PG&E Smart Thermostat Study: First Year Findings

ET Project Number ET13PGE1462

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Issued: **December 21, 2016**

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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 ET13PGE1462. Applied Energy Group conducted this technology evaluation for Pacific Gas and Electric Company with overall guidance and management from Phil Broaddus. For more information on this project, contact P1B8@pge.com.

LEGAL NOTICE

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

Smart thermostats are receiving much media attention for their usability and remote operation, and many in the energy-efficiency field have identified them as a game changer in terms of more efficient usage for heating, cooling and ventilation (HVAC). There is, however, a lack of reliable trials or objective data on this topic, and many important questions remain unanswered regarding the energy efficiency savings potential of this technology in California. In order to address these questions, PG&E designed the Smart Thermostat Study (Study) as an Emerging Technologies Program scaled field placement to gather data from customer homes that have been randomly assigned to receive a free smart thermostat.

PROJECT GOAL

The purpose of the Study is to understand the effect of this emerging technology in residential homes within certain hot and cold climate zones in PG&E's service territory. The two focus areas for the study are an estimation of the energy savings for participating households, and an assessment of the participants' experience while taking part in the study.

PROJECT DESCRIPTION

The Study is a randomized encouragement design (RED) trial in which several thousand homes were randomly assigned to the encouraged group, all of whom were offered a free, directly-installed smart thermostat, and two thousand similar homes were randomly assigned to a control group, none of whom were offered a thermostat. Three different brands of thermostats were tested in the study; the goal was to install 1,000 of each type of thermostat in participants' homes.

PG&E sent out an email recruitment survey to create a pool of interested and eligible study participants. To be eligible for the study customers responding to the survey had to own their home, have WiFi, and use central heating and cooling. Customers were ineligible if they already had a smart thermostat or had plans to move in the next 15 months. Finally, customers were asked if they would be interested in participating in a study to receive a free smart thermostat with in-home installation. The recruitment survey resulted in 30,090 customers in the eligible pool.

Three encouragement groups, one for each brand of thermostat, and one control group were drawn from the pool of eligible customers. PG&E then reached out to customers in each of the encouraged groups to install thermostats. 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 offered to them. There was a negative reaction from customers to Thermostat 3 and 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 thermostats installed.

Energy savings were estimated by first using a statistical difference-in-difference (DID) approach and then 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.

PROJECT FINDINGS/RESULTS

All three thermostats achieved annual electric savings ranging from 4-5%. One of the thermostats tested, Thermostat 3, also achieved annual gas savings.

TABLE ES-1. ANNUAL ELECTRIC SAVINGS ESTIMATES BY THERMOSTAT

TREATMENT GROUP	REFERENCE (KWH)	ACTUAL (KWH)	SAVINGS (KWH)	% SAVINGS
Thermostat 1	6,170	5,953	217	4%
Thermostat 2	6,401	6,076	324	5%
Thermostat 3	5,853	5,560	293	5%

TABLE ES-2. ANNUAL GAS SAVINGS ESTIMATES BY THERMOSTAT

TREATMENT GROUP	REFERENCE (THERMS)	ACTUAL (THERMS)	SAVINGS (THERMS)	% SAVINGS
Thermostat 1	380	380	0	0%
Thermostat 2	386	386	0	0%
Thermostat 3	368	352	16	4%

PROJECT RECOMMENDATIONS

The first-year findings of this study show promising electric savings during the cooling season for all three brands of thermostat and natural gas savings during the heating season for Thermostat 3. The following recommendations should be considered when continuing this study and conducting future research of this technology:

- Continue the current study for another year to better determine the persistence of the energy savings.
- Obtain and analyze data from the thermostat manufacturers to provide additional insight into how participants interact with the thermostat and how savings are achieved (or not achieved).
- For future research, consider limiting the geographic area if providing thermostat installation. Geographic outliers led to more untreated customers in the encouraged groups and increased the cost of implementation.
- For future research expand the area of study beyond the three climate zones tested.
- During future recruitment efforts ask participants where their HVAC unit is located. Consider determining eligibility based on ease of access. Difficult to access HVAC

units make installation difficult or not possible and led to an increased number of untreated customers.

- Consider customer acceptance when deciding on which thermostats to include in any future study. Many customers rejected Thermostat 3 because it did not have the "look and feel" they expected from a smart thermostat. This resulted in customer satisfaction issues, increased implementation costs, and a smaller pool of customers in that treatment group.

INTRODUCTION

Smart thermostats are receiving media attention for their usability and remote operation, and many in the energy-efficiency field have identified them as a game changer in terms of more efficient HVAC usage. There is, however, a lack of reliable trials or objective data on this topic, and many important questions remain unanswered regarding the energy efficiency potential of this technology in California. In order to address these questions, PG&E designed the Smart Thermostat Study as an Emerging Technologies Program scaled field placement to gather data from customer homes that have been randomly assigned to receive a free smart thermostat. The purpose of the Study is to understand the effect of this emerging technology in residential homes within certain hot climate zones in PG&E's service territory. The Study is a randomized encouragement design (RED) trial with several thousand homes randomly assigned to receive a free directly-installed smart thermostat, and two thousand similar homes that do not receive a free smart thermostat serving as a control group.

BACKGROUND

Traditional thermostats let you adjust the temperature in your home manually, e.g., if a customer is cold they turn the thermostat up; they turn the temperature down before going to bed at night. Programmable thermostats let customers set a schedule and the thermostat automatically adjusts the temperature based on the time of day. What makes smart thermostats "smart" is that the technology learns from customer's behaviors, allows customers to control the climate in their home remotely, displays energy consumption in real-time, and adjusts to ambient conditions such as humidity.

Smart thermostats are thought to encourage energy efficient behavior by making it easy for customers to program "smart" schedules and control their thermostats from home or away with a wireless connection.

EMERGING TECHNOLOGY/PRODUCT

Three different brands of smart thermostats are being tested in this study. While the definition of a "smart" thermostat may vary throughout the industry, in order to be considered for this study each thermostat was required to have the following "smart" features:

- WiFi enabled
- Automatic scheduling where the smart thermostat or the connected service automatically creates a configurable schedule of temperature set points and automatic variations to that schedule to better match HVAC system runtimes to meet occupant comfort needs.
    - These schedules must be established through user interaction where the smart thermostat learns user temperature setting preferences over time, and can be scheduled and controlled manually at the device or remotely through a web or mobile application.
- Automatic Variations to that schedule driven by local occupancy sensor or geo-fencing sensor and software algorithms, and/or through connectivity to an internet software service that automatically installs software updates/upgrades. Data triggers to automatic schedule changes might include, for example: occupancy/activity detection, arrival & departure in conditioned spaces, historical and population energy usage trends, weather data and forecasts. Additionally, automatic variations include automatic adjustments where the smart thermostat adjusts itself based on ambient conditions such as humidity. The smart thermostat may also provide users an indication of how long it will take to reach their chosen temperature and whether the temperature set point they have chosen is efficient and allows users to make an adjustment to a more efficient setting.
- Energy History is a feature that provides customer performance reports that detail data on energy consumption or HVAC status and allows customers to monitor their energy usage and obtain valuable insight into the performance of their heating and cooling equipment.

ASSESSMENT OBJECTIVES

The two focus areas for the study are an estimation of the energy savings for participating households, and an assessment of the participants' experience taking part in the study.

TECHNICAL APPROACH/TEST METHODOLOGY

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 but all customers were not expected to accept that offer. 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 below, 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.

RECRUITMENT AND ASSIGNMENT

PG&E implemented several rounds of targeting and recruitment in order to obtain a pool from which the three encouraged groups and single control group could be selected. Ultimately, the goal was to install 3,000 new smart thermostats in customers' homes, approximately 1,000 of each brand of thermostat.

PG&E first reached out to a targeted group of 294,844 customers with an email-based recruitment survey. PG&E selected the approximately 300,000 homes for initial targeting based on third party demographic data. Targeted customers were required to have an active residential account, 12 months of service at the current address, a valid email address on file, receive both electric and gas service from PG&E and be in the selected group of climate zones included in the study. Customers on Smart rates or electric vehicle rates were excluded from the targeted group[1]. Information about the climate zones selected in the study is included in the Appendix.

Of the 294,844 customers in the initial target group, 30,090 customers responded to the recruitment survey. To be eligible for the study, customers responding to the survey had to own their home, have WiFi, and central heating and cooling. Customers were ineligible if they already had a smart thermostat or had plans to move in the next 15 months. The survey invitation was sent directly from PG&E and asked customers to help PG&E understand the market for the smart thermostat technology. The survey was intentionally short to maximize response rate. At the end of the survey customers were asked if they would be interested in participating in a study to receive a free smart thermostat with in-home installation. No promises were made about study participation. A total of 13,438 interested and eligible customers were recruited into this pool.[2]

Next, three encouraged groups, one for each brand of thermostat, and one control group were randomly assigned from the pool of eligible customers. The encouraged groups were

[1] Additional customers that were net-metered (e.g., solar customers) were intended to be excluded from the targeted sample as well, but were not due to a misunderstanding in the data request.

[2] CLEAResult, who managed the installation of the smart thermostats, reviewed the pool of eligible customers and removed 451 customers that they considered geographic outliers, the original pool of interested customer included 13,889.

notified via email that they were chosen for the study and were provided with directions to schedule an installation appointment. Two reminder emails were sent to notified customers who did not respond followed by an outreach phone call from the installation contractor. As part of this notification, customers were informed that they had been selected to participate in a smart thermostat trial but were not told what brand or model they would receive.

Assignment to the control and encouraged groups occurred in waves, in order to maximize the ratio of treated to encouraged customers. The assignments were completed as follows:

- 8,000 customers were randomly selected proportionally in each of three categories: climate zone, CARE or non-CARE customers, and net metered or not net metered customers.
- The 8,000 customers were randomly assigned to the control group or one of the three encouraged groups with equal probability (n =2,000 in the control group and each encouraged group).
- When it was determined that additional encouraged customers were needed to reach the installation goal, two additional blocks (Blocks A and B) of customers were randomly assigned to each encouraged group (n= 500 for each encouraged group in each block).[3]
- PG&E decided to discontinue Thermostat 3 installations due to customer complaints and a higher walk away (refusal of installation) rate than the other two thermostats.
- An additional block (Block C) of 500 customers was assigned to the Thermostat 1 encouraged group based on the discontinuation of Thermostat 3 and expected relative installation rates of the other two thermostats.
- A final block (Block D) of customers was assigned to either Thermostat 1 or Thermostat 2 encouraged groups (559 Thermostat 1 and 466 Thermostat 2).

Table 1 shows the number of customers ultimately assigned to each encouraged group and the number in each treated group (e.g., had a successful smart thermostat installation).

[3] An error occurred during the assignment of Block B and some customers were assigned to both the Thermostat 3 and either Thermostat 1 and 2 treatment groups. This error was discovered after the Thermostat 3 installations were discontinued, but before the customers had been contacted, so customers with dual assignments were defaulted to the non-Thermostat 3 group (e.g., if a customer was assigned to both Thermostat 2 and Thermostat 3, they were re-assigned to Thermostat 2).

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 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.

VALIDATION

AEG used both visual and statistical techniques to validate the RED design and ensure that each of the three encouraged groups were equivalent to the control group.[4] Two comparisons were completed for each of the encouraged groups. First, the average daily kWh usage was compared for the control group, the encouraged group, and the treated group. Figure 1 through Figure 3 show the results of this comparison for each thermostat. Note that in all cases, the control group and the encouraged groups are very similar, as expected since they were randomly assigned from the same group. Because the treated groups (which are a subset of the encouraged group) are determined by customer willingness, which is not random, these groups are expected to be different from both the encouraged and the control group. As expected, the treated groups appear to be somewhat different from the control - in this case the treated group seems to be more frequently in the lower energy-use ranges than the other two groups. The RED anticipates these differences and is specifically designed to control for self-selection bias.

[4] Some of the customers did not have pre-treatment energy usage data available, and therefore they were excluded from this sample validation analysis.

