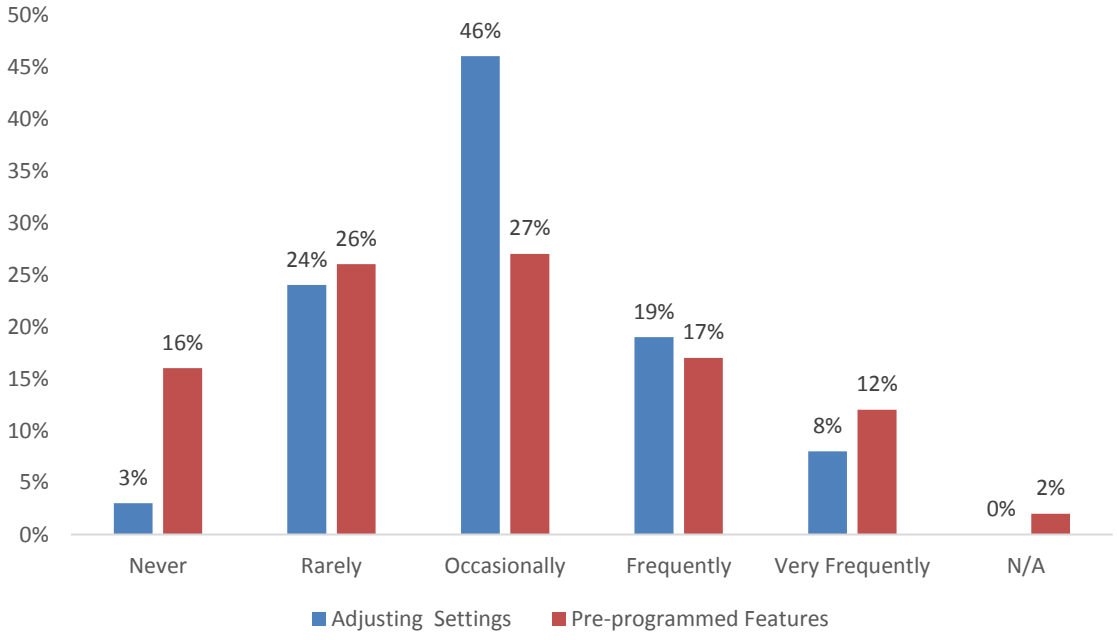


FIGURE 6. FREQUENCY OF ADJUSTING AND USING PRE-PROGRAMMED SETTINGS (N = 1,309)

The use of a "Green" setting differs substantially by thermostat. Twenty-one percent of Thermostat 3 customers and 14% of Thermostat 2 customers said such a feature was not applicable. Forty-two percent of Thermostat 1 customers, however, said they frequently or very frequently use the "Green" setting (Figure 7).

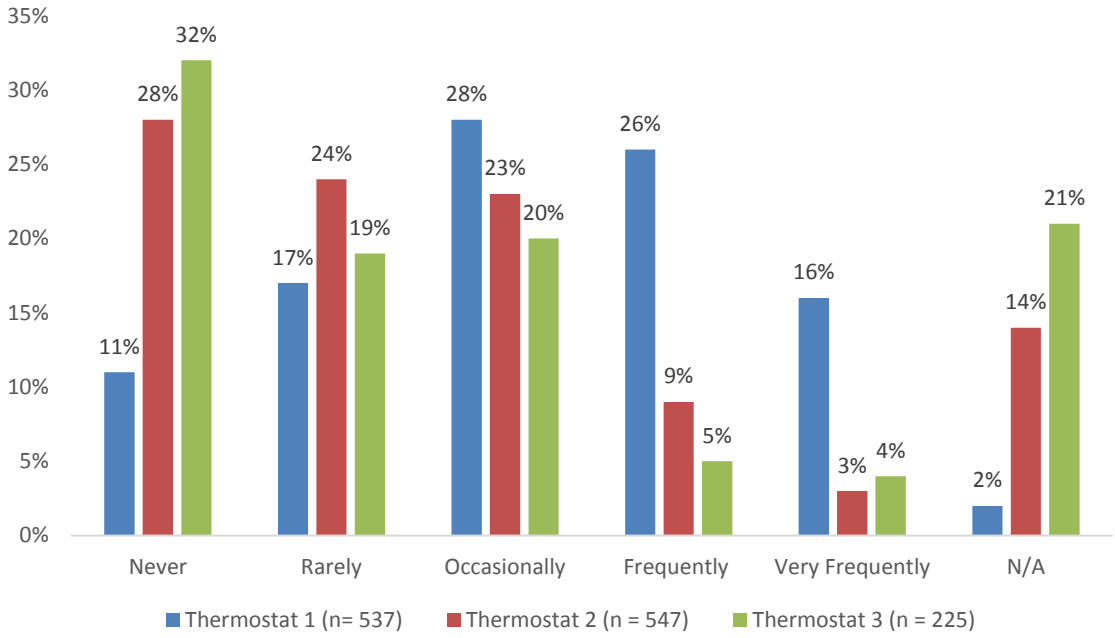


FIGURE 7. FREQUENCY OF USING GREEN SETTINGS

SATISFACTION WITH THE SMART THERMOSTAT

Overall satisfaction with all three thermostats is high with the majority giving top box ratings of a 4 or 5 on a 5-point satisfaction scale. Fewer treated customers with Thermostat 3, however, are very satisfied and more tend to give neutral or low ratings about the thermostat (Figure 8).

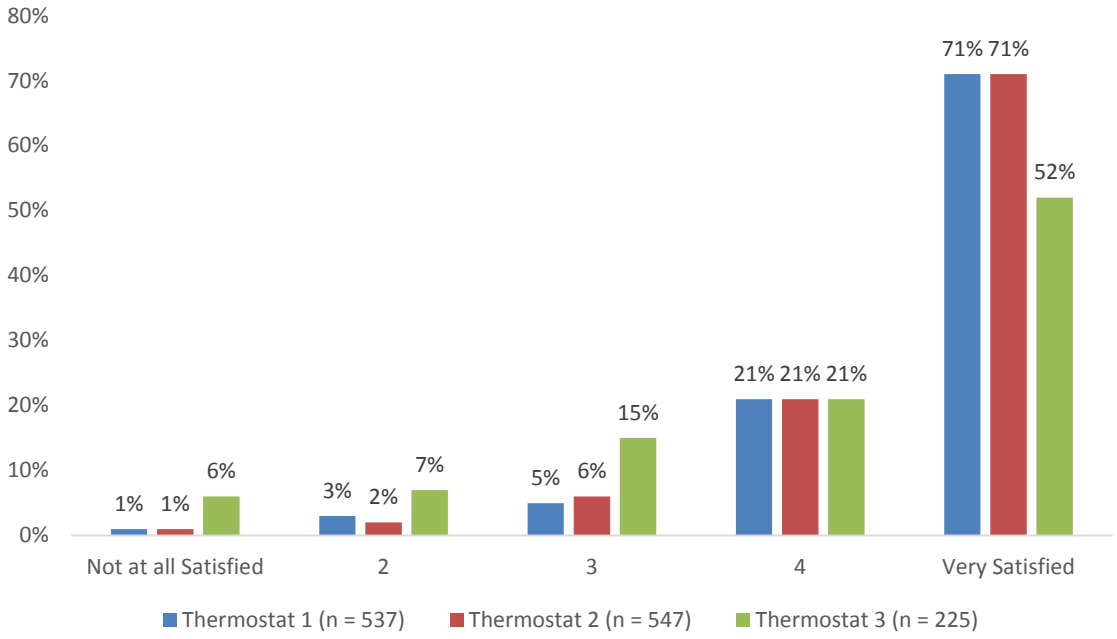


FIGURE 8. OVERALL SATISFACTION WITH SMART THERMOSTAT

Treated customers rated their satisfaction with the mobile app for the Smart Thermostats high, although once again larger proportions of customers with Thermostat 3 gave low or neutral ratings (Figure 9). Treated customers with Thermostat 1 or 2 also rated the Smart Thermostat website high, but only a third of customers with Thermostat 3 gave the website a 5 on a 5-point satisfaction scale and forty-four percent gave a rating of 3 or lower (Figure 10).

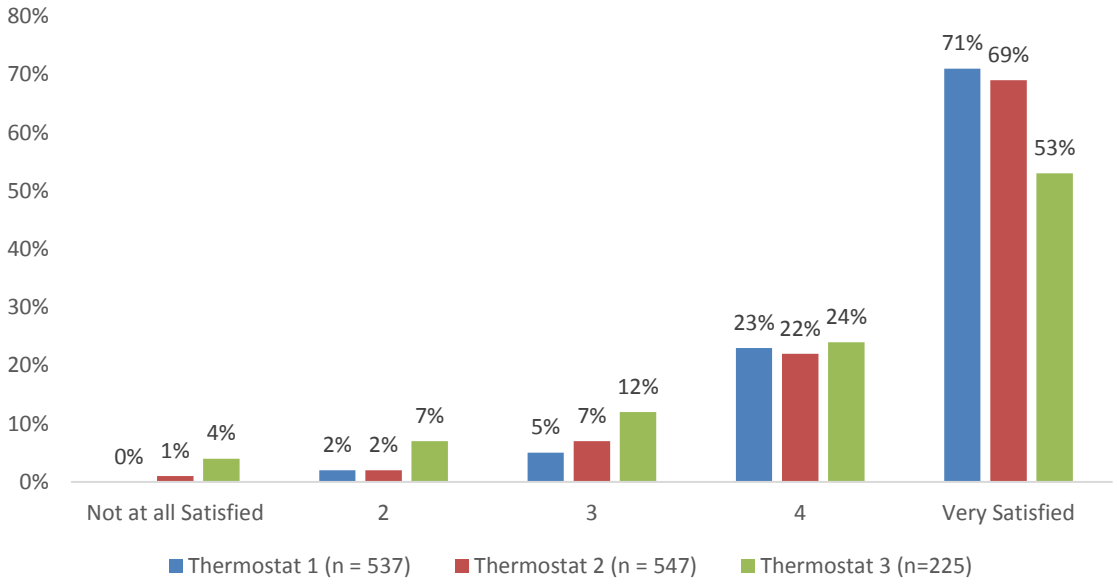


FIGURE 9. SATISFACTION WITH THE SMART THERMOSTAT MOBILE APP

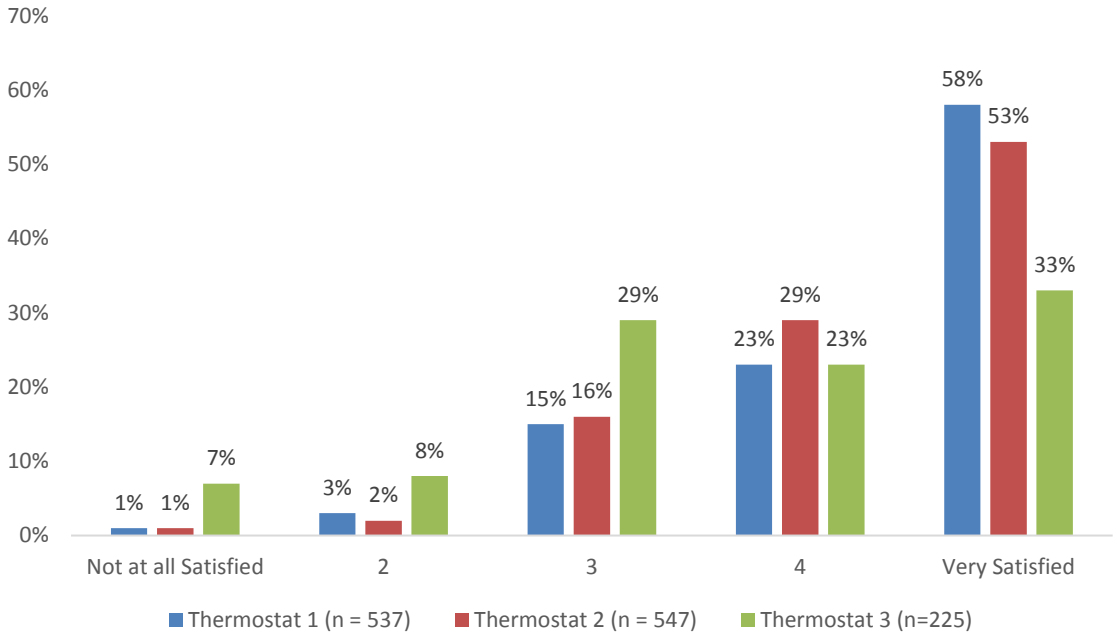


FIGURE 10. SATISFACTION WITH SMART THERMOSTAT WEBSITE

Most treated customers would recommend a Smart Thermostat to a friend, family member or co-worker, with the majority saying they would be somewhat or very likely to recommend the thermostat. Once again fewer customers with Thermostat 3 said they would be less likely to recommend the thermostat (Figure 11).

