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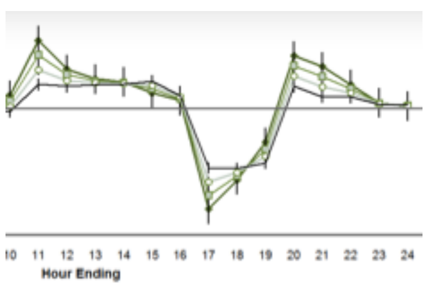
SMUD's 2012 Residential Precooling Study – Load Impact Evaluation



Hourly load impacts resulting from residential precooling followed by peak temperature offset

Prepared by Herter Energy Research Solutions
for the Sacramento Municipal Utility District,
Sacramento, California

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EXECUTIVE SUMMARY

The objective of this study was to determine how different precooling strategies initiated prior to direct load control events would affect hourly load impacts, overall energy use, and participant comfort. Effects were considered in light of outdoor temperatures and the level of ceiling insulation in participating homes. Findings were used to create bill and load impact scenarios for different electricity rates and insulation levels, and to provide recommendations for future program offerings.

In August and September of 2012, three different precooling treatments were rotated among 175 residential customers prior to a 3-hour 3°F peak load shed event:

- **P0** was the business-as-usual treatment of no precooling before the event
- **P2** was a 2-hour precool at 4°F below the minimum peak setpoint
- **P6** was a 6-hour precool at 2°F below the minimum peak setpoint

Rotation of these three treatments across three groups of participants allowed direct comparison of the strategies to each other. In addition, regression analysis of event and non-event days made possible comparison to a modeled baseline of what the load would have been in the absence of an event.

The main findings of this study are as follows.

1. **Hourly load impacts**
   a. Precooling significantly increased loads prior to the event period. In the 2 hours before the event, P2 increased average participant loads by 1.5 kW (+73%), and P6 increased average loads by 0.39 kW (+19%).
   b. Load shed – averaging 1.0 kW for P0 (-35%), 1.1 kW for P2 (-37%), and 1.3 kW for P6 (-43%) – was statistically significant in all 3 event-hours for all 3 treatments. P6 precooling, higher insulation levels, and higher temperatures increased this effect. At lower temperatures, load shed following P6 was significantly deeper than the load sheds following P2 or P0. At higher temperatures, precooling did not affect peak load shed.
   c. Post-peak rebound – averaging 0.30 (+15%) for P0 and 0.26 kW (+12%) for the precooling treatments – was statistically significant in the five hours after the event ended for all treatments. Precooling, higher insulation levels, and lower temperatures reduced this effect.

2. **Energy, comfort and bill impacts**
   a. On average, P0 reduced energy use while P2 and P6 increased energy use; however, P6 precooling reduced overall energy use for participants with higher levels of ceiling insulation (at least R38).
   b. Participants were most comfortable under the P6 precooling strategy. Compared to a benchmark day with no precooling or offset, the P6 comfort levels were statistically similar,

whereas comfort ratings for P0 and P2 precooling strategies were significantly worse than the benchmark ratings.

c. The eight events did not significantly affect monthly energy use or bills for PowerStat participants, who were all on SMUD's standard residential rate.

d. Under SMUD's SmartSacramento® Pricing Pilot TOU rate, customers with higher insulation levels could precool every weekday to achieve energy and bill savings without discomfort.

Figure 1 illustrates the effects of the three precooling treatments followed by a 3°F temperature increase during the 4-7 p.m. peak period. Treatment and baseline loads – modeled from the actual 2012 PowerStat event and non-event day data, respectively – are plotted as hourly averages across the eight event days. Note the expected precooling impacts, the visibly lower peak loads for P6 under average temperature and insulation conditions, and similar rebound effects.