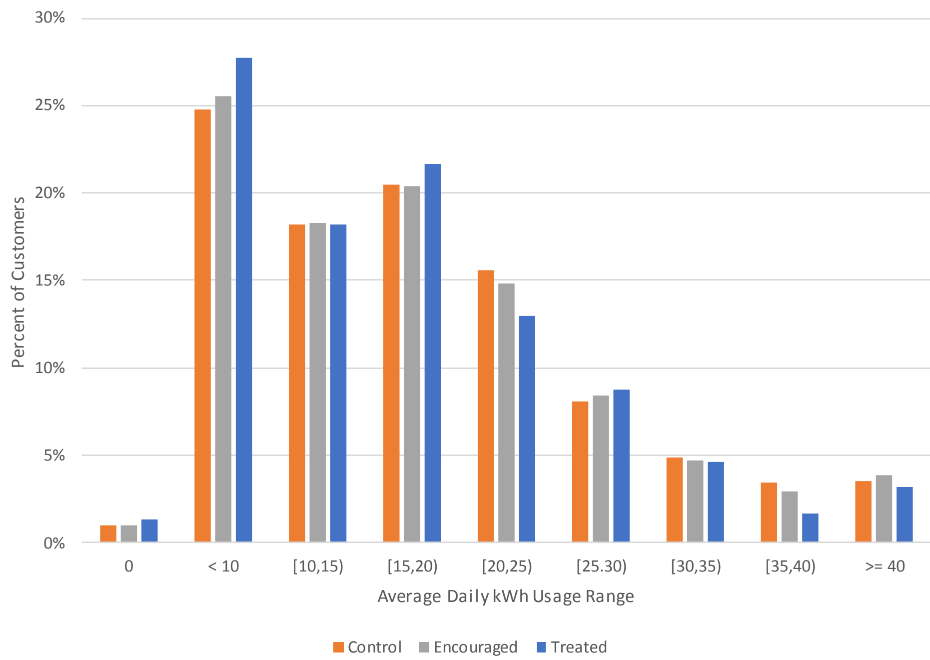


FIGURE 1. DISTRIBUTION OF AVERAGE PRE-TREATMENT DAILY KWH USAGE: THERMOSTAT 1 TREATMENT AND CONTROL

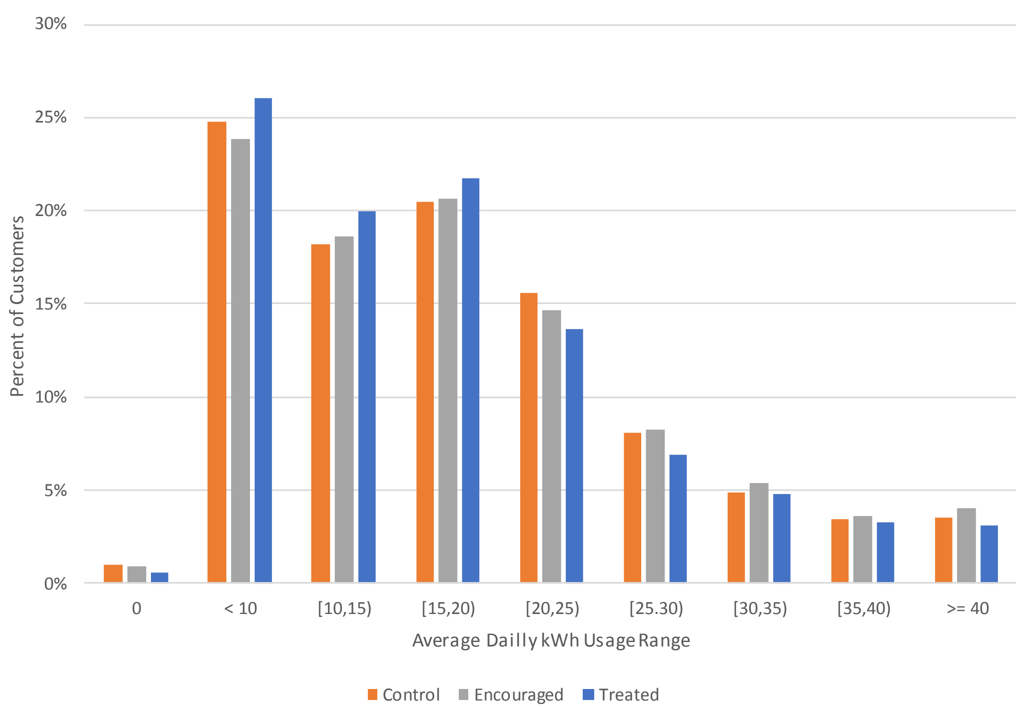


FIGURE 2. DISTRIBUTION OF AVERAGE DAILY KWH USAGE: THERMOSTAT 2 TREATMENT AND CONTROL

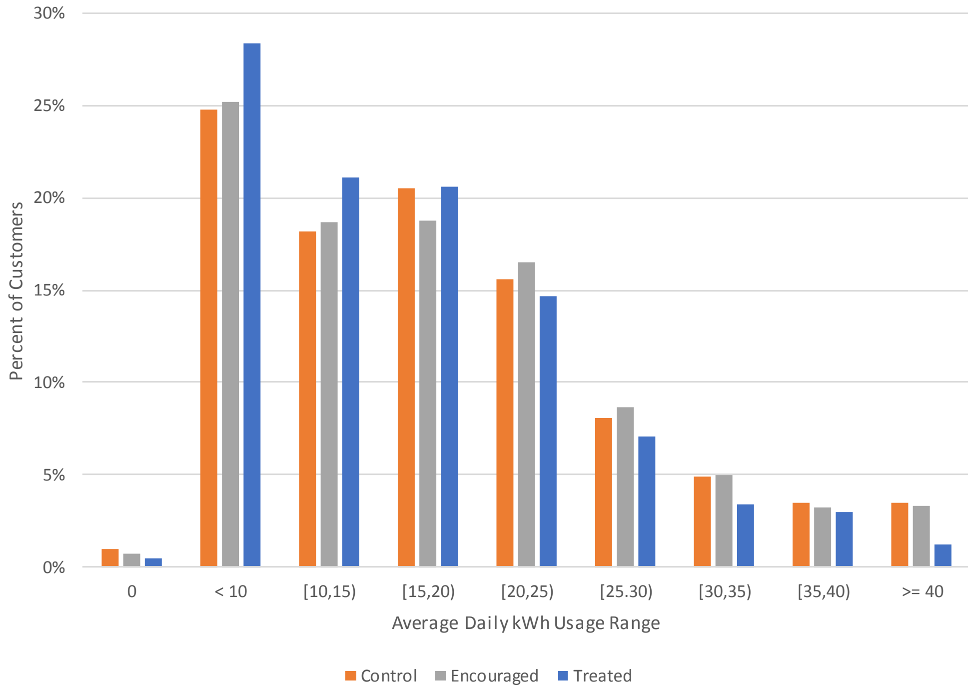


FIGURE 3. DISTRIBUTION OF AVERAGE DAILY KWH USAGE: THERMOSTAT 3 TREATMENT AND CONTROL

In order to test the similarity of the distributions shown in the figures above, a Chi-Squared goodness of fit test was used, using the control group proportions applied to the encouraged group populations as the expected counts by range. The Chi-Squared test compares actual with expected, and indicates whether there is a statistically significant difference in the number across all ranges. This test is more appropriate than looking at each individual range for each thermostat, since the ranges are not independent. Table 2 below shows the p-values for the tests of the distributions. Those less than 0.10 (shown in red) indicate that the distributions across the ranges are statistically significantly different. Note that while none of the encouraged groups are significant, two of the three thermostats show significant differences between the control group and the treated group.

TABLE 2. CHI-SQUARED GOODNESS OF FIT TEST P-VALUES BY TYPE OF THERMOSTAT

Type of Thermostat	Encouraged-Control	Significant?	Treated-Control	Significant?
Thermostat 1	0.4190	No	0.0189	Yes
Thermostat 2	0.3481	No	0.3897	No
Thermostat 3	0.2335	No	0.0849	Yes

T-tests were also performed to compare the average daily kWh consumption for the control versus encouraged groups and control versus treated groups in total and by climate zone. A t-test is a statistical test of significance for the difference between two means. The null hypothesis (the assumption going into the test) is that there is no difference between the true mean for the two groups. If there is a large p-value, this indicates that there is not enough evidence to reject the null hypothesis, concluding that the two means are equal. Table 3 below shows the t-test results for encouraged versus control for each of the three thermostats. In this case the p-value for each group is large indicating that there is not enough evidence to conclude that the two means are statistically different from each other.

Table 3. T-Test Results – Average Daily kWh for Encouraged vs. Control by Thermostat

Treatment Group	Count	Mean	P-Value
Control	1980	17.33	
Thermostat 1 Encouraged	3989	17.15	0.5719
Thermostat 2 Encouraged	3428	17.62	0.3453
Thermostat 3 Encouraged	2741	17.89	0.6766

Table 4 shows the t-test results comparing the average daily kWh consumption for treated versus control for each of the three thermostats. Note that for this comparison, two of the three p-values (shown in red) are less than the significance level 0.10 indicating that there is a significant difference between the two means.

Table 4. T-Test Results – Average Daily kWh for Treated vs. Control by Thermostat

Treatment Group	Count	Mean	P-Value
Control	1980	17.33	
Thermostat 1 Treated	904	16.14	0.0080
Thermostat 2 Treated	875	16.66	0.1413
Thermostat 3 Treated	406	15.15	0.0003

In total 18 additional t-tests were conducted, comparing encouraged and control groups by climate zone, of which 6% showed enough evidence to conclude that the means were statistically different from each other. Similar tests were completed comparing the control group with the treated groups, resulting in a total of 20% of tests with significant p-values.

It is important to note that with multiple t-tests, such as for several climate zones, about one in ten t-tests with a critical value of 0.10 will be significant simply by random chance. So with many tests, relatively few significant differences (anything near one in ten) may not be an indication of a deviation from randomness.

Based on the experimental design and selection methods used, and verified by the comparison shown above, the distribution of average daily kWh consumption between the customers assigned to the three encouraged groups and the control group appears consistent by climate zone and across all climate zones. None of the t-tests for encouraged customers versus control are statistically significant. As a result there is no evidence of systematic bias by climate zone or across all climate zones.

Treated customers however, are significantly different in terms of average daily kWh consumption when compared to customers in the control group. For all three thermostats, customers in the treated group have lower average daily kWh consumption than customers in the control group. Differences between the treated groups and the control group are not unexpected. Because the treated customers chose to accept treatment, opted-in, they are likely to be different than the customers who did not opt-in. These differences are usually referred to as self-selection bias. The RED is specifically designed to control for this bias by using the encouraged group for the estimation of impacts. [5]

RESULTS

The results of the energy savings analysis and results of the post-installation participant surveys are discussed below.

ENERGY SAVINGS 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

[5] Because of the error in the selection described in Footnote 3 above (e.g., customers assigned to more than one thermostat) there were some slight differences in assignment by climate zone. During analysis the data was analyzed by climate zone to determine if any adjustments were necessary. It was determined that no adjustment was necessary.

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.

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

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

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,
$Period_t$	is an indicator variable that takes on the value of one in the treatment period or the first month of installations, September 2015,
$Encrgd_i$	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.

ENERGY IMPACTS

Table 5 shows the monthly estimated electric savings achieved for the average customer in each treated group. All three thermostats achieved significant positive savings from April through September, indicating cooling savings. November through March, however, did not yield any statistically significant results (shown in red). All three thermostats achieved electric annual savings ranging from 4-5%.

TABLE 5. ANNUAL ELECTRIC SAVINGS ESTIMATES BY THERMOSTAT

MONTH	T-STAT 1 (KWH)	T-STAT 1 (%)	T-STAT 2 (KWH)	T-STAT 2 (%)	T-STAT 3 (KWH)	T-STAT 3 (%)
Nov-15	-7	-1%	9	2%	3	1%
Dec-15	-24	-4%	32	5%	13	2%
Jan-16	-17	-3%	23	4%	9	2%
Feb-16	-11	-2%	15	3%	6	1%
Mar-16	-3	-1%	4	1%	2	0%
Apr-16	1	0%	3	1%	3	1%
May-16	22	5%	33	7%	30	7%
Jun-16	46	7%	69	10%	62	10%
Jul-16	59	7%	87	10%	79	10%
Aug-16	54	7%	80	10%	73	10%
Sep-16	35	6%	52	8%	47	8%
Annual Total	217	4%	324	5%	293	5%

Figure 4 shows the electric savings by month from November 2015 to September 2016 for the three treated groups. As indicated above, only months April 2016 to September 2016 yielded statistically significant savings.

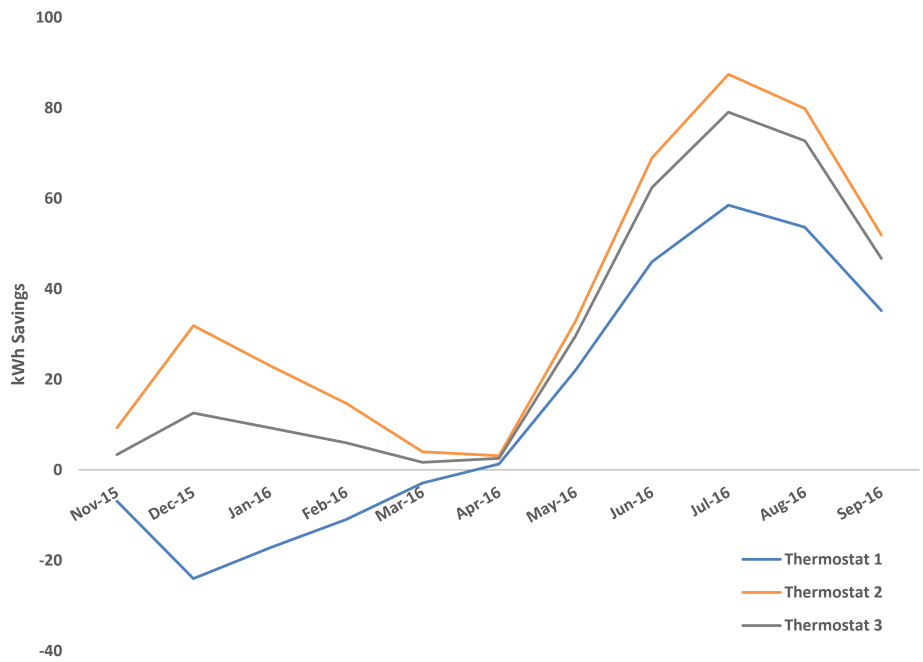


FIGURE 4. MONTHLY ELECTRIC SAVINGS ESTIMATES BY THERMOSTAT

Table 6 shows the monthly estimated natural gas savings achieved for the average customer in each treated group. Only Thermostat 3 achieved statistically significant natural gas savings (insignificant savings shown in red).