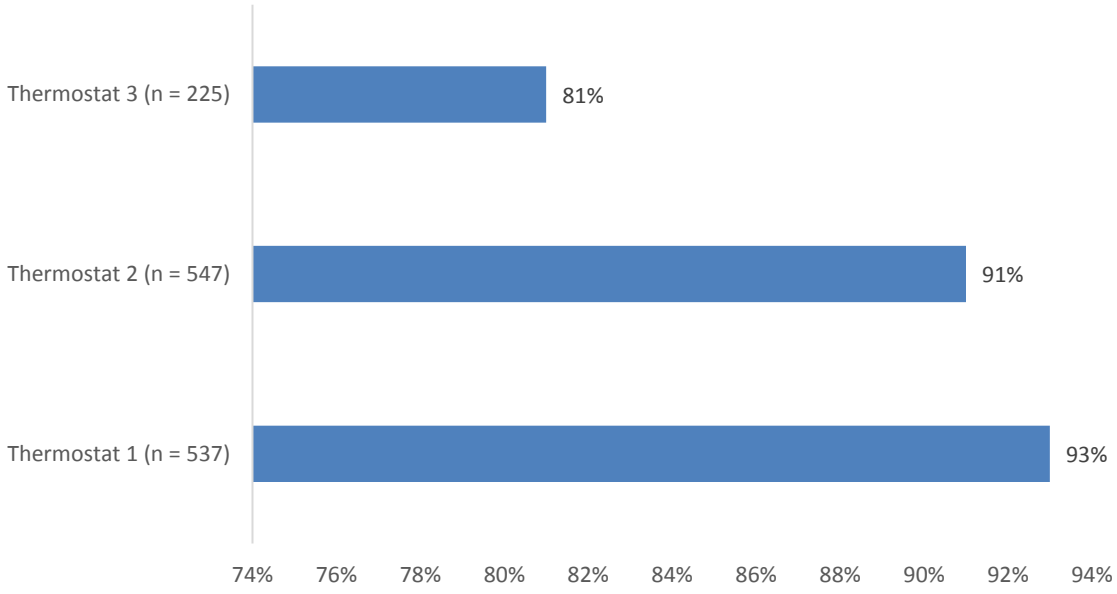


FIGURE 11. LIKELY TO RECOMMEND SMART THERMOSTAT (TOP BOX RATING)

Most treated customers feel they have saved energy on their PG&E bill using the Smart Thermostat. With most saying either "yes, definitely," or "yes, I think so". More customers with Thermostat 1 think they definitely saved energy using their Smart Thermostat with 38% saying definitely compared to 25% of customers with Thermostat 2 or 3 (Figure 12).

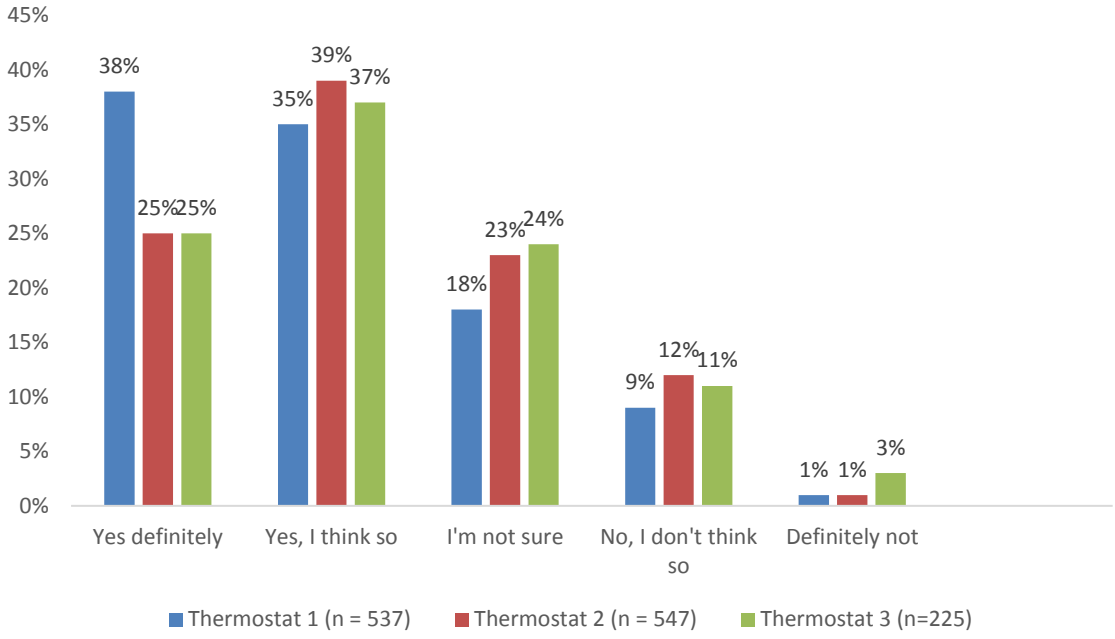


FIGURE 12. HAVE SAVED ENERGY WITH THE SMART THERMOSTAT

Most treated customers think the Smart Thermostat has made their home more comfortable, although sizeable portions feel their home is about the same. Once again, fewer customers with Thermostat 3 feel their home is more comfortable (Figure 13).

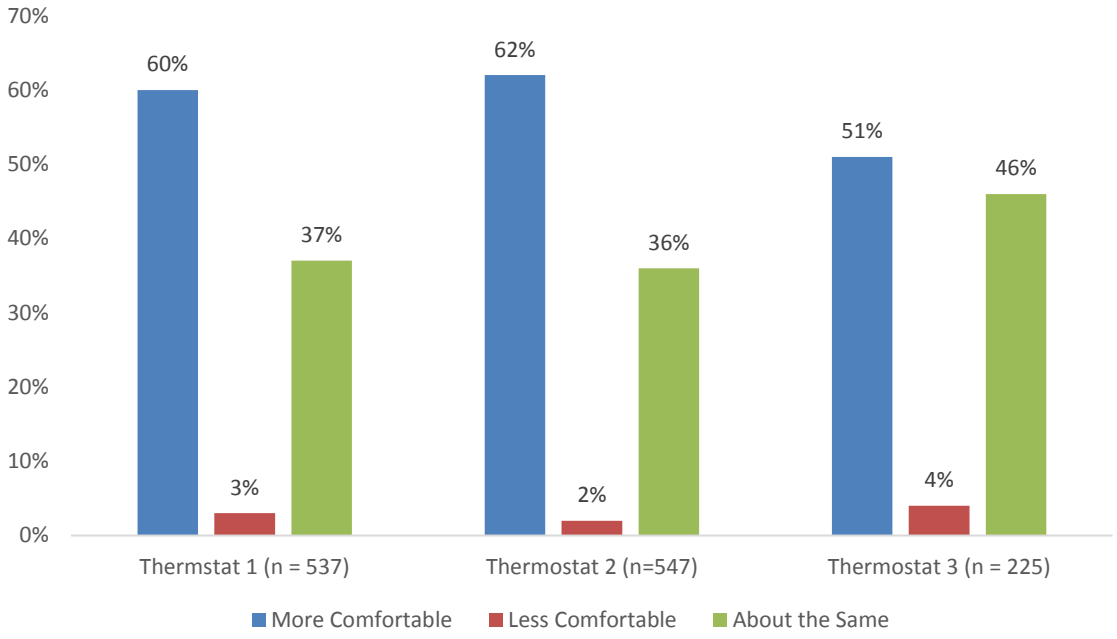


FIGURE 13. COMFORT OF HOME SINCE USING THE SMART THERMOSTAT

Most treated customers feel their Smart Thermostat is easy to use, with a large majority saying it is very easy or easy. More customers with Thermostat 3 say the thermostat is difficult to use or are more neutral in their rating (Figure 14).

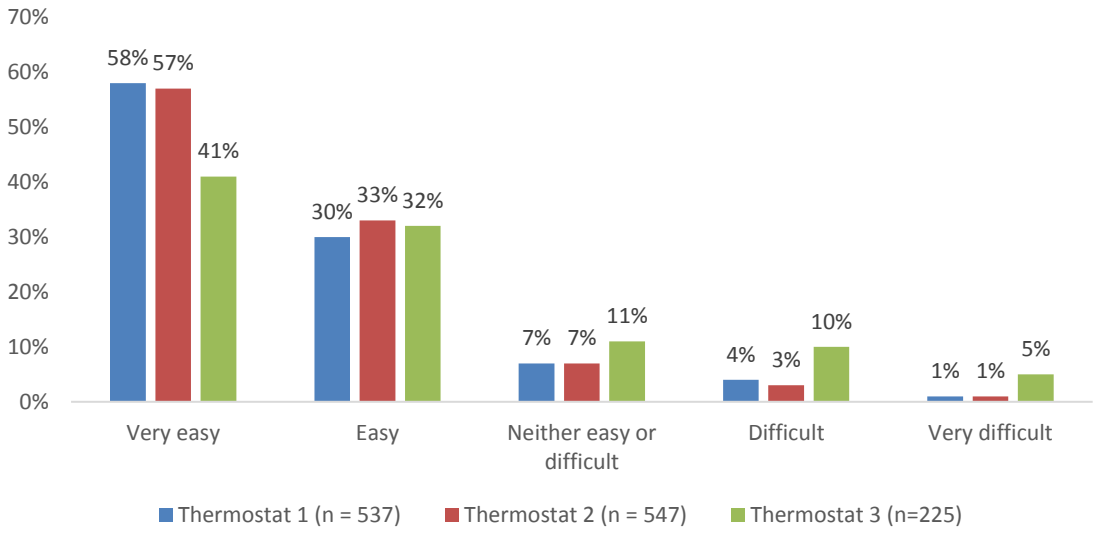


FIGURE 14. EASE OF USING THE SMART THERMOSTAT

The majority of treated customers would purchase a Smart Thermostat in the future, although 41% of customers with Thermostat 3 said they would purchase a WiFi connected programmable thermostat instead (Figure 15).