FIGURE 1. AVERAGE HOURLY IMPACTS DURING 2012 POWERSTAT EVENT DAYS

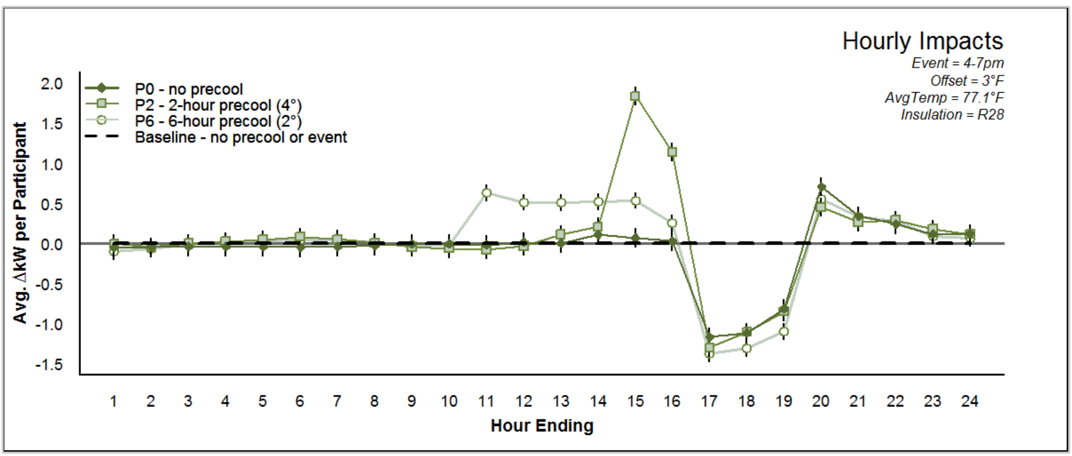


Figure 2 shows that, on average, peak loads following the P6 precooling were roughly 17% lower than loads following the P2 precooling strategy, and 22% lower than load following P0. These differences are statistically significant. (Note that, to be consistent with load shape graphs, savings are plotted throughout the report as negative load values.)

FIGURE 2. AVERAGE PEAK IMPACTS ON 2012 POWERSTAT EVENT DAYS

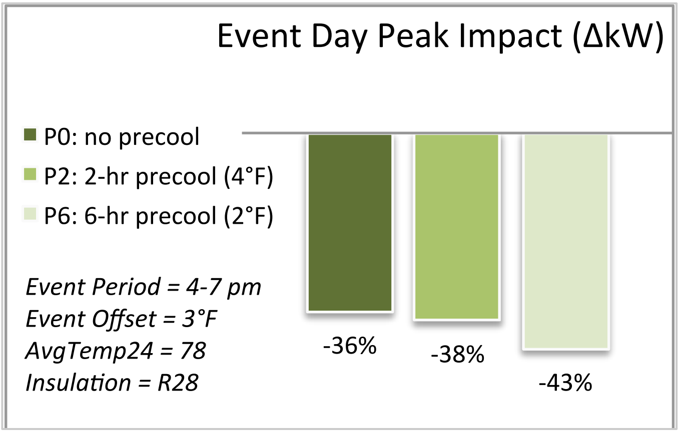
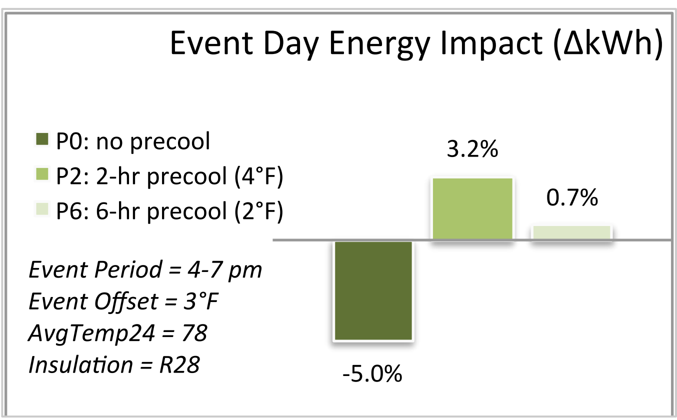


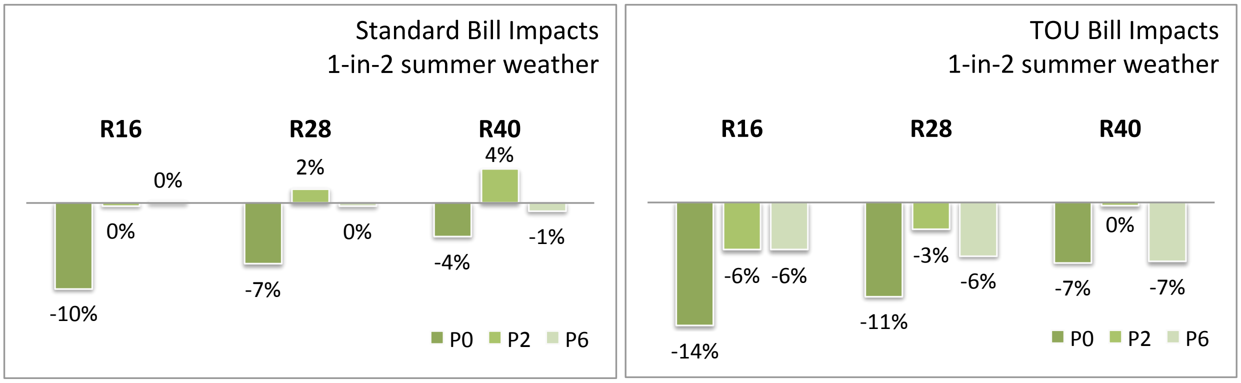
Figure 3 shows that only P0 saved energy at the average PowerStat insulation level (R28) and event temperature (77.1°F). These results change on cooler days and at higher insulation levels. For example, where the average temperature is at or below the average 2012 event temperatures, homes with at least R38 ceiling insulation showed energy *reductions* under P6 precooling. This implies that the P6 precooling strategy could be used to save energy and reduce peak on non-event weekdays, while the P0 strategy may be more effective – but probably less comfortable – on the hottest event days.