TABLE 6. ANNUAL GAS SAVINGS ESTIMATES BY THERMOSTAT

MONTH	T-STAT 1 (THM)	T-STAT 1 (%)	T-STAT 2 (THM)	T-STAT 2 (%)	T-STAT 3 (THM)	T-STAT 3 (%)
Nov-15	0.0	0%	-0.7	-1%	1.5	3%
Dec-15	0.1	0%	-2.2	-3%	6.1	8%
Jan-16	0.1	0%	-1.5	-2%	4.5	6%
Feb-16	0.0	0%	-1.0	-2%	2.9	6%
Mar-16	0.0	0%	-0.3	-1%	0.8	2%
Apr-16	0.0	0%	0.0	0%	0.2	1%
May-16	-0.1	0%	-0.1	0%	1.1	7%
Jun-16	-0.2	-1%	-0.1	-1%	2.3	19%
Jul-16	-0.2	-2%	-0.2	-2%	2.9	27%
Aug-16	-0.2	-1%	-0.2	-1%	2.7	25%
Sep-16	-0.1	-1%	-0.1	-1%	1.7	14%
Annual Total	0.0	0%	0.0	0%	16.0	4%

Figure 5 shows the natural gas savings by month for each treatment group. Note that only November 2015 to April 2016 for Thermostat 3 yielded statistically significant savings.

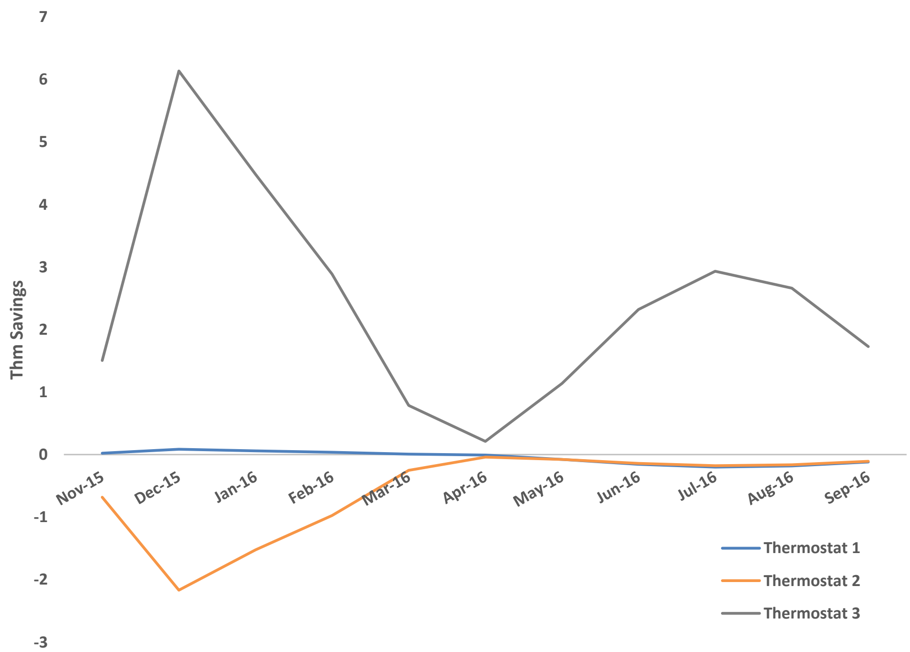


FIGURE 5. MONTHLY NATURAL GAS SAVINGS ESTIMATES BY THERMOSTAT

Several years of heating degree day data was analyzed to determine if the weather during the winter in the treatment period was different than prior years and could potentially explain the low gas savings (e.g., if the treatment period winter was a much milder winter). The analysis showed however that the winter during the treatment period was very similar to prior years (2010- 2014).

POST-INSTALLATION PARTICIPANT SURVEY RESULTS

Participants in the treated groups received an email with a link to an online survey on the Thursday of the week following their installation. Participants who had not yet completed the post-installation survey received one reminder email a week after the first survey invitation. Table 7 shows total installations, completed surveys and response rate by thermostat type. As indicated in the table, the survey response rate was high and consistent, ranging from 84% to 87% across all three thermostats. An additional survey of the treated group participants and the control group participants will be conducted at the end of Year 2 of the study.

TABLE 7. SURVEY RESPONSE RATE

TYPE OF THERMOSTAT	NUMBER IN TREATED GROUP	COMPLETED SURVEY	RESPONSE RATE
Thermostat 1	916	774	84%
Thermostat 2	881	764	87%
Thermostat 3	410	357	87%

The following topics were addressed in the post installation survey:

- Previous thermostat type and behavior
- Satisfaction with the enrollment and installation process
- Satisfaction with the smart thermostat
- Energy efficient actions taken in the past 12 months
- Demographics (included in the Appendix)

PREVIOUS THERMOSTAT AND BEHAVIOR

As shown in Figure 6, most customers in the treated group (85%) had a programmable thermostat (one that lets users program a regular schedule for different times of the day and/or different days of the week) and 15 percent had a standard/ manual thermostat before the new smart thermostat was installed.

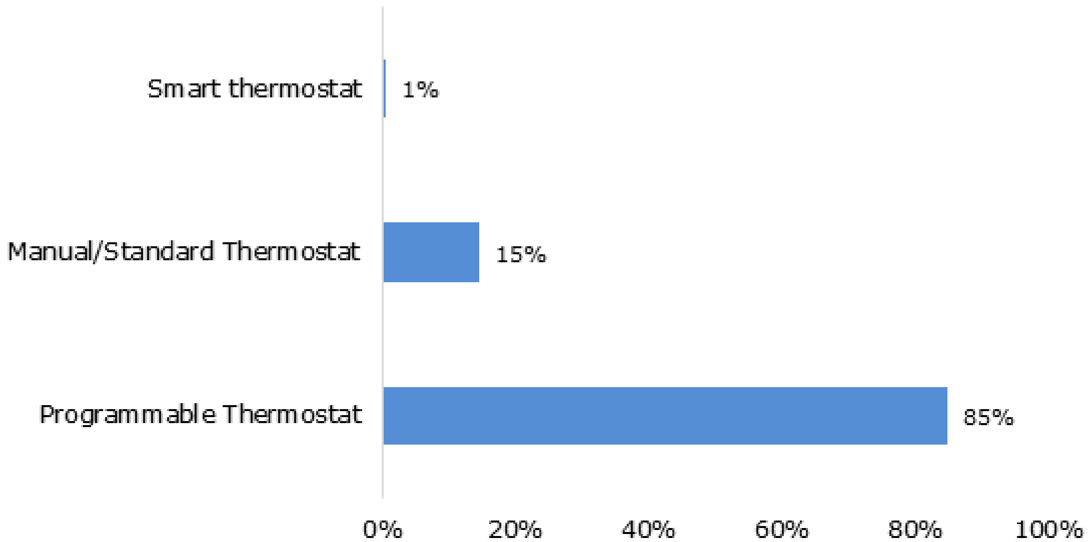


FIGURE 6. PREVIOUS THERMOSTAT INSTALLED IN HOME

About 84% of all survey participants responded that they typically changed or turned off their previous thermostats when they left their home for extended periods of time, such as for a vacation. Because detecting occupancy and behavior is an important energy-saving feature of smart thermostats, the extent to which customers were already doing this may have affected savings in the study.

Regulating thermostats is often a balancing act between maximizing comfort and minimizing cost. Most study participants are neutral regarding whether comfort or cost dictated their thermostat usage (Figure 7). Slightly more treated customers value reducing cost over comfort.

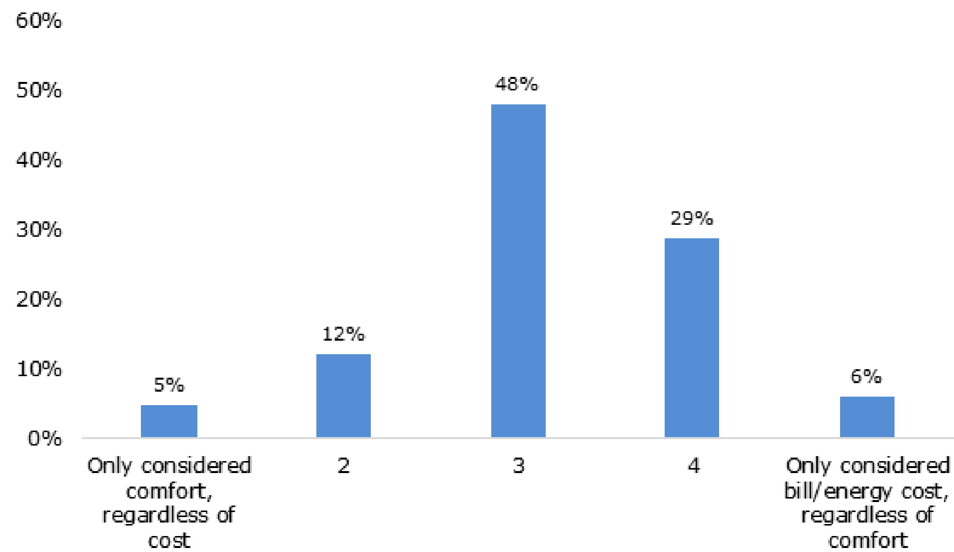


FIGURE 7. MAIN DRIVER OF THERMOSTAT USAGE – COMFORT VS. COST

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 8) and the cooling season (Figure 9).

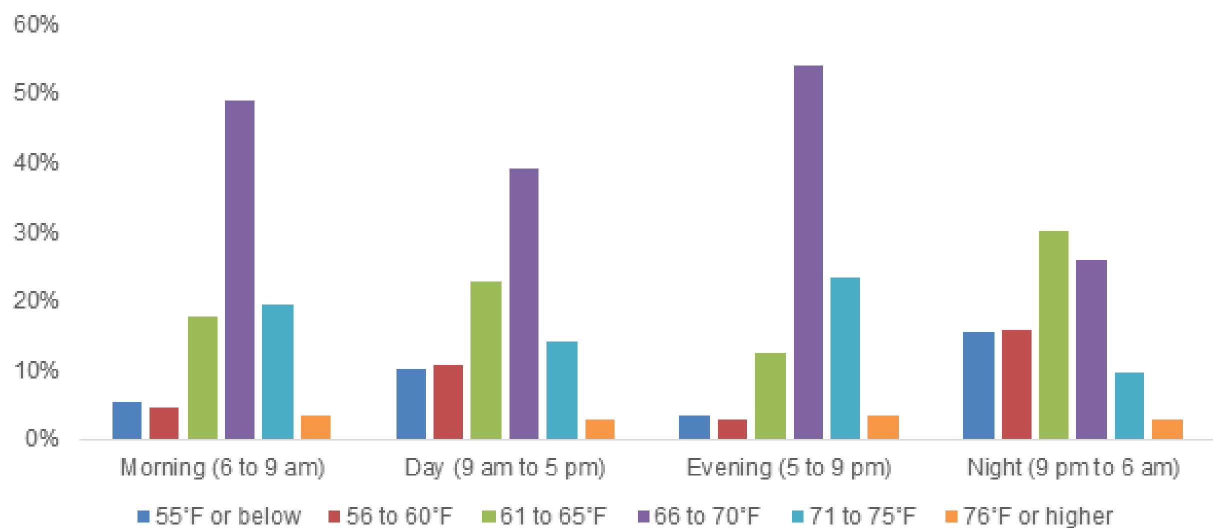


FIGURE 8. HEATING TEMPERATURE SETTING PREFERENCES

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.

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.

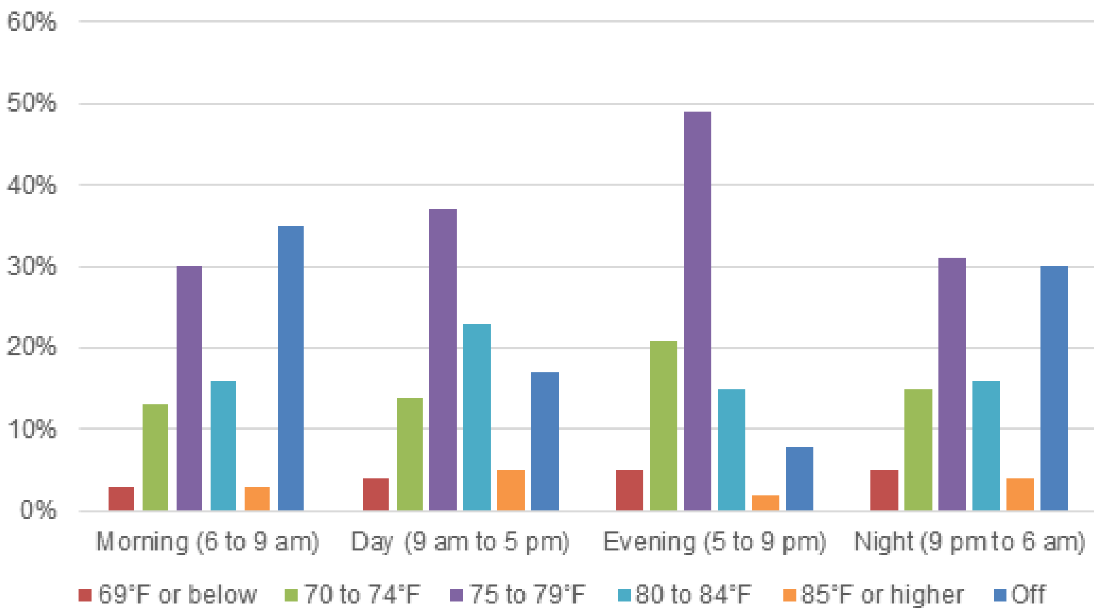


FIGURE 9. COOLING TEMPERATURE SETTING PREFERENCES

ENROLLMENT AND INSTALLATION

Treated customers were asked to rate the enrollment and installation process in terms of how easy or difficult it was. Figure 10 shows that most treated customers rated the appointment scheduling process for installation of their new smart thermostat as very easy. Only 2% of treated customers found the process to be very difficult. A handful of customers complained about the long wait time on the phone to schedule their appointments and some of the customers complained of multiple rescheduling of appointments by technicians.