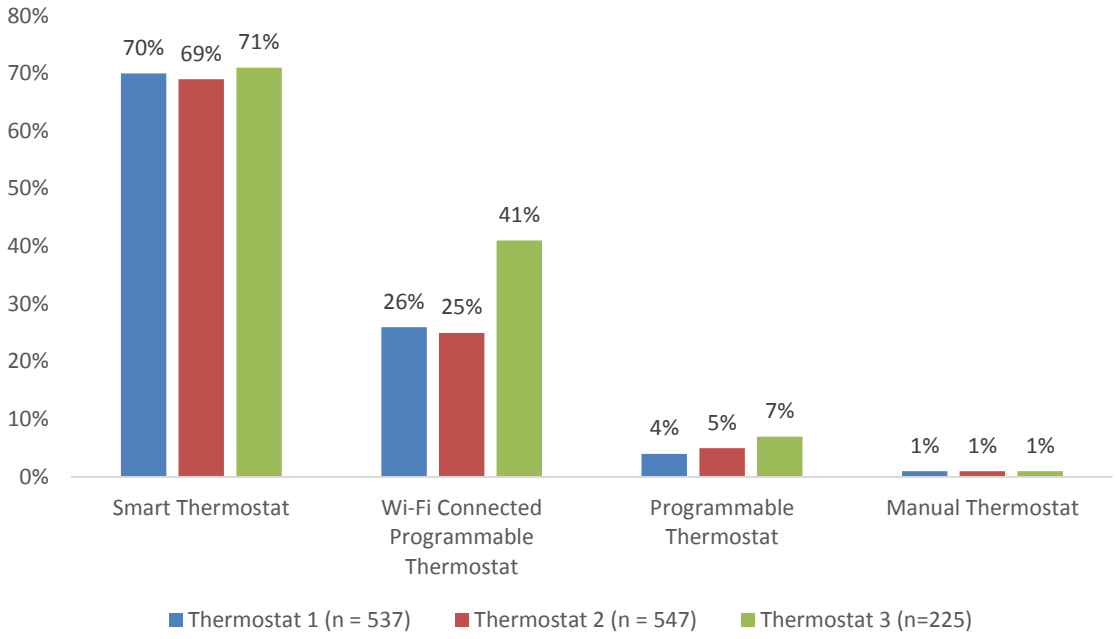


FIGURE 15. TYPE OF THERMOSTAT LIKELY TO PURCHASE IN THE FUTURE

Most treated customers are unlikely to upgrade to a new model of a Smart Thermostat if their current model was still working. This did not differ greatly by thermostat type (Figure 16).

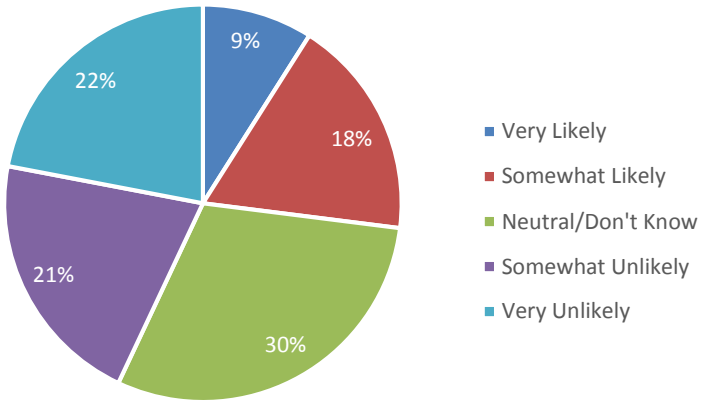


FIGURE 16. LIKELIHOOD OF UPGRADING TO A NEW VERSION OF A SMART THERMOSTAT (N = 1,309)

Energy Efficiency Actions and Attitudes

About a third of treated customers said they made some change in their household in the last 24 months that affected their energy use. This included additional people living in the home or being home during the day (e.g. retired), purchasing new equipment or appliances, remodeling, adding solar energy, adding weatherization upgrades and/or fewer people living in the household. This did not differ greatly by thermostat type.

The majority of treated customers say they frequently think about their household's energy use and consciously make a decision to minimize it. This did not differ greatly by thermostat type (Figure 17).

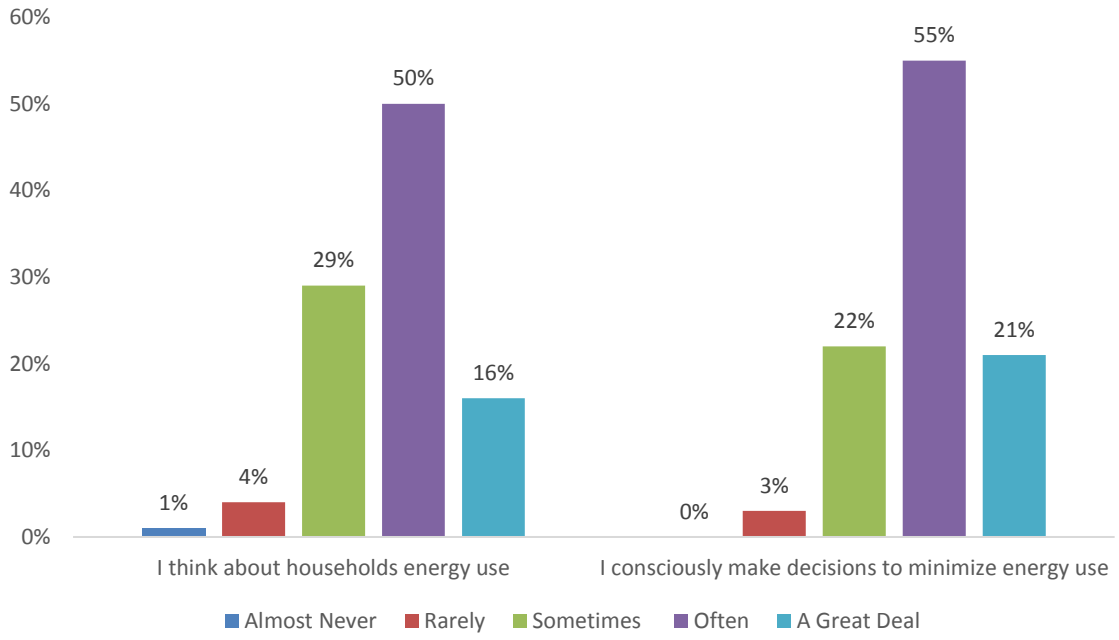


Figure 17.Frequency of Thinking About Energy Use (n=1,309)

The majority of treated customers also feel personal responsibility for their energy use and the environment (Table 17).

Table 17. Attitudes Regarding Personal Responsibility and Energy Use (n = 1,309)

Statement	Agree	Neutral	Disagree
Each individual has a responsibility to do their part for the environment	95%	4%	1%
I don't see any problem with using lots of energy	4%	7%	89%
I feel personally obliged to reduce my energy use regardless of what others are doing	86%	4%	10%

End of Study Control/Untreated Customer Survey Results

All of the 2,000 customers assigned to the control group and the 8,122 customers who were selected for participation but did not have a thermostat installed (e.g., untreated)[6] were sent an email invitation to take the end of the study survey. A reminder email was sent out to all non-respondents three days after the initial invite.

A total of 289 control group customers and 1,231 untreated customers responded to the survey. Table 18 shows the breakdown of surveys by group.

Table 18. Survey Response Rate

Group	Population	Surveys Completed	% of Respondents
Control	2000	289	14%
Untreated	8,122	1,231	15%

Control and untreated customers were asked about the type of thermostat used, energy efficiency actions and attitudes, and some basic demographic questions about their household. If customers had a Smart Thermostat they were also asked about their satisfaction with the Smart Thermostat and the use of Smart Thermostat features.

Differences Between Customer Groups

The only statistically significant differences between control and untreated customer is that control customers with a Smart Thermostat (n= 42) are more likely to believe a benefit of the smart thermostat is that it improves the comfort of their home than do untreated customers with smart thermostats (n = 178). Sixty-four percent of control customers with smart thermostats vs. 46% of untreated customer with smart thermostats say improved comfort is a benefit.

In addition to the analysis discussed above control/untreated results were compared to the results of PG&E Smart Thermostat Study treated customers. There were no statistically significant differences between Control/Untreated participants with smart thermostats and PG&E Smart Thermostat Study treated customers.

[6] A portion of customers who were selected for participation did not respond to attempts to schedule an installation. In addition a portion of customers scheduled for an installation could not get a unit installed mainly because of the location of their HVAC system (e.g., on the roof of the house) or because they didn't like the brand of thermostat provided. There was a sufficiently negative reaction from customers to Thermostat 3, resulting in trips by installers to the customer residences that did not result in a successful installation that PG&E decided to discontinue installations of that brand of thermostat mid-way through the installation phase of the study

Thermostat Status and Use

Fifteen percent of respondents to the survey said they had a Smart Thermostat installed (15% of control group customers and 14% of untreated customers). This suggests that there is some naturally occurring adoption in the marketplace. A proportion of customers in this high tech segment located in warmer climates are purchasing Smart Thermostats on their own.

Seventy percent of control and untreated customers have a programmable thermostat and 15% have a manual thermostat (Figure 18 and Figure 19). Thirty-five percent of customers without a smart thermostat say they are at least somewhat likely to purchase a Smart Thermostat in the next two years.

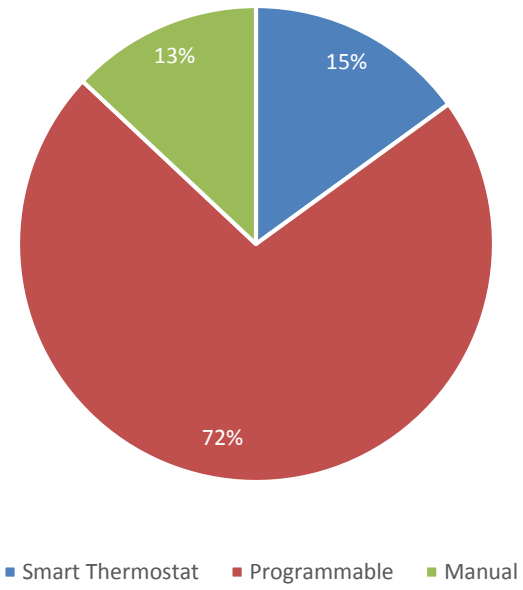


Figure 18. Type of Thermostat – Control Customers (N = 289)

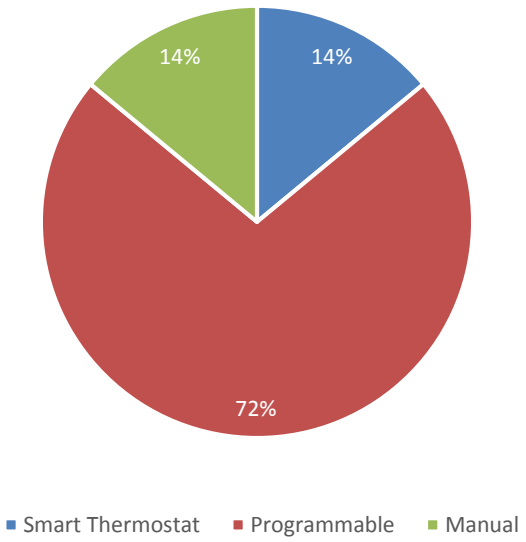


FIGURE 19. TYPE OF THERMOSTAT – UNTREATED CUSTOMERS (N = 1,231)

A little less than half of control and untreated customers are neutral regarding whether comfort or cost dictated their thermostat usage (Figure 20). But more customers value reducing cost over comfort.

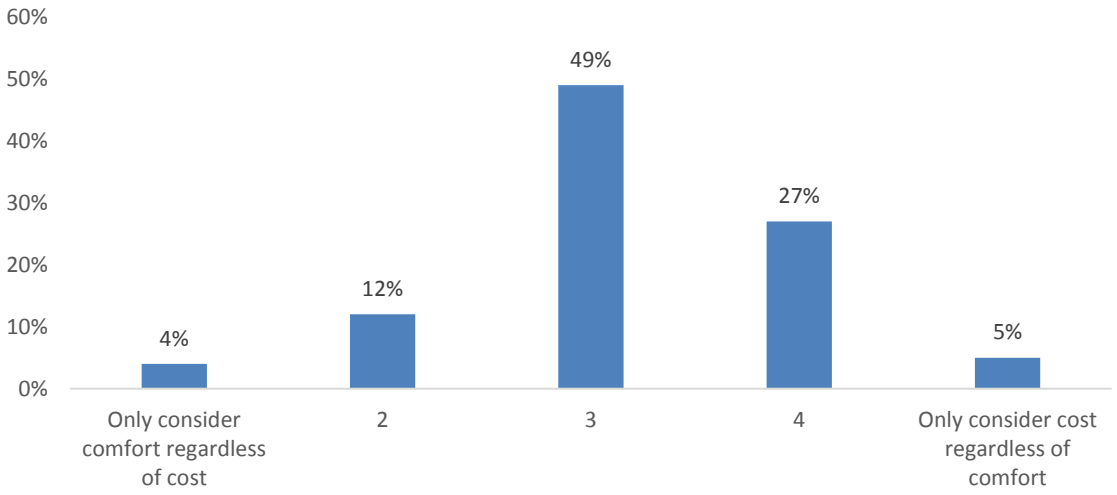


FIGURE 20. MAIN DRIVER OF THERMOSTAT USAGE – COMFORT VS. COST (N = 1,520)

ENERGY EFFICIENCY ACTIONS AND ATTITUDES

Thirty-eight percent of customers said they made some change in their household in the last 24 months that affected their energy use. This included additional people living in the home or being home during the day (e.g. retired), purchasing new equipment or appliances, remodeling, adding solar energy, adding weatherization upgrades and/or fewer people living in the household.

The majority of customers say they frequently think about their household's energy use and consciously make a decision to minimize it (Figure 21).

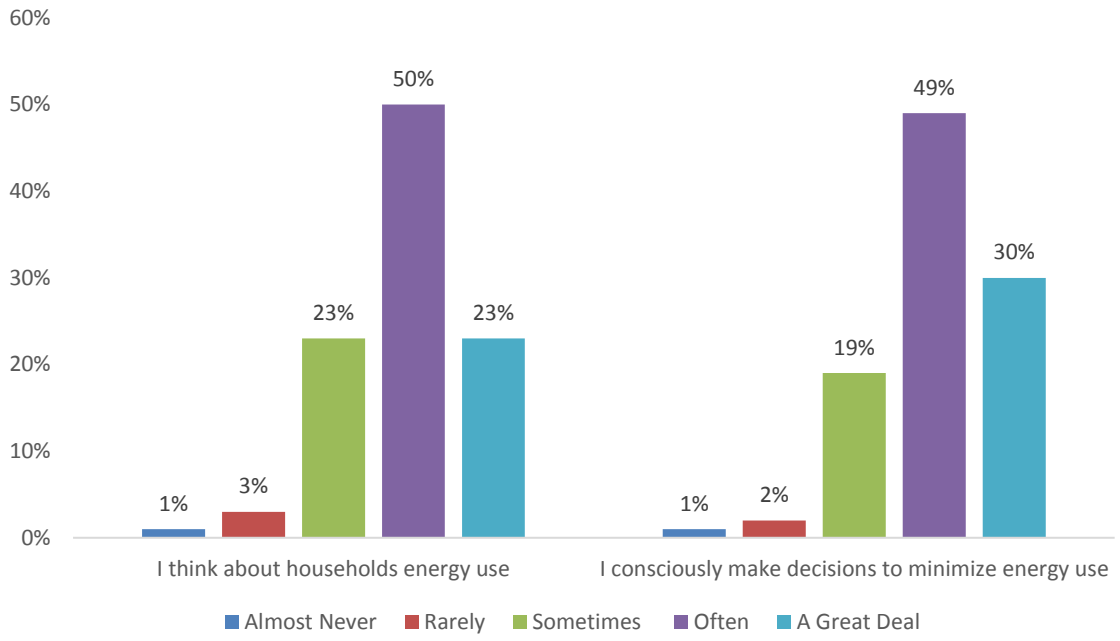


FIGURE 21.FREQUENCY OF THINKING ABOUT ENERGY USE (N = 1,520)

The majority of control and untreated customers also feel personal responsibility for their energy use and the environment (Table 19).

TABLE 19. ATTITUDES REGARDING PERSONAL RESPONSIBILITY AND ENERGY USE (N = 1,520)

STATEMENT	AGREE	NEUTRAL	DISAGREE
Each individual has a responsibility to do their part for the environment	91%	6%	3%
I don't see any problem with using lots of energy	4%	9%	87%
I feel personally obliged to reduce my energy use regardless of what others are doing	82%	12%	6%

SATISFACTION WITH THE SMART THERMOSTAT

Control and untreated customers who reported having a Smart Thermostat (n= 220) were asked how frequently they used various features of the Smart Thermostats. Monitoring and controlling the Smart Thermostat remotely was used at least occasionally by the majority of control and untreated customers with smart thermostats (Figure 22).

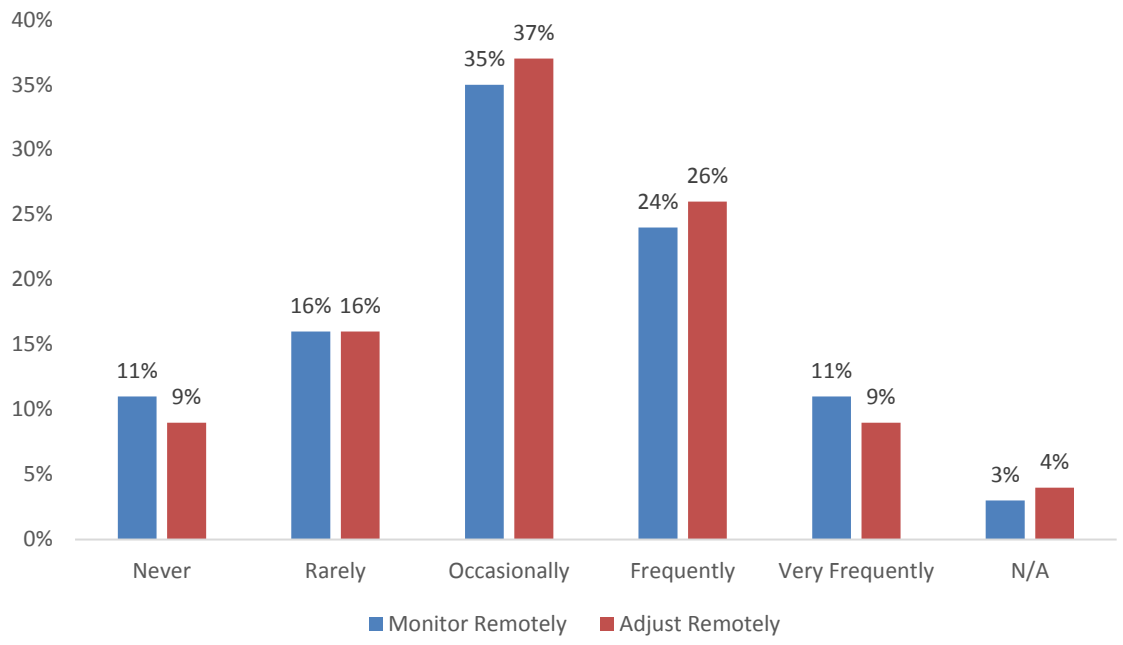


FIGURE 22. USE OF SMART THERMOSTAT REMOTE FEATURES (N = 220)

The majority of control and untreated customers with Smart Thermostats at least occasionally adjust or change their thermostat settings, although more than a quarter say they rarely or never adjust their Smart Thermostat. The majority also at least occasionally use the pre-programmed settings such as auto-away, but more than forty percent rarely or never use this feature (Figure 23).

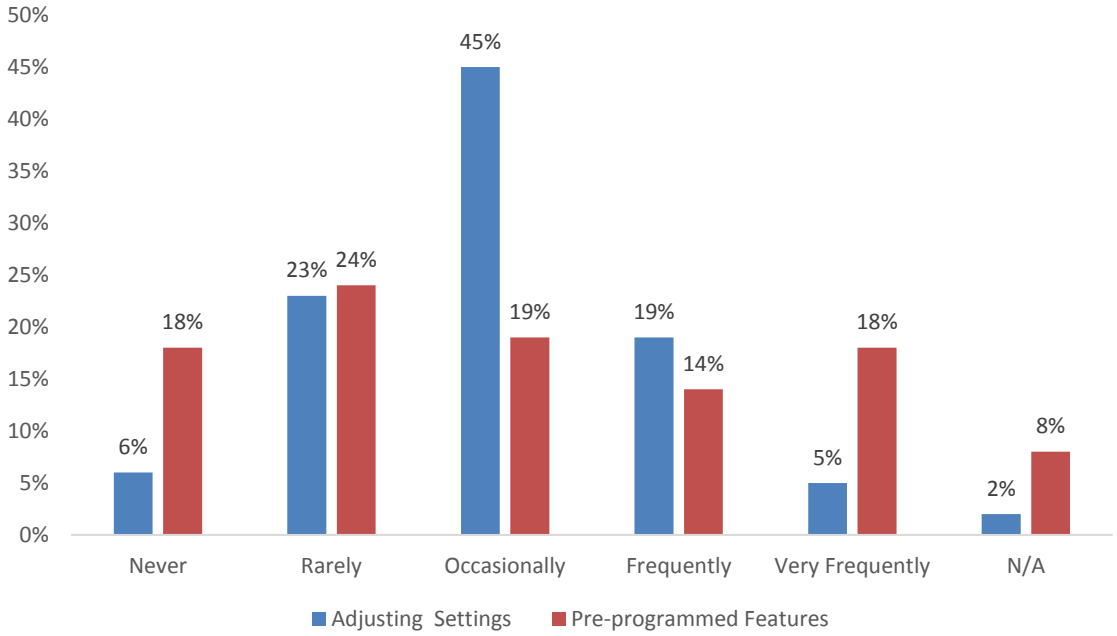


FIGURE 23. FREQUENCY OF ADJUSTING AND USING PRE-PROGRAMMED SETTINGS (N = 220)

The use of a "Green" setting is used by about half of control and untreated customers with Smart Thermostats at least occasionally. Seventeen percent say this feature is not applicable to their smart thermostat (Figure 24).