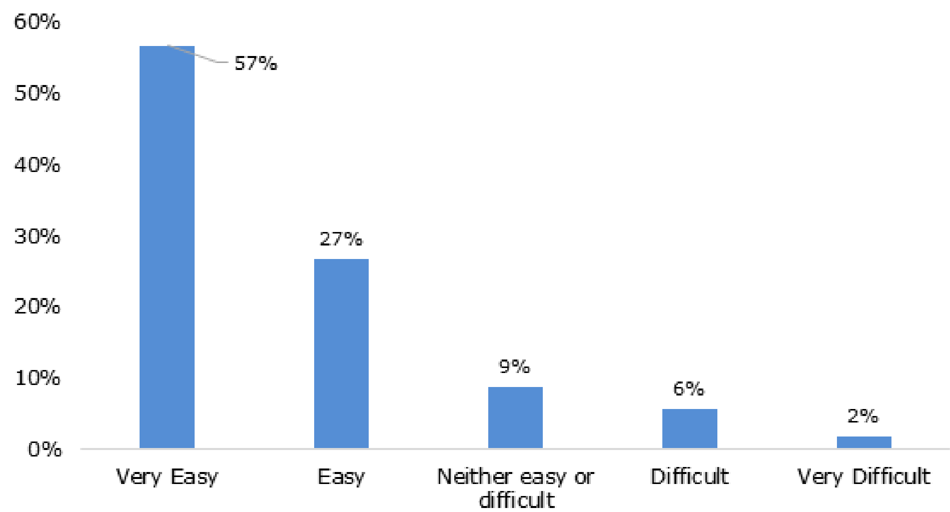


FIGURE 10. SATISFACTION WITH APPOINTMENT SCHEDULING

The majority of treated customers rated their customer service experience during the appointment scheduling process highly (Figure 11), with 84% rating it an 8 higher on a 10-

point scale, with 1 meaning poor customer service and 10 meaning excellent customer service.

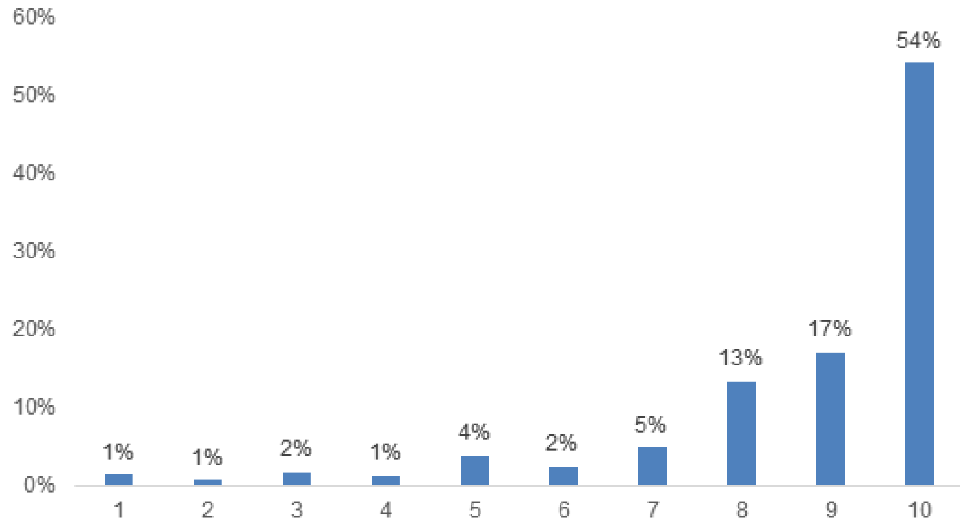


FIGURE 11. SATISFACTION WITH CUSTOMER SERVICE DURING THE SCHEDULING PROCESS

To evaluate the installation process, treated customers were asked about their satisfaction with the removal of the old thermostat and the installation of the new smart thermostat; the helpfulness, skills, and friendliness of the installation technicians; and finally their overall satisfaction with the installation appointment. Customers rated their satisfaction on a scale of one to five, with one meaning "Not at All Satisfied" and five meaning "Very Satisfied". As shown in Figure 12 the majority of the customers rated each of the different aspects of the installation process highly, with friendliness/courtesy being rated slightly higher than the other areas.

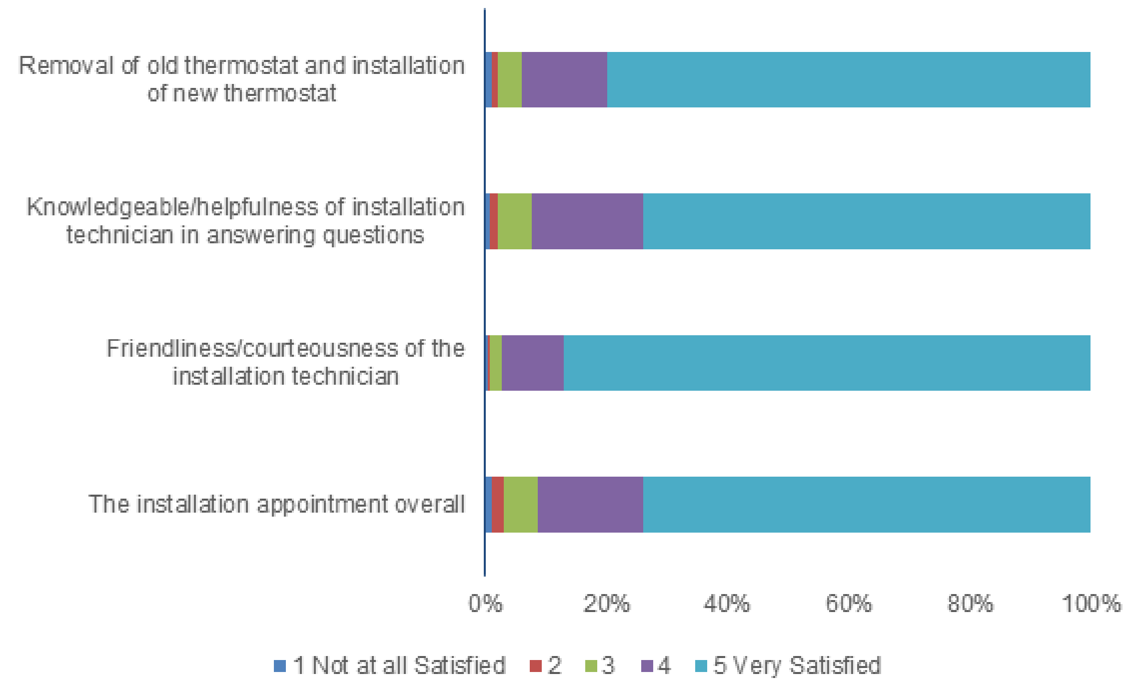


FIGURE 12. SATISFACTION WITH SMART THERMOSTAT INSTALLATION

SATISFACTION WITH THE SMART THERMOSTAT

In general, treated customers signed up for the study because of the potential to save money and energy. As shown in Figure 13, participants also liked the ability and convenience to remotely control their thermostats, and were interested in trying out a new technology.

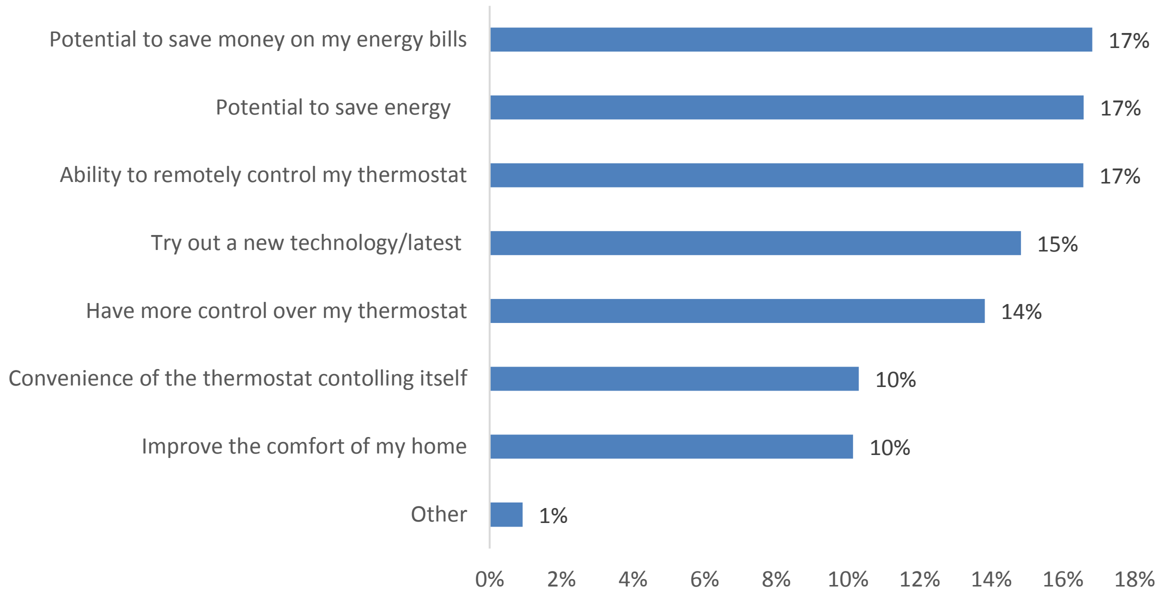


FIGURE 13. PRIMARY REASONS FOR PARTICIPATING IN STUDY

When asked about their satisfaction with their new thermostat, Thermostat 2 received the highest customer satisfaction overall, with Thermostat 1 close behind, but satisfaction is relatively high for all three thermostats. While Thermostat 3 was rated lower than the other two, there were still a majority who chose "Very Satisfied," somewhat surprising given the higher rejection rate of Thermostat 3 during the installation process.

TABLE 8. SATISFACTION WITH NEW THERMOSTAT

SATISFACTION RATING	THERMOSTAT 1	THERMOSTAT 2	THERMOSTAT 3	TOTAL
1 "Not at all Satisfied"	1%	0%	2%	1%
2	1%	1%	6%	2%
3	4%	4%	12%	5%
4	21%	15%	28%	20%
5 "Very Satisfied"	73%	80%	52%	72%

One factor that likely affected customer satisfaction with the thermostat and how likely customers are to take advantage of the various features available with the smart thermostats is ease of use. Treated customers were asked to indicate the level of ease or difficulty they experienced while setting up their newly installed smart thermostat. The options for these questions ranged from "Very Difficult" to "Very Easy". Figure 14 illustrates that the vast majority found it easy or very easy to set up the WiFi connection to the thermostat and sync it with a smart device, although Thermostat 3 received lower ratings than the other two thermostats in this area.

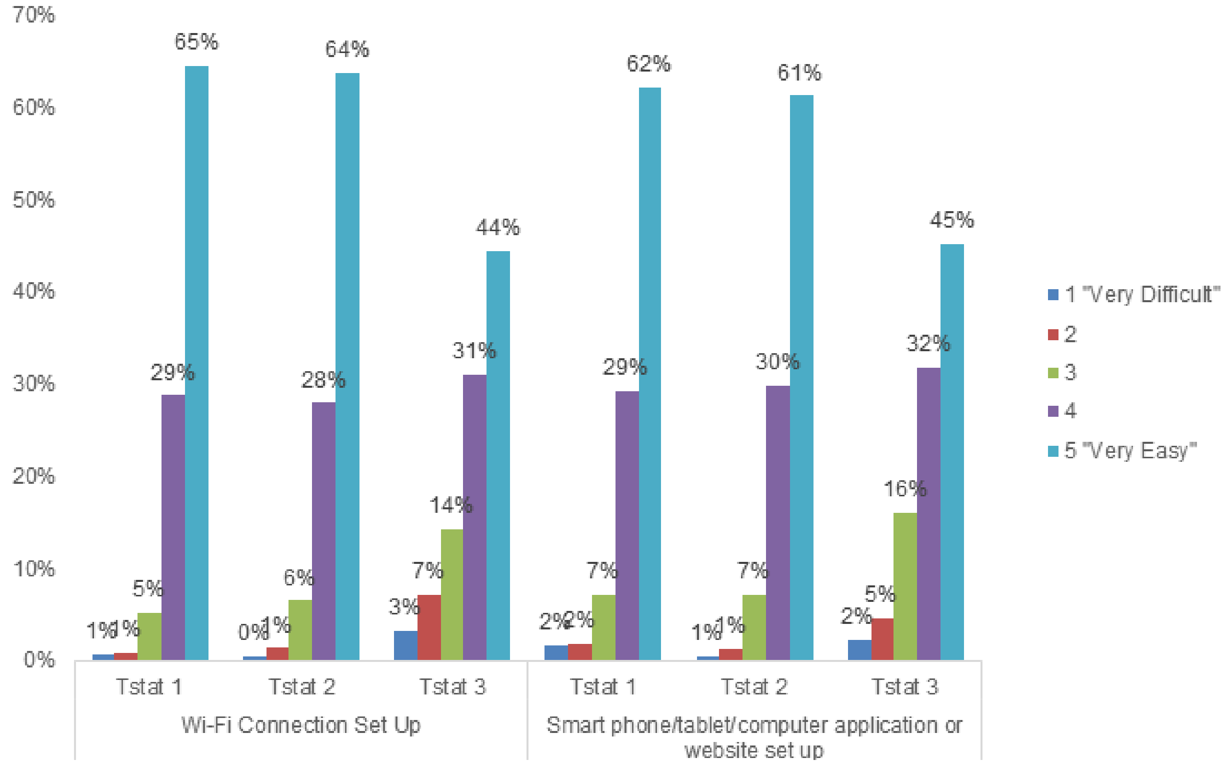


FIGURE 14. EASE OF THERMOSTAT SET UP

Figure 15 shows how treated rated their satisfaction with thermostat functions: adjusting, setting, and controlling their new thermostat and the ease of registering their new thermostat. Again, few customers had difficulty with these features. Thermostat 3 is not rated as highly as the other two, but still a majority found Thermostat 3 easy or very easy to set up and control.

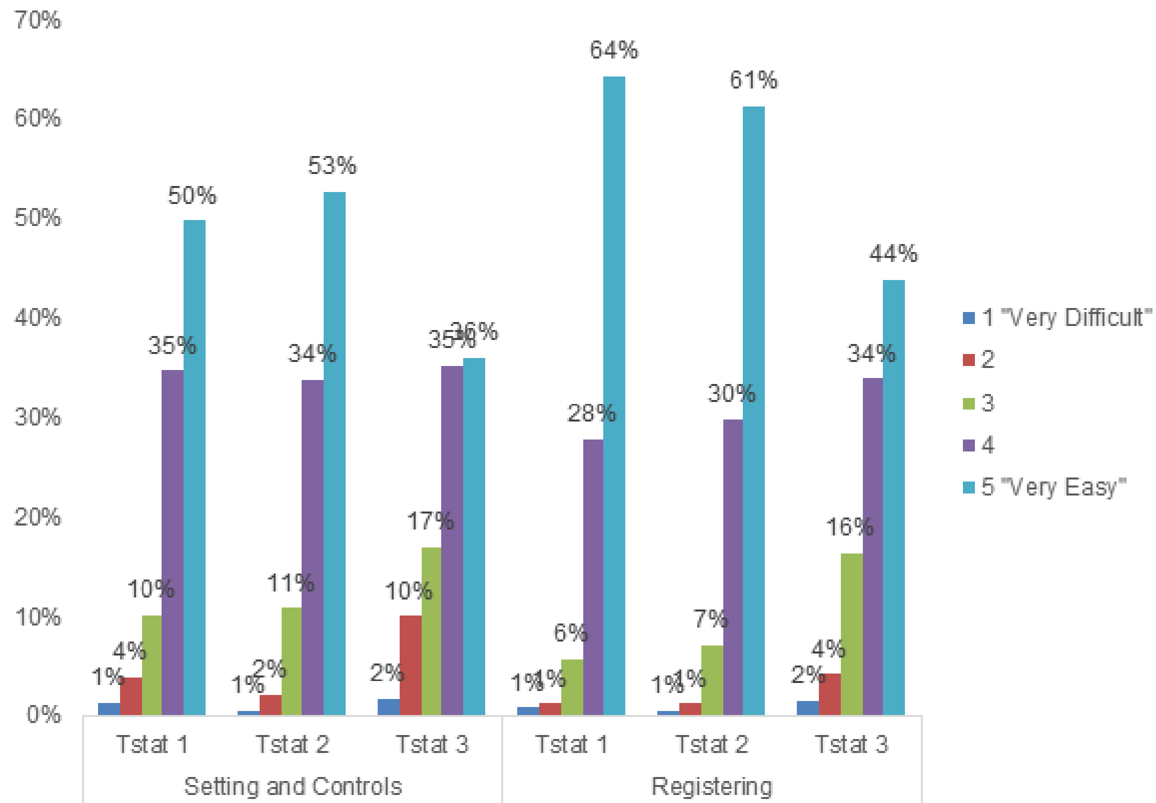


FIGURE 15.SATISFACTION WITH THERMOSTAT FUNCTIONS

ENERGY EFFICIENT ACTIONS

Treated customers were asked a series of questions to better understand if they had made any fundamental changes in the previous 12 months that might have affected their home's energy use. Almost three-fourths of treated customers had not made any change. There are about the same proportion (one quarter) of customers having made changes for each of the three thermostats.

TABLE 9. PARTICIPANTS WHO MADE ENERGY EFFICIENT CHANGES IN LAST 12 MONTHS

THERMOSTAT TYPE	% REPORTED MAKING ENERGY EFFICIENT CHANGES
Thermostat 1	25%
Thermostat 2	27%
Thermostat 3	26%
Total	26%

The 26% of the treated customers who responded yes to making changes that could affect their energy use were asked an open-ended question to describe those changes. The changes mainly include: Solar installations, remodeling or upgrading equipment, and changes in the number of people in the household. To the extent that these changes differ between the three thermostat groups or between these treated customers and the control group, the changes described, particularly remodeling, adding solar, and adding a pool could have affected savings estimates in the analysis. That question could be explored in the final analysis when survey data will be available from a sample of the control group at the end of the second year.

RECOMMENDATIONS

The first-year findings of this study show promising electric savings during the cooling season for all three brands of thermostat and natural gas savings for Thermostat 3. The following recommendations should be considered when continuing this study and conducting future research of this technology:

- Continue the current study for another year to better determine the persistence of the energy savings.
- Obtain and analyze data from the thermostat manufacturers to provide additional empirical insight into how participants interact with the thermostat and how savings are achieved (or not achieved).
- For future research expand the area of study beyond these three climate zones.
- For future research consider limiting the geographic area if providing thermostat installation. Geographic outliers led to more untreated customers in the encouraged groups and increased the cost of implementation.
- During future recruitment efforts ask participants where their HVAC unit is located and consider determining eligibility based on ease of access. Difficult to access HVAC units make installation difficult or impossible and led to an increased number of untreated customers.
- Consider customer acceptance when deciding on which thermostats to include in any future study. Many customers rejected Thermostat 3 because it did not have the "look and feel" they expected from a smart thermostat. This resulted in customer satisfaction issues, increased implementation costs, and a smaller pool of customers in that encouraged group.

APPENDICES

T-TEST RESULTS BY CLIMATE ZONE

Table 10 shows the t-test results comparing the average daily kWh for encouraged versus control for each of the three treatment groups by climate zone. Only one of these tests is significant at the 0.10 critical value. With 15 tests being done, this is still fewer than one in ten, so the assumption that the differences are random can be accepted. Also note that while there are big differences in means for Climate Zone T, this is due to the very small sample sizes, and is not an indication of any systematic or non-random sample bias.

TABLE 10. T-TEST RESULTS – COMPARISON OF AVERAGE DAILY KWH FOR ENCOURAGED VS. CONTROL FOR EACH TREATMENT GROUP BY CLIMATE ZONE

CLIMATE ZONE	TREATMENT GROUP	COUNT	MEAN	P-VALUE
P	Control	27	16.96	
	Thermostat 1 Encouraged	56	16.30	0.7828
	Thermostat 2 Encouraged	43	15.36	0.5360
	Thermostat 3 Encouraged	36	17.79	0.7393
R	Control	349	19.80	
	Thermostat 1 Encouraged	717	19.81	0.9876
	Thermostat 2 Encouraged	584	20.46	0.4380
	Thermostat 3 Encouraged	463	19.78	0.9850
S	Control	944	17.42	
	Thermostat 1 Encouraged	1798	17.08	0.4456
	Thermostat 2 Encouraged	1570	17.50	0.8594
	Thermostat 3 Encouraged	1331	17.11	0.5209
T	Control	1	6.55	
	Thermostat 1 Encouraged	4	11.22	0.7239
	Thermostat 2 Encouraged	3	11.02	0.5965
	Thermostat 3 Encouraged	2	18.30	0.5387
W	Control	113	20.49	
	Thermostat 1 Encouraged	195	19.95	0.7338
	Thermostat 2 Encouraged	172	20.73	0.8889
	Thermostat 3 Encouraged	165	21.04	0.7372
X	Control	546	14.97	
	Thermostat 1 Encouraged	1219	15.31	0.5126
	Thermostat 2 Encouraged	1056	15.86	0.0939
	Thermostat 3 Encouraged	744	14.83	0.7758

Table 11 shows the t-test results comparing the average daily kWh for treated versus control for each of the three thermostats by climate zone. With only one or zero installed customers in Climate Zone T, calculation of a t value is not possible, so there are only 15 tests done here. Three of them are significant. This result, especially combined with the two of three that are significant in Table 4, indicates that there are significant differences between the average daily kWh for the control group and each treated group.

Table 11. T-Test Results – Comparison of average Daily kWh for Treated vs. Control for Each Treatment Group by Climate Zone

Climate Zone	Treatment Group	Count	Mean	P-Value
P	Control	27	16.96	
	Thermostat 1 Treated	9	19.04	0.6109
	Thermostat 2 Treated	10	18.71	0.6762
	Thermostat 3 Treated	8	16.03	0.8282
R	Control	349	19.80	
	Thermostat 1 Treated	108	19.69	0.9393
	Thermostat 2 Treated	114	20.82	0.4547
	Thermostat 3 Treated	47	18.21	0.4102
S	Control	944	17.42	
	Thermostat 1 Treated	399	16.03	0.0370
	Thermostat 2 Treated	385	16.44	0.1365
	Thermostat 3 Treated	206	15.91	0.0767
T	Control	1	6.55	
	Thermostat 1 Treated	0		
	Thermostat 2 Treated	1	10.50	
	Thermostat 3 Treated	0		
W	Control	113	20.49	
	Thermostat 1 Treated	31	16.88	0.2011
	Thermostat 2 Treated	34	19.55	0.7322
	Thermostat 3 Treated	11	21.54	0.8095
X	Control	546	14.97	
	Thermostat 1 Treated	357	15.05	0.9019
	Thermostat 2 Treated	331	15.15	0.7987
	Thermostat 3 Treated	134	12.47	0.0038

CUSTOMER DEMOGRAPHICS (TREATED GROUP)

The last section of the post-installation survey focused on key demographic information about households and customer characteristics. This information is summarized in the tables below.