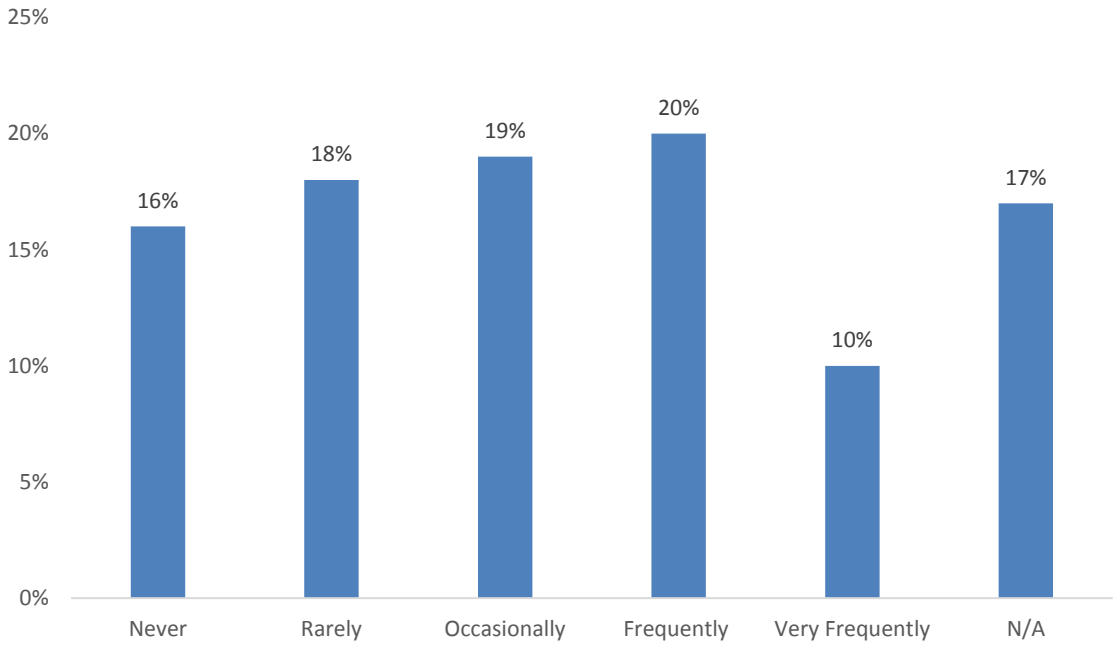


FIGURE 24. FREQUENCY OF USING GREEN SETTINGS (N = 220)

Satisfaction with smart thermostats overall is high with the majority of control and untreated customers giving top box ratings of a 4 or 5 on a 5-point satisfaction scale. Most customers are also very satisfied with the smart thermostat mobile app and website, although almost quarter of customers rated the website a 3 or lower (Figure 25).

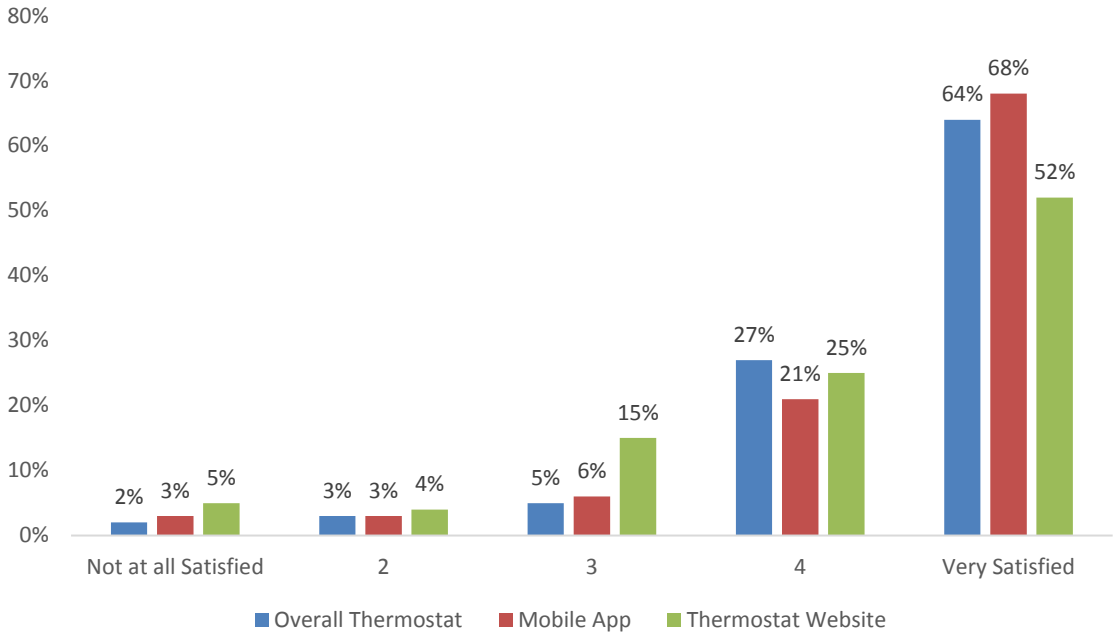


FIGURE 25. OVERALL SATISFACTION WITH SMART THERMOSTAT (N = 220)

The vast majority of control and untreated customers with smart thermostats would recommend a smart thermostat to a friend, family member or co-worker, with 89% saying they would be somewhat or very likely to recommend the thermostat.

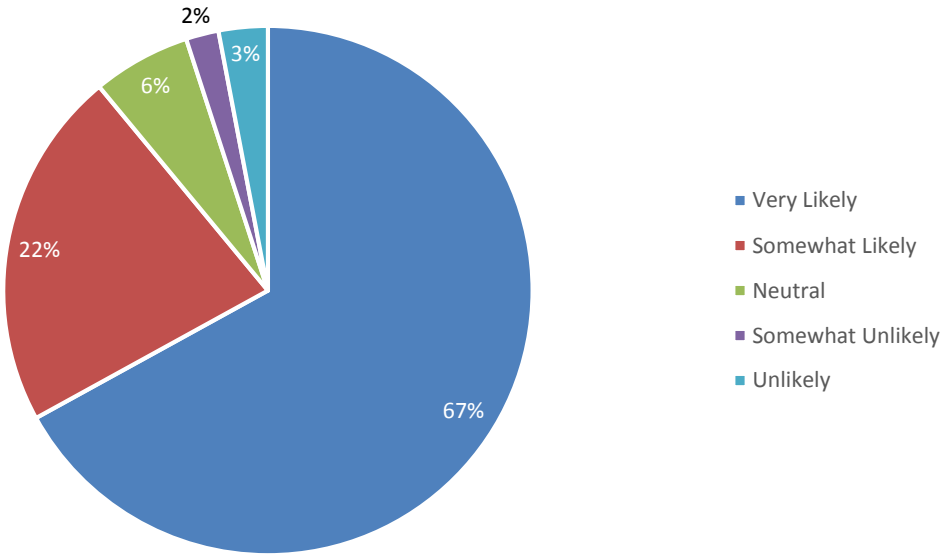


FIGURE 26.LIKELY TO RECOMMEND A SMART THERMOSTAT (N = 220)

Most control and untreated customers feel they have saved energy on their PG&E bill using the Smart Thermostat (Figure 27).

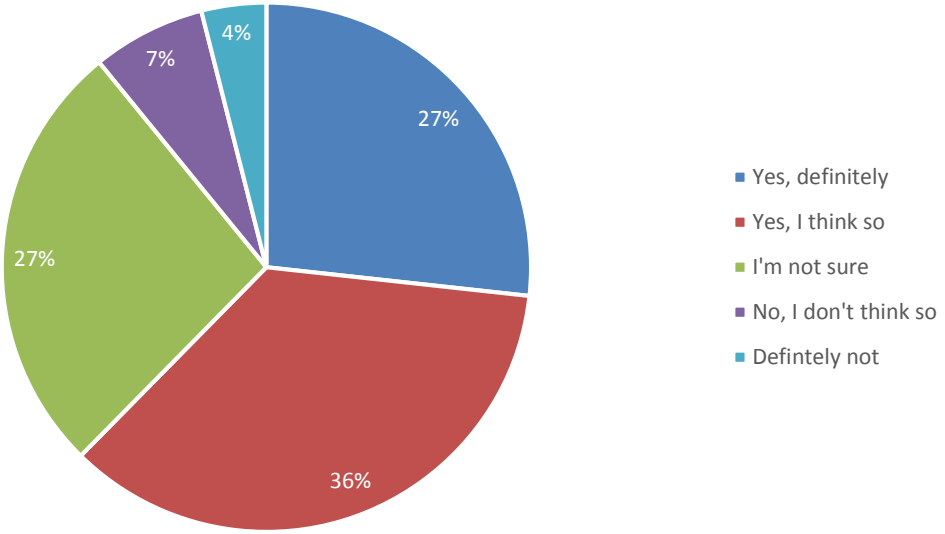


FIGURE 27.HAVE SAVED ENERGY ON PG&E BILL USING SMART THERMOSTAT (N = 220)

More than half of customers think the Smart Thermostat has made their home more comfortable, although sizeable portions feel their home is about the same (Figure 28).

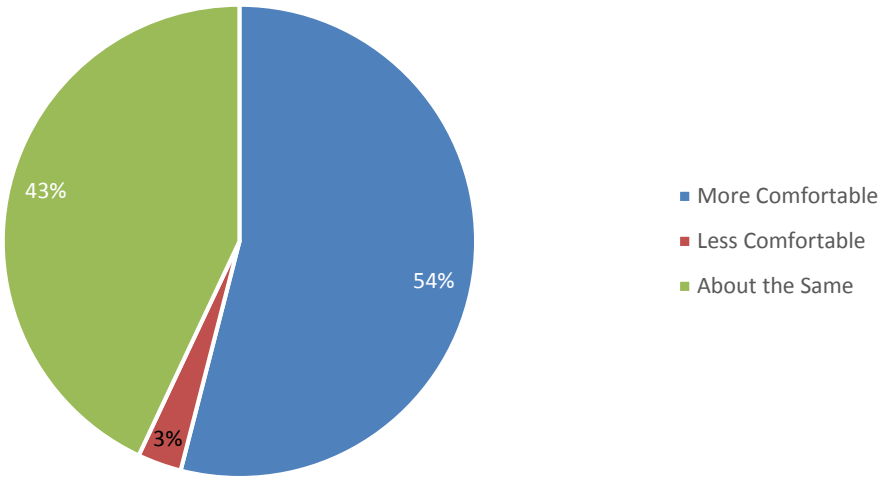


FIGURE 28. COMFORT OF HOME SINCE USING THE SMART THERMOSTAT (N = 220)

Most control and untreated customers feel their smart thermostat is easy to use, with 81% saying it is very easy or easy (Figure 29).