TABLE 12. YEAR HOME BUILT

YEAR HOME BUILT	% OF TREATED CUSTOMERS
Before 1940	2%
1940-1948	3%
1950-1959	9%
1960-1969	11%
1970-1979	18%
1980-1989	16%
1990-1999	19%
2000-2009	20%
2010 – Present	3%

TABLE 13. SIZE OF HOME

SQUARE FOOTAGE OF HOME	% OF TREATED CUSTOMERS
Less than 1000	2%
1001 – 1500	24%
1501 – 2000	40%
2001 – 2500	23%
2501 – 3000	9%
3001 or more	2%

TABLE 14. TYPE OF HEATING SYSTEM

HEATING SYSTEM	% OF TREATED CUSTOMERS
Natural Gas Forced Air Furnace	87%
Electric Central Forced Air Furnace	6%
Other	7%

TABLE 15. FUEL USED BY HOT TUB OR SPA

FUEL	% OF TREATED CUSTOMERS W/HOT TUB OR SPA
Electricity	66%
Natural gas	24%
Solar and electricity	2%
Solar and natural gas	4%
Bottled Gas	3%
Other	2%

Table 16. Fuel Used to Heat Pool

Fuel	% Of Treated Customers w/Pool
Pool is not heated	61%
Electricity	2%
Natural gas	12%
Solar	21%
Bottled Gas	2%
Other	2%

Table 17. Home Occupancy During the Week

At Least One Person Home Weekdays	% Of Treated Customers
Heating Season	67%
Cooling Season	73%

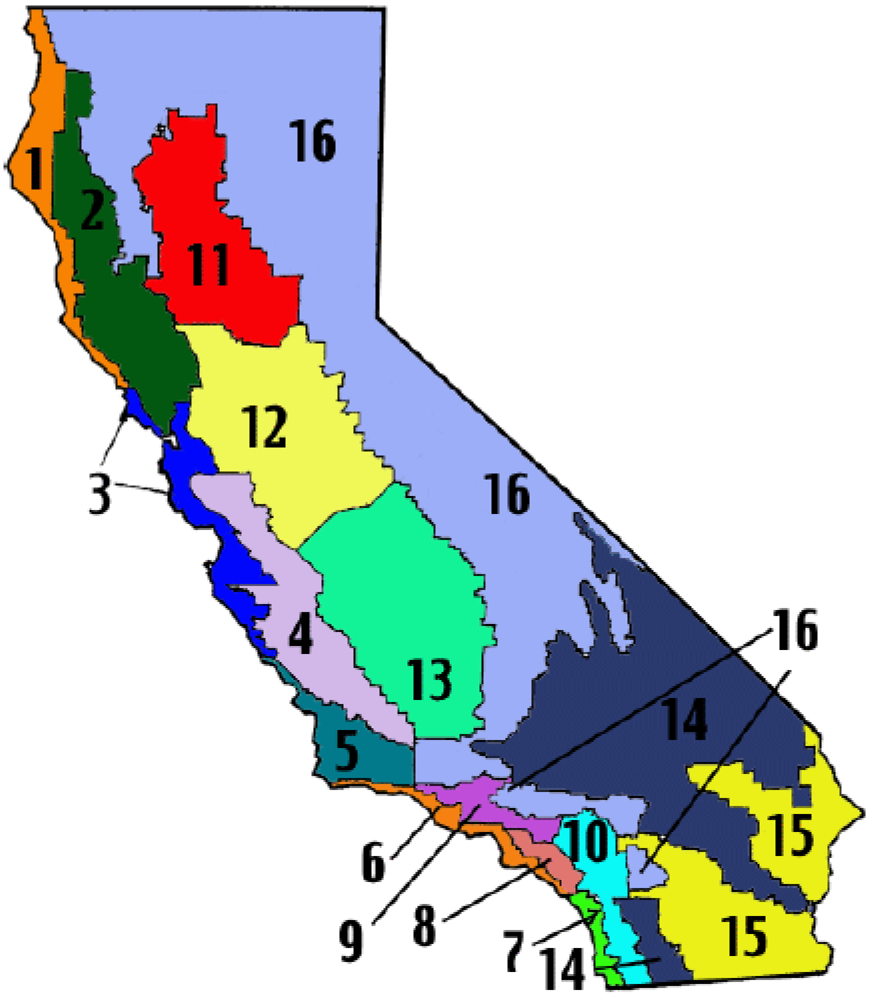
Table 18. Education

Highest Level Completed	% Of Treated Customers
Grade School	0%
High School	6%
Some College	29%
4 Year College Degree	34%
Graduate Degree	31%

PG&E CLIMATE ZONES

The Pacific Energy Center's Guide to:

California Climate Zones



http://www.energy.ca.gov/maps/climate_zones.html

and Bioclimatic Design

October 2006

PEC's Guide to California Climate Zones

This document of climate data was made for designers to inform energy-conscious design decisions. The information for 16 California Climate Zones is summarized and suggestions are given for passive design strategies appropriate to each climate.

Weather data is given for a reference city typical of each zone. Each zone contains a summary of the following types of data:

Basic Climate Conditions: Summer Temperature Range, Record High and Low Temperature
Design Day Data: Percentage of time dry bulb temperature in given season is *above* the stated value. Mean Coincident Wet-bulb Temperatures, and Relative Humidity also given for the summer.
Climate Design Priorities: Suggestions of design strategies to use in this zone for winter and summer seasons for a more energy passive design.
Title 24 Requirements: California's residential building energy code requires minimum ceiling and wall insulation values specific to different zones. Window U-values and maximum total area is also given. The complete document of requirements can be found on the California Energy Commission's website www.energy.ca.gov.
Climate Description: An overview of the general characteristics of the climate zone, such as geographical influence, typical patterns of weather and seasons, and precipitation.
HDD (Heating Degree Days) and CDD (Cooling Degree Days): Given for four cities in each zone. HDD value is the summation of degrees of the average temperature per day below 65F for the year. CDD is the summation of degrees of the average temperature per day above 80F for the year.

Charts and Graphs

Bioclimatic Chart: Defines dry bulb temperature and humidity levels for occupant thermal comfort and passive design strategies. The average minimum relative humidity and maximum temperature is plotted with the maximum relative humidity and minimum temperature for each month on the Bioclimatic chart. The chart is broken up into zones corresponding to design strategies for thermal comfort appropriate for that particular combination of temperature and humidity ranges. The best passive design strategies for each location are identifiable from the plotted data.

Zones and Strategies for the Bioclimatic Chart:

Comfort Zone: Humans are comfortable within a relatively small range of temperature and humidity conditions, roughly between 68-80 F (20-26.7 C) and 20-80% relative humidity (RH).
Passive Solar Heating: If 1700 BTU-day/sf from the sun comes into a given space, then occupants will feel comfortable inside if it is between 45-68 outside. This range can be lowered with better the insulation and more effective solar heat collected in thermal mass.
Natural Ventilation: Passive cooling strategies for natural ventilation are effective for temperatures in the range 68F to 90F. Cooling effectiveness decreases with higher humidity. In conditions below 20% RH natural ventilation may seem too dry.
Evaporative Cooling: Below 80% RH, evaporative cooling can be an effective passive cooling strategy. Adding moisture to the air can effectively cool temperatures up to 105F.
High Thermal Mass: Thermal Mass dampens and delays temperature swings to make it cool during the warm day, and warm during cool nights. It is most effective for places with large diurnal temperature changes. Thermal Mass is effective for temperatures up to 95F, with decreasing effectiveness in higher humidity.
High Thermal Mass with Night Ventilation: Thermal mass absorbs heat during the day and releases heat at night. By opening the building at night, cool air flushes out the hot air and cools down the thermal mass. This strategy is effective for average high temperatures up to 110F. This strategy requires occupant intervention.

California Climate Zone 11

Reference City:	Red Bluff
Latitude:	40.09 N
Longitude:	122.15 W
Elevation:	342 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	32
Record High Temperature (1978)	119
Record Low Temperature (1975)	20

Design Day Data

Winter	99%	29		
	97.5%	31		
Summer				
	1%:	105	MCWB	68
	2.5%:	102	MCWB	67

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night Ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R19
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Climate

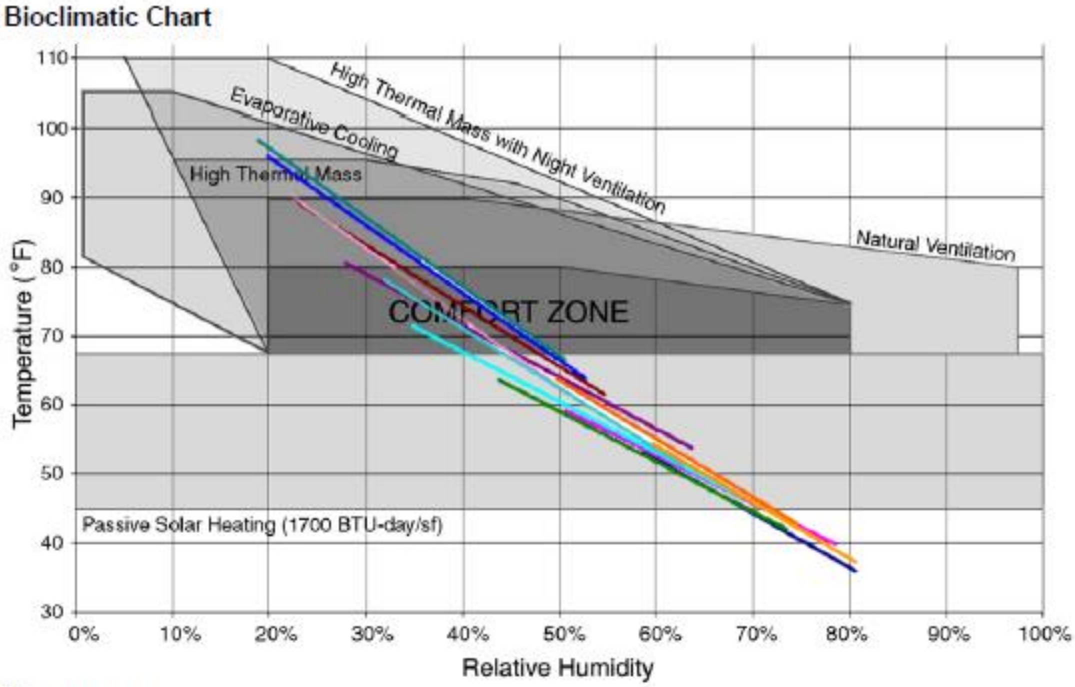
Climate Zone 11 is the northern California valley, south of the mountainous Shasta Region, east of the Coastal Range, and west of the Sierra Cascades.

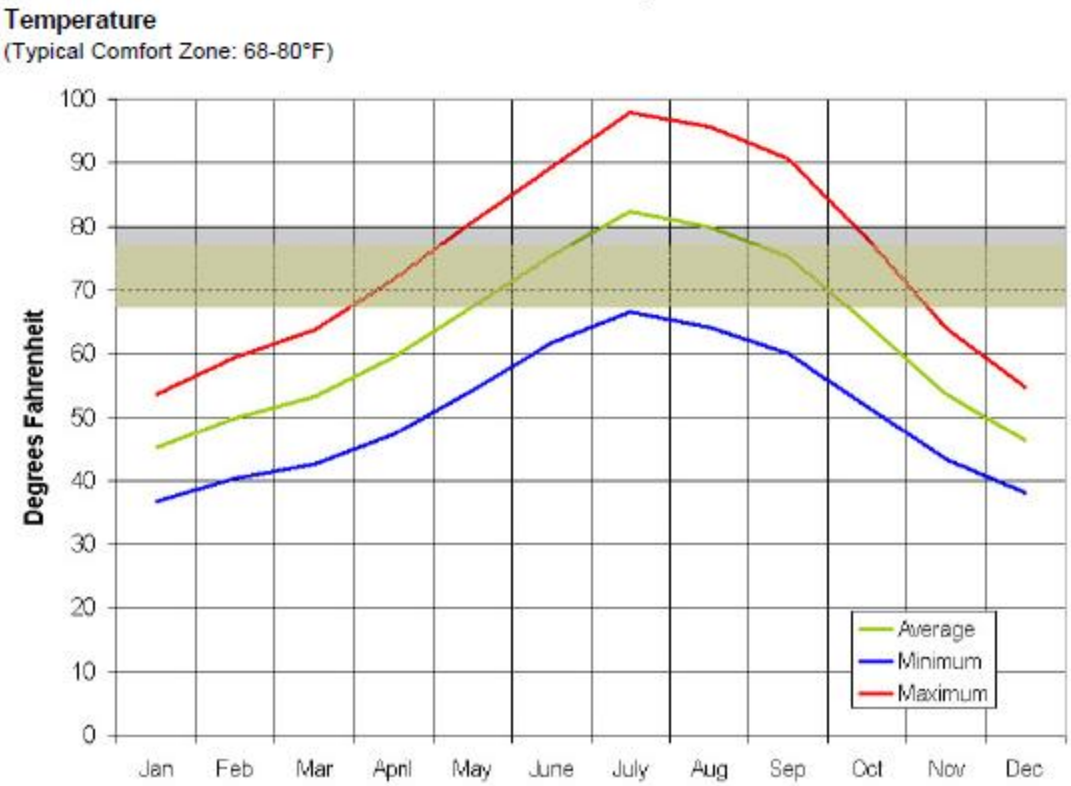
Seasons are sharply defined. Summer daytime temperatures are high, sunshine is almost constant, and the air dry. Winters are very cold with piercing north winds, possibility of snow and thick Tule fog. Cold air rolls off the hillsides on winter nights and pools in the colder flatlands. Quite a bit of rain falls between October and March, as much as 4.75" per month.

	Red Bluff	*Auburn*	*Grass Valley*	*Marys-ville*
HDD	2688	3095	4287	2524
CDD	1904	1292	612	1607

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

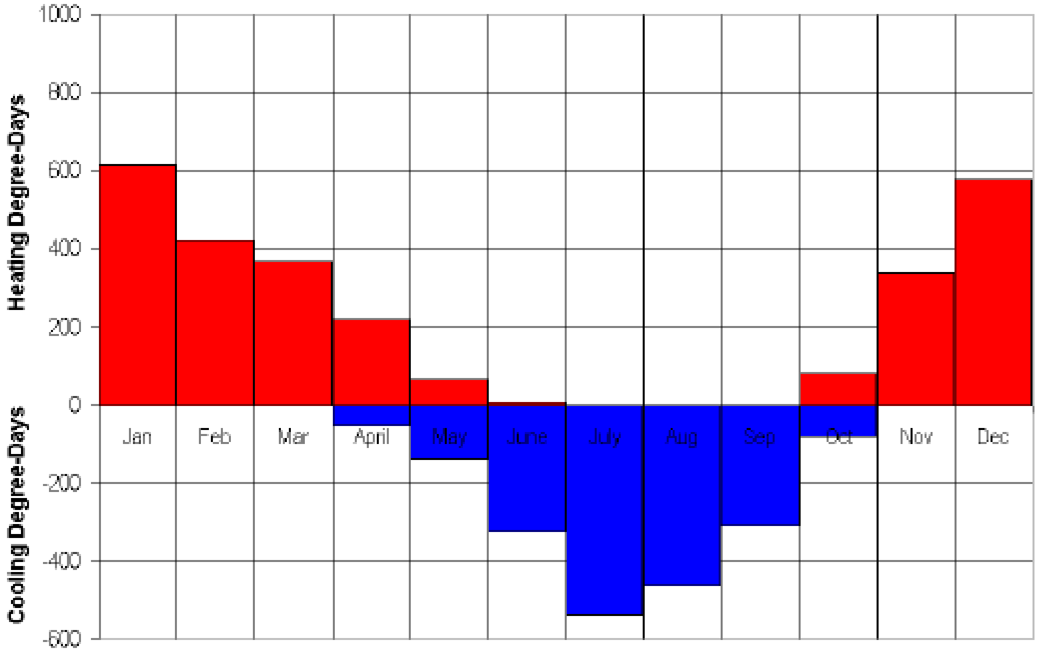
Because there is extreme weather, cooling and heating is necessary. Climate Zone 11 consumes a lot of energy consumption to meet comfort standards.