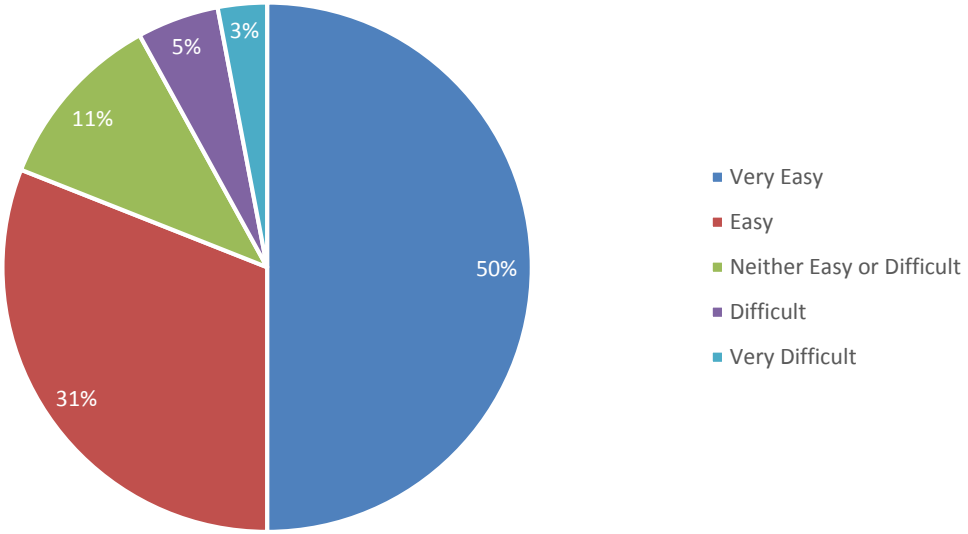


FIGURE 29. EASE OF USING SMART THERMOSTAT (N = 220)

Saving energy, having remote control, saving money and having more control over their thermostat are cited as benefits of a smart thermostat by the majority of control/untreated customers (Figure 30).

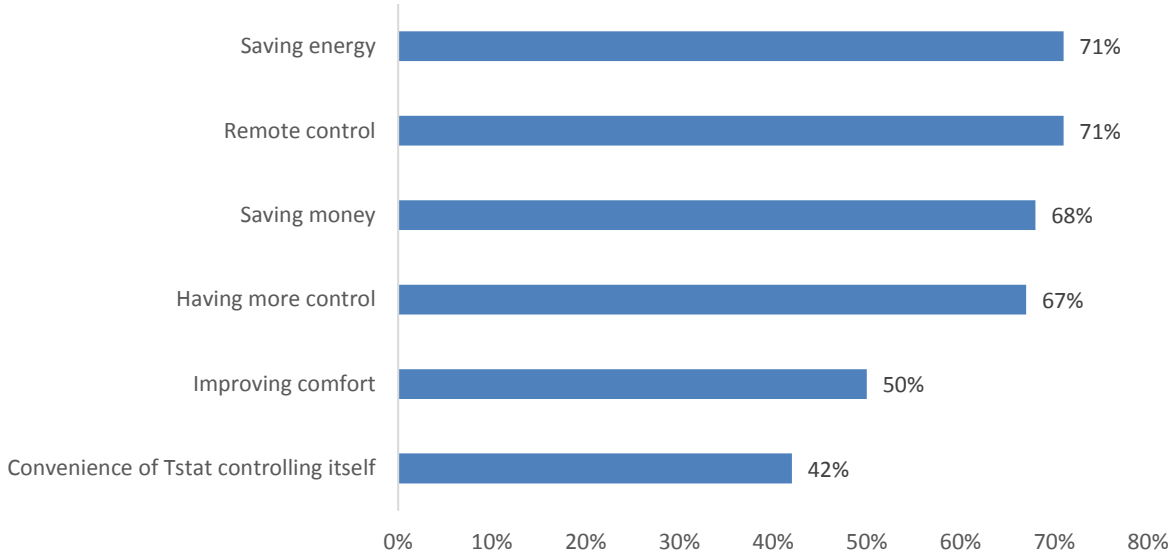


FIGURE 30. BENEFITS OF A SMART THERMOSTAT (N = 220)

ANALYSIS BY SAVING SUBGROUP

An additional task for the Study involved analyzing the two survey datasets and thermostat microdata from the study by the savings level of the treated customers. The survey data was analyzed to determine if various customer attitudes, actions, satisfaction levels and demographics were associated with different levels of energy savings. The thermostat data was analyzed to determine if the way treated customers used their thermostats differed among savings subgroups.

AEG constructed a one-to-one matched control group for each treated customer using the first-year data. Using the RED control group as the control group pool, a segmented Euclidean distance (ED) match was performed a using the following guidelines:

- The ED metric used 12 months of pretreatment data (September 2014 through August 2015) and the customers were segmented by climate.
- Matched control sharing was allowed between thermostats, since analysis for each thermostat is performed separately.
- Matching for electric and gas was performed separately, i.e., a treated customer's electric match and gas match can be two different control customers.

The graphs below show the pretreatment period comparisons between each treatment and control group, by thermostat and energy type. The gas graphs show excellent pretreatment period matches between the treated and control customers. The energy graphs show less than ideal matches in the colder months (October through January), but these differences

should be addressed through the DID analysis. Also, the warmer months show excellent pretreatment period matches between the treated and control customers, which holds more weight in our electric impact analysis.

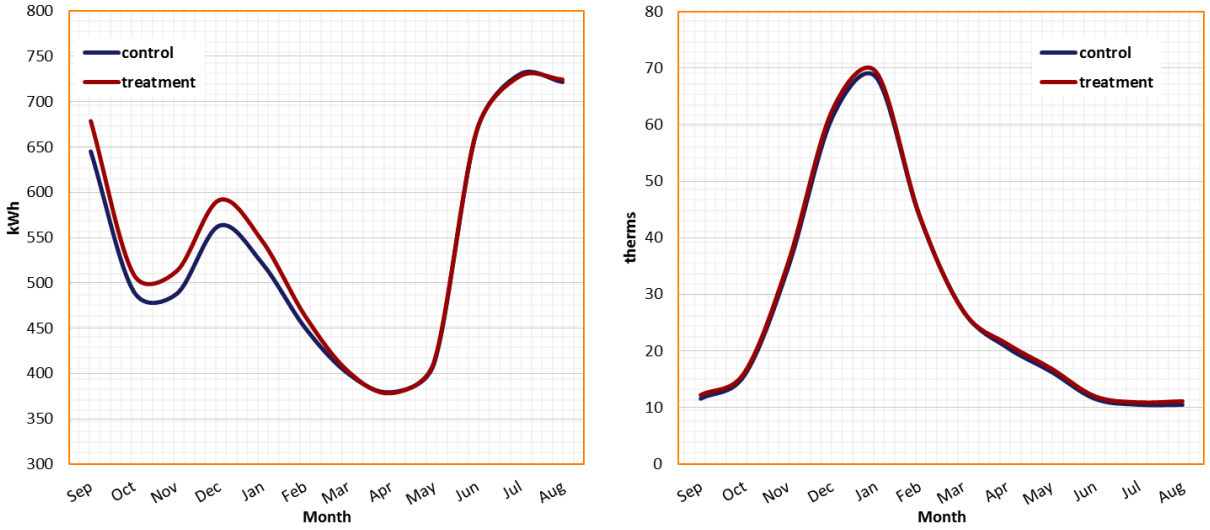


FIGURE 31. PRETREATMENT PERIOD COMPARISONS, CONTROL VS. TREATMENT – THERMOSTAT 1

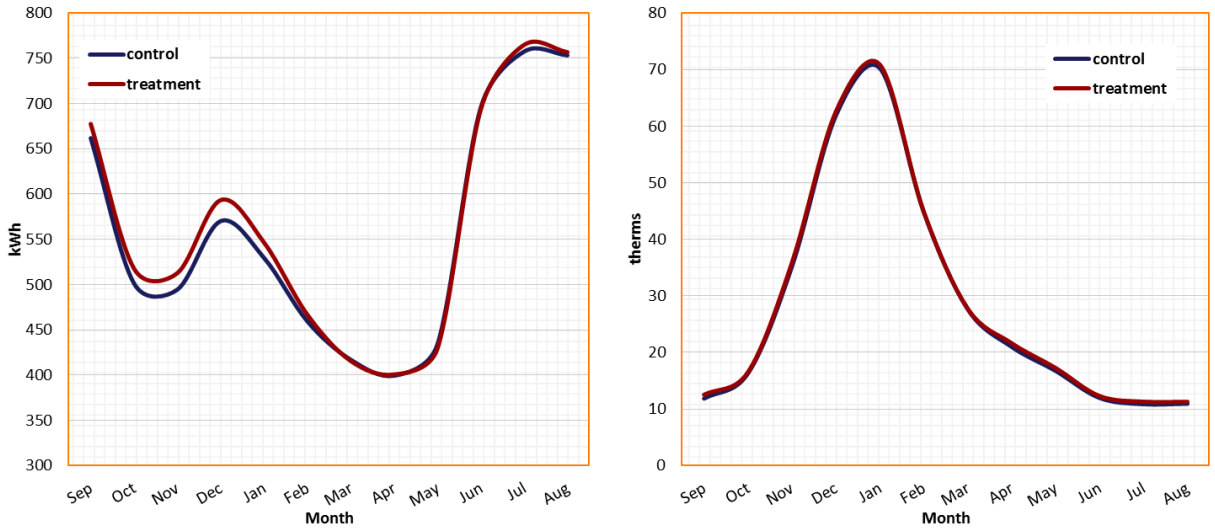


FIGURE 32. PRETREATMENT PERIOD COMPARISONS, CONTROL VS. TREATMENT – THERMOSTAT 2

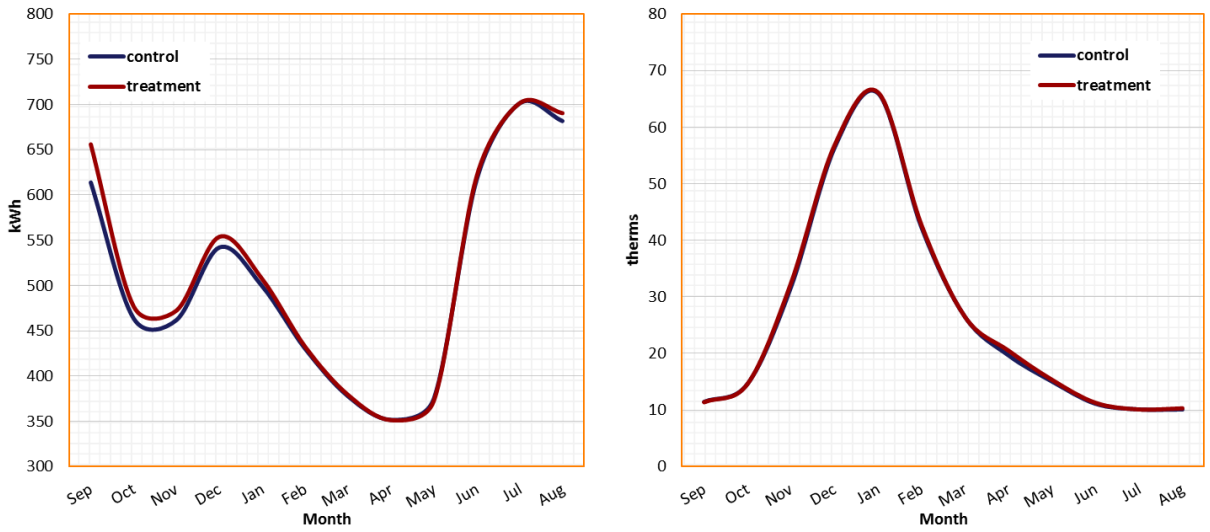


FIGURE 33. PRETREATMENT PERIOD COMPARISONS, CONTROL VS. TREATMENT – THERMOSTAT 3

Once the treated customers were matched, a one-to-one statistical DID on monthly data was done to estimate savings.