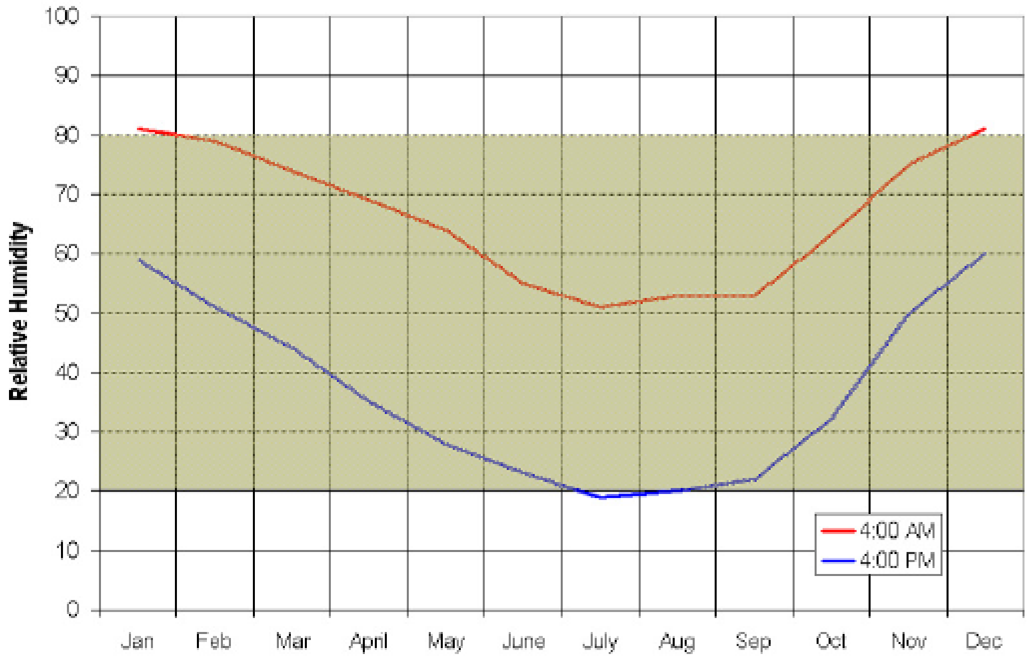


Zone 11: Red Bluff
2 of 4

Degree Day
(Base 65°)



Relative Humidity
(Typical Comfort Zone: 20-80%)



Zone 11: Red Bluff
3 of 4

California Climate

Zone 12

Reference City:	Stockton
Latitude:	37.54 N
Longitude:	121.15 W
Elevation:	22 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	35
Record High Temperature (1972)	114
Record Low Temperature (1963)	19

Design Day Data

Winter	99%	28		
	97.5%	30		
Summer				
	1%:	100	MCWB	69
	2.5%:	97	MCWB	68

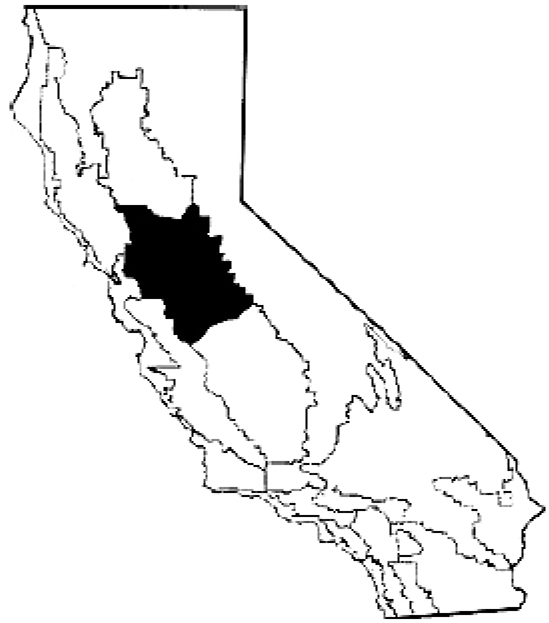
Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R19
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%



Climate

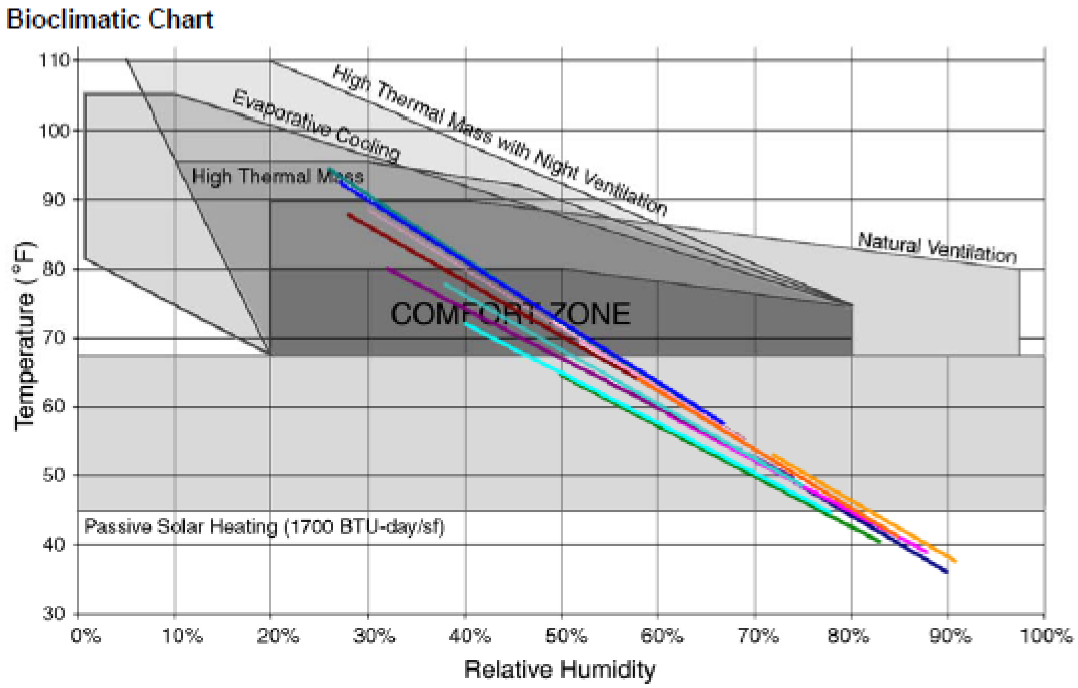
This part of the Northern California Central Valley is situated just inland of the Bay Area. Parts of Contra Costa County east of the Caldecott Tunnel are also part of Zone 12.

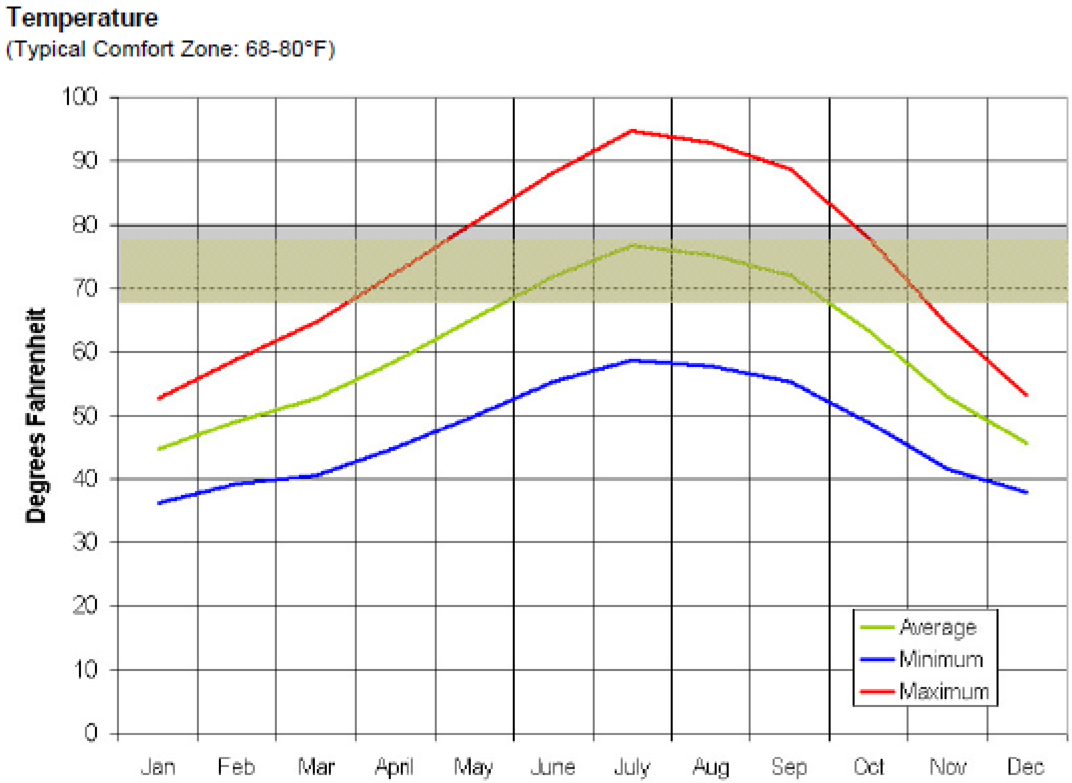
This climate zone experiences cooler winters and hotter summers than Climate Zone 3 (Bay Area). Winter rains fall from November to April. Tule fog is common in the winter east of Mount Diablo. Some lower areas receive frost on winter nights.

	Stockton	*Merced*	*Concord*	*Lafayette*
HDD	2702	2430	2751	2602
CDD	1470	995	860	1578

HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

There are more HDD to design for than CDD. High temperatures are usually over 100F. While the marine air may influence temperatures in the areas closest to the Bay Area, the ocean influence is negligible on the hottest days when blinds blow off shore.





Zone 12: Stockton
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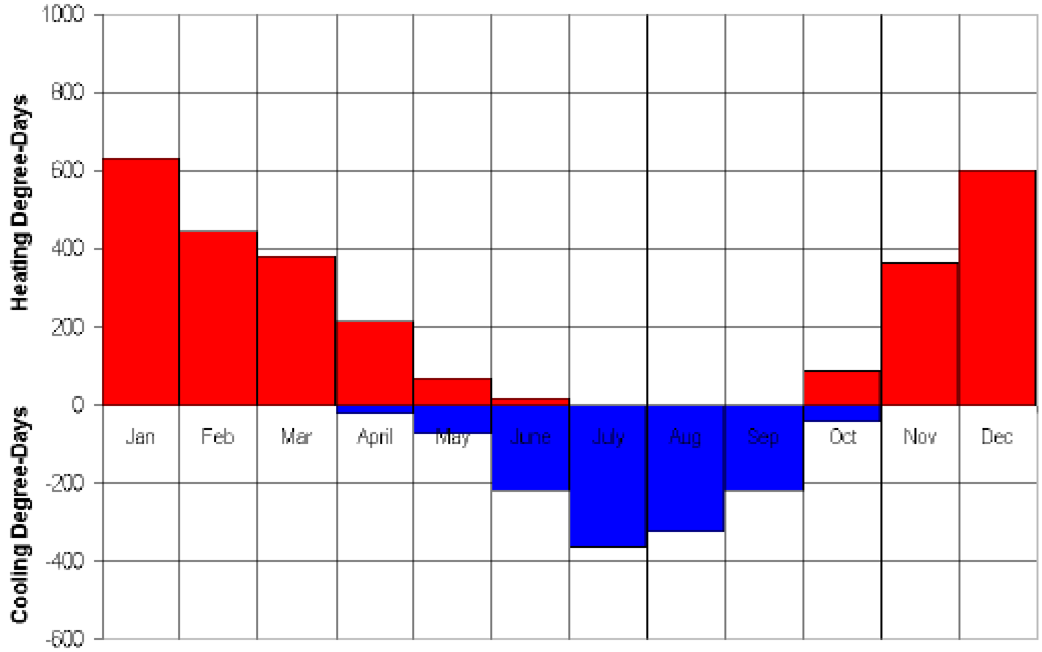
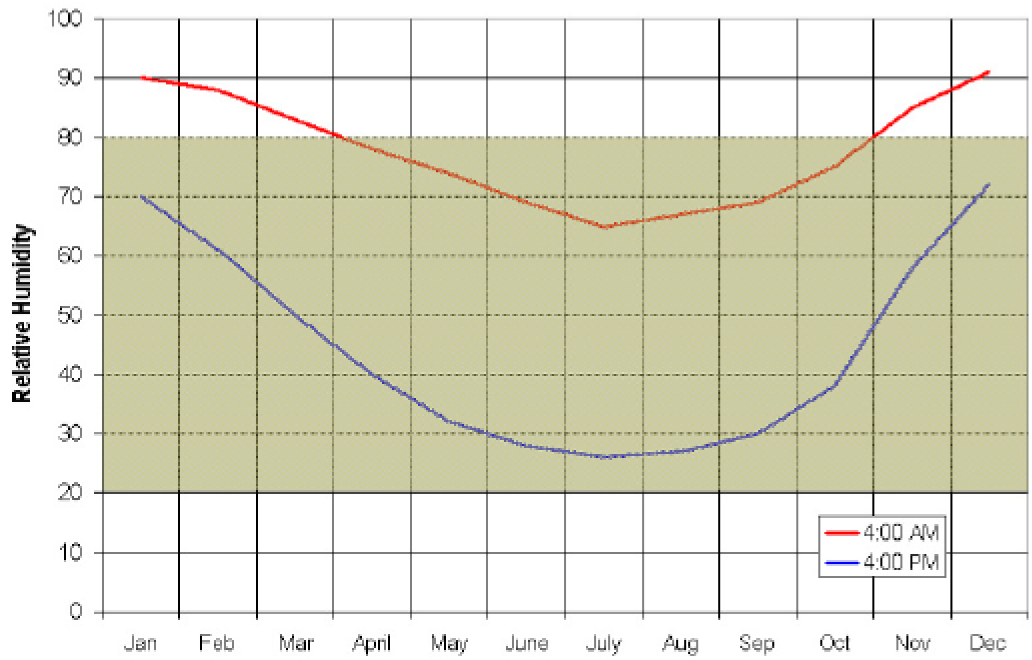
Degree Day
(Base 65°)