Since data availability and completeness is not consistent within the groups, the average monthly savings were used to determine the savings distribution of the treated customers (by thermostat). Breakpoints were then determined to allocate the treated customers into comparable-sized groups based on their savings estimate. The sub-groups are:

1. Positive Savers – On average these participants save more than 400 kWh or 30 therms per month.
2. No Savers – Savings for these participants range from -250 to 250 kWh or -15 to 15 therms per month
3. Negative Savers – On average these participants use more than 400 kWh or 30 therms per month
4. Excluded – Participants with savings that fall in-between the defined savings groups are excluded from this categorization.[7]

[7] 11% to 18% of participants from each thermostat are uncategorized because they are in-between the defined savers' group.

The following table shows the number of treated customers within the three subgroups: positive savers, no savers, and negative savers.

TABLE 20. SUBGROUPING DISTRIBUTION[8]

	Subgroup	Thermostat 1		Thermostat 2		Thermostat 3	
		Count	% of Total	Count	% of Total	Count	% of Total
Electric	Positive	203	27%	176	23%	66	19%
	No Savers	253	34%	277	36%	138	40%
	Negative	167	22%	190	25%	80	23%
	Total	**623**	**83%**	**640**	**83%**	**284**	**82%**
Gas	Positive	222	30%	218	28%	105	30%
	No Savers	210	29%	227	29%	111	32%
	Negative	247	34%	257	33%	106	30%
	Total	**702**	**93%**	**679**	**89%**	**322**	**92%**

SURVEY SUBGROUP ANALYSIS RESULTS

Using the controlled matched savings subgroups explained above, the survey data was analyzed to determine if thermostat behavior, perceived ease of use, satisfaction with the Smart Thermostat, energy savings attitudes and behavior, and/or housing and demographic characteristics differed by savings group. Electric and gas savings groups were analyzed separately.

Table 21 below lists the survey finding where the results had statistically significant differences by electric savings group.

[8] For the sub-grouping, we have filtered outliers where electric savings was higher than 625 kWh or lower than -625 kWh per month or gas savings that was higher than 60 therms or lower than -60 therms per month.

TABLE 21. STATISTICALLY SIGNIFICANT DIFFERENCES BY ELECTRIC SAVINGS SUBGROUP

SURVEY FINDING	NEGATIVE	NO SAVER	POSITIVE
Reported typically manually adjusting their previous thermostat	*63.6%*	59.3%	53.6%
Definitely have not saved energy w/smart thermostat	*3.9%*	2.0	.4%
Never monitor smart thermostat remotely	*14.3%*	6.4%	6.5%
Never adjust/change their thermostat programs or settings	5.2%	4.0%	*1.2%*
Someone is home during the day during the cooling season	*83.6%*	73.3%	74.1%
Home is 2,501 square feet or larger	*17.1%*	9%	7.7%
Home has a hot tub or spa	*20.1%*	12.4%	13.4%

Main findings from the electric savings subgroup analysis include the following:

- Negative savers are more likely than no and positive savers to say they typically manually adjusted their previous thermostat.
- Negative savers are more likely than positive savers to say they have definitely not saved energy with their smart thermostat.
- Negative savers are more likely than no or positive savers to say they never monitor their smart thermostat remotely.
- Positive savers are less likely than no or negative savers to say they never adjust/change their program or settings.
- Negative savers are more likely than no or positive savers to have someone home during the day during the cooling season.
- Negative savers are more likely than positive savers to have a home larger than 2,500 square feet.
- Negative savers are also more likely to have a hot tub or spa.

Table 22 below lists the survey finding where the results had statistically significant differences by gas savings group.

TABLE 22. STATISTICALLY SIGNIFICANT DIFFERENCES BY GAS SAVINGS SUBGROUP

SURVEY FINDING	NEGATIVE	NO SAVER	SAVER
Set heat at 55 or below during the day	1.9%	2.7%	*4.6%*
Definitely saved energy with their smart thermostat	26.3%	29%	*35.1%*
Saving energy is a benefit of having a smart thermostat	73.1%	70.1%	*81.5%*
Saving money on energy bills is a benefit of having a smart thermostat	71.6%	66%	*79.4%*

Main findings from the gas savings subgroup analysis include the following:

- Positive savers are more likely than negative savers to set their heat at 55 or below during the daytime (9 a.m. – 5 p.m.)
- Positive savers are more likely than negative savers to think they definitely saved energy with their smart thermostat.
- Positive savers are more likely than no or negative savers to think saving energy and saving money on energy bills is a benefit.

CONCLUSIONS

The following conclusions can be drawn from this analysis:

- Some thermostat behaviors such as manually adjusting a previous thermostat (as opposed to setting a program), not lowering he heating temperature during the daytime, and not using the remote monitoring feature of the smart thermostat may lead to lower or negative savings.
- It may be more challenging for larger households, households with someone home during the day during the cooling season, and households with a hot tub or spa to save energy with a smart thermostat.
- Treated customers are generally aware of their savings. Negative savers are more likely to say they are not saving. Positive savers are more likely to say they are saving and that saving energy and money is a benefit of having a smart thermostat.

SAVINGS BY SUBGROUP THERMOSTAT DATA ANALYSIS

Using the controlled matched savings sub groups explained above, individual thermostat level data was analyzed to determine if the way treated customers used their thermostats differed among positive, no and negative saving customers. The following data was available for customers with Thermostat 1 included in the study:

- Heating and cooling runtime
- Average indoor temperature setting

The goal of this analysis was to answer the following research questions:

- Do positive savers set their thermostats at more efficient settings (e.g., higher temperature settings in summer, lower temperature settings in winter) compared to no and negative savers?
- Do positive savers have shorter heating and cooling run times than no and negative savers?

The results of this analysis were inconclusive. There was no consistent patterns or differences in the set points or runtimes for customers with the thermostat by savings subgroup. This may be because since the data was only available for one thermostat the sample sizes were small, and because there was no baseline thermostat behavior data available (e.g., data was not available on how the previous thermostat was used during the baseline period – the year prior to participation in the Study).

RECOMMENDATIONS AND LESSONS LEARNED

The findings of this study show persistent electric savings for all three brands of thermostat and persistent natural gas savings during the heating season for Thermostat 3. The following recommendations/lessons learned should be considered when conducting future research of this technology:

- The savings from this pilot combined with other secondary research could be used to develop ex ante savings estimates for a similar program.
- Given the level of natural market adoption (15%) among this high-tech segment of the population located in warmer climate zones, PG&E may want to investigate savings for those that purchased their own thermostats.
- PG&E may also want to look at the additional potential savings that could be achieved through programmatic efforts such as educational messaging, or additional features that might be available or "turned on", (such as "green" settings or "away" settings that automate lower usage) for the different thermostats.
- DR potential for customers with smart thermostats should be researched and explored and PG&E could leverage any and all smart thermostats in their territory to participate in DR events in a BYOT thermostat pilot.
- The microdata available from Smart Thermostats was not as useful as anticipated at this time:
    - The microdata available varies greatly across thermostat manufacturers
    - The datasets are very large and considerable time is required to match, clean and aggregate the data.
    - The potential results derived from the data are intuitive and don't provide additional insight into thermostat use or behavior. For example, an analysis could show that individuals who had longer thermostat runtimes saved less energy. This finding does not improve our understanding of customer behavior since it is already assumed that customers who save energy set their thermostats at temperatures that require it to run less often.
    - It is difficult to find meaningful results from an analysis of the Smart Thermostat data without comparable data from the thermostat customers before the Smart Thermostat was installed. Obtaining this data would require

significant planning and expense and would extend the timeline of the study considerably.

- The RED design has both advantages and disadvantages. The advantages are realized mainly during the study implementation (easier recruitment, lower installation costs, etc.) while the disadvantages are mainly realized during the analysis. The disadvantages experienced during this Study included the following:
    - The sample size of the treated customers was a small proportion of the encouraged group (15 – 25% depending on type of thermostat). The sample size of the treated customers with respect to the overall encouraged group significantly diluted the savings estimates making them hard to detect with significance in the impact analysis. For example, if we estimate a savings of 10% annually for the treated customers, and only 25% of the encouraged group received the treatment, that savings translates to only a 2.5% savings at the encouraged group level. Therefore, small savings were difficult to detect at the encouraged group level.
    - The experimental design eroded over time. Over the course of the study, we have lost participants across all groups due to simple churn (e.g. customers moving to another home or out of the territory). As our overall sample size decreased, we lost statistical power, and it was harder to estimate savings with significance.
    - Smart Thermostat adoption increased in the control/untreated groups. This affected the baseline against which the treated customers were measured. For example, if the treated customers saved electricity relative to their own pretreatment usage, their savings relative to the control and encouraged (but untreated groups) appear smaller as more customers in the control/untreated adopt Smart Thermostats.[9]
    - These disadvantages may explain why savings were somewhat lower during the second year of the study.
- Due to the RED limitations we recommend the following:
    - Additional research with this sample is not recommended.
    - When using a RED design for future research, effort should be taken during implementation to achieve as high a ratio of treated versus encouraged customers as possible. This could include limiting the outreach to a smaller geographical area, extending the installation period, and using secondary data to estimate a take rate (e.g., the percent of encouraged that accept treatment) to determine the appropriate size of the encouraged group.

[9] Fifteen percent of control/untreated customers purchased a Smart Thermostat during the study period.

APPENDICES

PG&E Smart Thermostat End of Study Survey

Participant Final

[LANDING PAGE]

Welcome! [PG&E LOGO]

Thank you for having participated in Pacific Gas and Electric Company's (PG&E) Smart Thermostat Study. As a final step, we ask that you complete this survey about your experience with the smart thermostat provided as part of this study. This survey is being conducted by Applied Energy Group (AEG) on behalf of PG&E.

We encourage your candid feedback in this survey. Your answers will be kept confidential and only used for purposes of the study. This survey will take less than 10 minutes to complete and is important for our final assessment.

SCREENER

1. Is the Smart Thermostat you received through the PG&E study currently installed in your home?

   Yes –SKIP TO Q1b
   No

1a. Why is the Smart Thermostat no longer installed?
   [OPEN ENDED]

THANK AND TERMINATE

TERMINATION

Thank you for your time.

1b: Is the Smart Thermostat connected to your home's internet/Wi-Fi?

   Yes
   No

THERMOSTAT

First, we would like to ask you some questions about how you control your Smart Thermostat.