Relative Humidity
(Typical Comfort Zone: 20-80%)



Zone 12: Stockton
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California Climate

Zone 13

Reference City: Fresno
Latitude: 36.46 N
Longitude: 119.43 W
Elevation: 328 ft

Basic Climate Conditions

	(F)
Summer Temperature Range	34
Record High Temperature (1980)	111
Record Low Temperature (1963)	19

Design Day Data

Winter	99%	28		
	97.5%	30		
Summer	1%:	102	MCWB	70
	2.5%:	100	MCWB	69

Climatic Design Priorities

Winter: Insulate
Reduce Infiltration
Passive Solar

Summer: Shade
Use Evaporative Cooling
Use High Thermal Mass with Night ventilation

Title 24 Requirements

Package	*C*	*D*
Ceiling Insulation	R49	R38
Wood Frame Walls	R29	R19
Glazing U-Value	0.38	0.57
Maximum Total Area	16%	20%

Climate

California's Central Valley in this southern location is an ideal place to farm citrus trees. Summer daytime temperatures are high, sunshine is almost constant during growing season, and growing season is long.

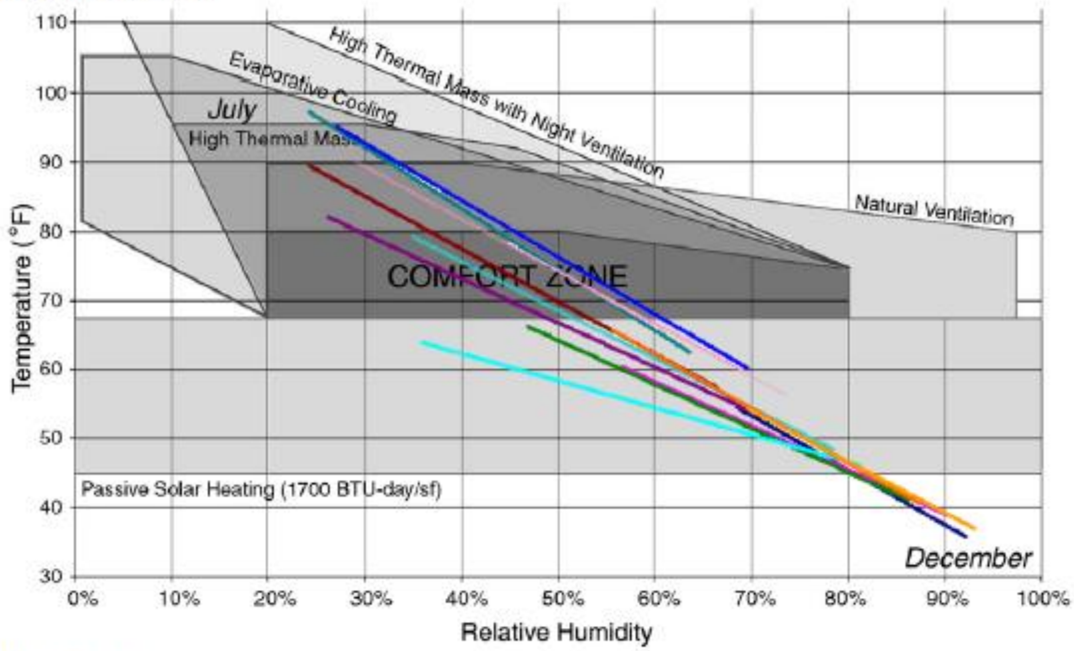
Summer humidity is higher here, than in other parts of the Central Valley, making cooling energy consumption higher in comparison. Winter rains fall between November and April on average 1.5"(+) per month. The winter cold can be quite intense, and piercing north winds can blow for several days at a time in the winter. Tule fog (extremely thick low fog) blankets the region for days in the winter.

	Fresno	*Bakers -field*	*Visalia*	*Porter-ville*
HDD	2702	2430	2588	2053
CDD	1470	995	1685	2246

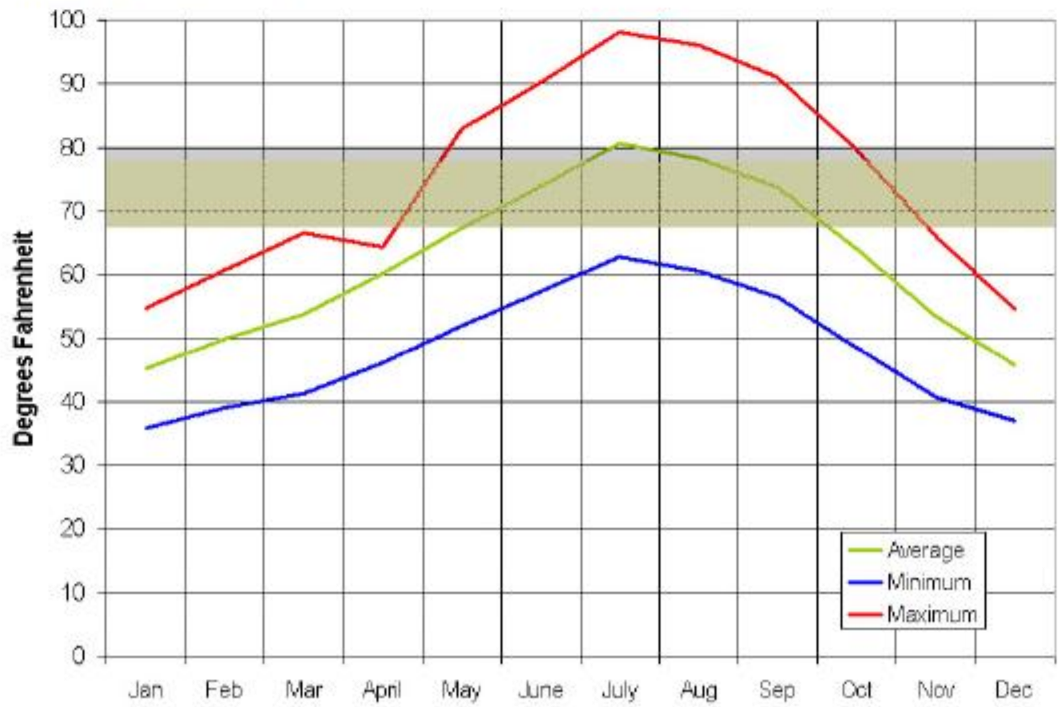
HDD = Heating Degree Days (base 65F)
CDD = Cooling Degree Days

There are almost as many CDD as HDD in this high energy consuming Climate Zone 13.

Bioclimatic Chart



Temperature
(Typical Comfort Zone: 68-80°F)



Zone 13: Fresno
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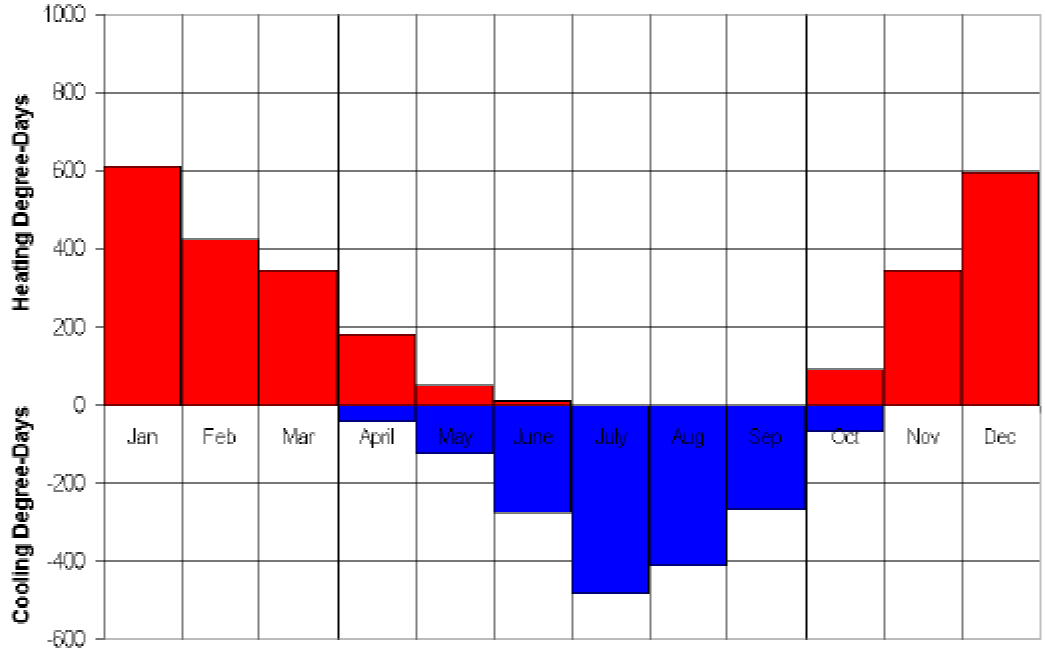
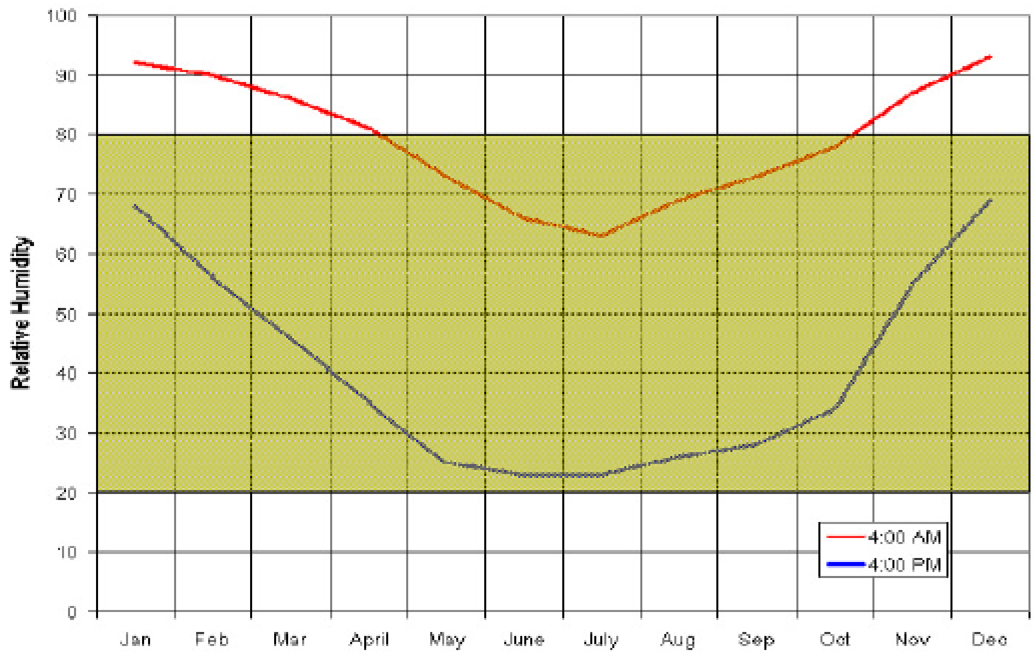
Degree Day
(Base 65°)



Relative Humidity
(Typical Comfort Zone: 20-80%)



Zone 13: Fresno
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