2. Using the scale below please indicate how you typically decide how to set your thermostat, with 1 meaning you only consider comfort and 5 meaning you only consider your PG&E bill/the energy cost?

Only Consider Comfort, regardless of cost 1	2	3	4	Only consider bill/ energy cost, regardless of comfort 5

3. At what temperature do you set your Smart Thermostat during the following portions of a typical weekday?

	A. On days when you are using your **HEATING system**	B. On days when you are using your **COOLING System**
Morning (6 – 9 a.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher
Day (9 a.m. – 5 p.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher
Evening (5 – 9 p.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher
Night (9 p.m. – 6 a.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher

4. Using a scale of 1 to 5, with 1 meaning "Not at All Satisfied" and 5 meaning "Very Satisfied" please rate your satisfaction with the features of your Smart Thermostat:

	1 Not at All Satisfied	2	3	4	5 Very Satisfied	N/A
The Smart Thermostat overall						
The mobile app						
The thermostat website						

5. How likely are you to recommend a Smart Thermostat to friends, family or co-workers?

1 Very unlikely
2 Somewhat Unlikely
3 Neutral
4 Somewhat Likely
5 Very Likely

6. Do you think you have saved energy on your PG&E bills using the Smart Thermostat?

Yes, definitely
Yes, I think so
I'm not sure
No, I don't think so
Definitely not

7. How has your Smart Thermostat affected the comfort of your home compared to when you had your previous thermostat? Would you say your home is now . . .?

More comfortable
Less comfortable
About the same

8. How easy or difficult has it been to adjust/set/control your Smart Thermostat?

Very Easy
Easy
Neither Easy or Difficult
Difficult
Very Difficult
I don't adjust my thermostat

9. Please indicate how frequently you use the following Smart Thermostat features:

	Never	Rarely	Occasionally	Frequently	Very Frequently	N/A
Monitoring Smart Thermostat remotely						
Adjusting Smart Thermostat remotely						
Change/adjust settings or programs						
Pre-programmed settings such as auto-away						
Green or environmental settings						

10. Which of the following do you think are benefits of having a Smart Thermostat? (CHECK ALL THAT APPLY)

Trying a new technology/having latest gadget
Saving energy
Saving money on my energy bills
Having more control over my thermostat
Improving the comfort of my home
Remotely control my thermostat
Convenience of the thermostat controlling itself
Other (Please specify:_____)

11. How often have you lost WiFi connectivity to your Smart Thermostat?

Never
Occasionally
Often
Don't know

12. [IF Q11 OCCASSIONALLY OR OFTEN] After losing WiFi connectivity how quickly does your Smart Thermostat typically reconnect?

Within minutes
Within hours
Same day
Within a few days
Within a few weeks
Longer

13. If you've had any other issues or complications with your Smart Thermostat, please describe the issue/complication in detail below.

    [OPEN ENDED]

14. If you needed to purchase a new thermostat, which of these would you be most likely to purchase?

    1 Smart Thermostat
    2 WiFi-Connected Programmable Thermostat
    3 Programmable Thermostat
    4 Manual Thermostat

15. If a new model of a Smart Thermostat were available, how likely would you be to upgrade and purchase the new model, even if your current thermostat was still working and did not need to be replaced?

    1 Very unlikely
    2 Somewhat Unlikely
    3 Neutral/Don't know
    4 Somewhat Likely
    5 Very Likely

ACTIONS

Now we would like to know about any actions or behaviors that may have impacted your energy usage.

16. Have there been any changes in your household in the last 24 months that might have affected your home's energy use? Examples would be additional or fewer people living in the home, purchasing new heating or cooling equipment or appliances, making home weatherization improvements, major remodeling or additions, etc.

    Yes
    No

17. [IF Q16 = YES] What changes did you make to your home? Please describe in detail below.

    [OPEN ENDED]

18. Please indicate how frequently you do the following?

	1 Almost Never	2 Rarely	3 Sometimes	4 Often	5 A Great Deal
I think about my household's energy use					
I consciously make decisions to minimize my energy use					

19. Please indicate how much you agree or disagree with the following statements?

	1 Strongly Disagree	2 Disagree	3 Neither	4 Agree	5 Strongly Agree
Each individual has a responsibility to do their part for the environment					
I don't see any problem with using a lot of energy					
I feel personally obliged to reduce my energy use, regardless of what other people do					

DEMOGRAPHICS

Finally, we would like to ask you some questions about your home.

20. Are there any individuals living in your home that regularly stay at home all or most **weekdays during the winter (heating season)**?

Yes
No

21. Are there any individuals living in your home that regularly stay at home all or most **weekdays during the summer (cooling season)**?

Yes
No

22. What type of heating system do you use primarily to heat your home?

Natural gas central forced air furnace
Natural gas floor or wall heater/furnace
Electric resistance (baseboard/ceiling/floor/wall)
Electric central forced air furnace
Electric central heat pump
Electric through-the-wall heat pump
Bottled gas central forced air furnace
Bottled gas floor or wall heater/furnace
Solar
Other (please specify: _____)
Don't know

23. What type of central air conditioning/cooling do you have in your home?

Central air conditioning
Central evaporative (swamp) cooler
Heat pump
Other (please specify:_____)
Don't know

24. Do you have any additional comments or feedback for us about your smart thermostat or your experience participating in PG&E's Smart Thermostat Study?

[OPEN ENDED]

25. Would you be interested in participating in a future smart thermostat/smart home study?

Yes
No

Thank you for your time completing this survey, and for your participation in this study.

PG&E Smart Thermostat End of Study Survey

Control/Untreated Customer Draft Final

[LANDING PAGE]

Welcome! [PG&E LOGO]

Thank you for participating in this short survey from Pacific Gas and Electric Company (PG&E). This survey is being conducted by Applied Energy Group (AEG) on behalf of PG&E.

We'd like you to answer a few questions about your home and your thermostat use. We encourage your candid feedback. Your answers will be kept confidential and only used for purposes of the study. This survey will take less than 10 minutes to complete.

1. Do you have a working central heating and/or central cooling system in your home?

   Yes, central heating and central cooling
   Yes, central heating only
   Yes, central cooling only
   No

2. What type of thermostat(s) do you have? (CHECK ALL THAT APPLY)

   Smart thermostat (one that automatically adjusts itself and can be controlled remotely)

   Programmable thermostat (one that lets you program a regular schedule for different times of the day and/or different days of the week)

   Standard/ Manual thermostat (one that you have to manually adjust and that has only one setting for the internal temperature you want)

   Other (Specify:_____)

3. [IF Q2 NOT SMART THERMOSTAT] How likely are you to purchase a Smart Thermostat in the next 2 years?

   1 Not at all Likely
   2 Somewhat Unlikely
   3 Neutral
   4 Somewhat Likely
   5 Very Likely

5. Using the scale below please indicate how you typically decide how to set your thermostat, with 1 meaning you only consider comfort and 5 meaning you only consider your PG&E bill/the energy cost?

Only Consider Comfort, regardless of cost 1	2	3	4	Only consider bill/ energy cost, regardless of comfort 5

6. At what temperature do you set your thermostat during the following portions of a typical weekday?

	A. On days when you were using your **HEATING system**	B. On days when you were using your **COOLING System**
Morning (6 – 9 a.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher
Day (9 a.m. – 5 p.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher
Evening (5 – 9 p.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher
Night (9 p.m. – 6 a.m.)	1. 55°F or below 2. 56 - 60°F 3. 61-65°F 4. 66-70°F 5. 71 - 75°F 6. 76°F or higher	1. Off 2. 69°F or below 3. 70-74°F 4. 75-79°F 5. 80 - 84°F 6. 85°F or higher

SMART THERMOSTAT [IF Q2 = SMART THERMOSTAT; OR SKIP TO ACTIONS SECTION]

7. When did you purchase your smart thermostat? If you don't know for sure, please provide your best guess.

_____Month
_____ Year

8. Using a scale of 1 to 5, with 1 meaning "Not at All Satisfied" and 5 meaning "Very Satisfied" please rate your satisfaction with the features of your Smart Thermostat:

	1 Not at All Satisfied	2	3	4	5 Very Satisfied	N/A
The Smart Thermostat overall						
The mobile app						
The thermostat website						

9. How likely are you to recommend a Smart Thermostat to friends, family or co-workers?

6 Very unlikely
7 Somewhat Unlikely
8 Neutral
9 Somewhat Likely
10 Very Likely

10. Do you think you have saved energy on your PG&E bills using the Smart Thermostat?

Yes, definitely
Yes, I think so
I'm not sure
No, I don't think so
Definitely not

11. How has your Smart Thermostat affected the comfort of your home compared to when you had your previous thermostat? Would you say your home is now . . .?

More comfortable
Less comfortable
About the same

12. How easy or difficult has it been to adjust/set/control your Smart Thermostat?

Very Easy
Easy
Neither Easy or Difficult
Difficult
Very Difficult
I don't adjust my thermostat

13. Please indicate how frequently you use the following Smart Thermostat features:

	Never	Rarely	Occasionally	Frequently	Very Frequently	N/A
Monitoring Smart Thermostat remotely						
Adjusting Smart Thermostat remotely						
Change/adjust settings or programs						
Pre-programmed settings such as auto-away						
Green or environmental settings						

14. Which of the following do you think are benefits of having a Smart Thermostat? (CHECK ALL THAT APPLY)

Trying a new technology/having latest gadget
Saving energy
Saving money on my energy bills
Having more control over my thermostat
Improving the comfort of my home
Remotely control my thermostat
Convenience of the thermostat controlling itself
Other (Please specify:_____)

ACTIONS

Now we would like to know about any actions or behaviors that may have impacted your energy usage.

15. Have there been any changes in your household in the last 12 months that might have affected your home's energy use? Examples would be additional or fewer people living in the home, purchasing new heating or cooling equipment or appliances, making home weatherization improvements, major remodeling or additions, etc.

    Yes
    No

16. [IF Q15 = YES] What changes did you make to your home?

    [OPEN ENDED]

17. Please indicate how frequently you do the following?

	1 Almost Never	2 Rarely	3 Sometimes	4 Often	5 A Great Deal
I think about my households' energy use					
I consciously make decisions to minimize my energy use					

18. Please indicate how much you agree or disagree with the following statements?

	1 Strongly Disagree	2 Disagree	3 Neither	4 Agree	5 Strongly Agree
Each individual has a responsibility to do their part for the environment					
I don't see any problem with using a lot of energy					
I feel personally obliged to reduce my energy use, regardless of what other people do					

DEMOGRAPHICS

Now I would like to ask you some questions about your home.

19. Are there any individuals living in your home that regularly stay at home all or most **weekdays during the winter (heating season)**?

Yes
No

20. Are there any individuals living in your home that regularly stay at home all or most **weekdays during the summer (cooling season)**?

Yes
No

21. What type of heating system do you use primarily to heat your home?

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Natural gas floor or wall heater/furnace
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Electric central heat pump
Electric through-the-wall heat pump
Bottled gas central forced air furnace
Bottled gas floor or wall heater/furnace
Solar
Other (please specify: _____)

22. What type of central air conditioning/cooling do you have in your home?

Central air conditioning
Central evaporative (swamp) cooler
Heat pump
Other (please specify:_____)

Thank you for your time.