FIGURE 3. AVERAGE ENERGY IMPACTS ON 2012 POWERSTAT EVENT DAYS



Finally, bills were calculated under several scenarios with varying temperatures and insulation levels. Figure 4 shows that participants would save more money on SMUD's SmartSacramento® Pricing Pilot TOU rate than they would on the Standard 2-tier rate, regardless of the precooling strategy or insulation level. These results imply that customers would save even more money on a TOU-CPP rate such as SMUD's SmartSacramento® Pricing Pilot Combined Time of Use and Critical Peak Rate. (See Appendix F for rate details.)

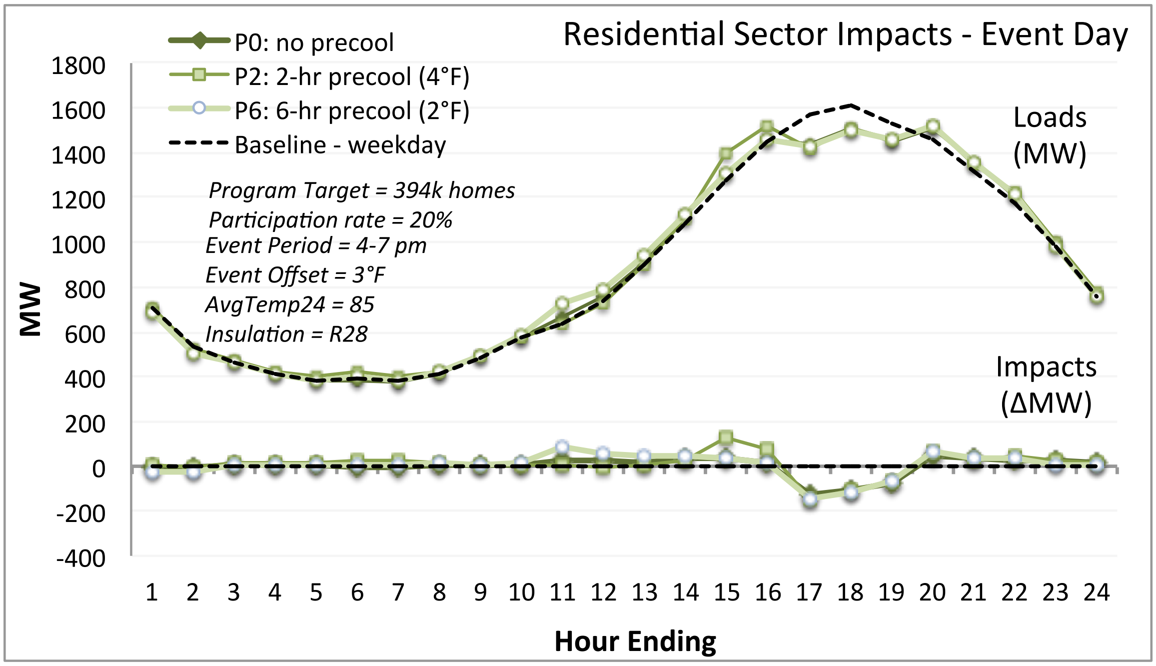
FIGURE 4. AVERAGE BILL IMPACTS WITH DAILY AC CONTROL: STANDARD VS. TOU RATES



On average, the P0 strategy saved the most money, however, P6 showed similar bill savings at higher insulation levels. Since comfort levels for the P6 precooling strategy were statistically similar to a benchmark (non-event) day, this implies that many or most customers with higher insulation levels could save money on TOU rate without discomfort by initiating a long, shallow P6-like precool every weekday. This theory is supported by anecdotal evidence found in a separate but concurrent study at SMUD, where participants were encouraged but not required to precool before peak periods: several participants commented on surveys that the precooling during the inexpensive off-peak period allowed them to maintain comfort throughout the high-priced peak periods without increasing their bills (Herter Energy Research Solutions 2013).

Figure 5 provides an illustrative example of an extrapolation of these results to the roughly 400,000 eligible single-family homes in the SMUD service territory. Under this scenario, which assumes a 1-in-2 peak day, average insulation levels, and a 20% participation rate, the P6 strategy would provide the greatest average peak impacts of 96 MW while increasing the energy use for the day by 104 MWh. In comparison, the P0 treatment would reduce average peak loads by 94 MW and increase overall energy use by just 4.4 MWh. P2 would be the least beneficial strategy of the three, with 95 MW peak load shed and 187 MWh daily energy increase.

FIGURE 5. EXTRAPOLATION OF RESULTS TO SMUD'S RESIDENTIAL SECTOR LOADS, 1-IN-2 PEAK DAY



1-in-2 event day: max temp 106°F, min temp 67°F. Prior day: max temp 104°F, min temp 65°F

Recommendations

The findings suggest that SMUD and their customers may benefit from offering one or more of the following programs:

1) **A Demand Response program** combined with the following features:
   a) Increased ceiling insulation to at least R38
   b) A thermostat that facilitates precooling and peak offset, to avoid occasional demand response events. For event response, the thermostat *must be* a communicating thermostat.
   c) Participants with at least R38 insulation should be encouraged to program their thermostat to precool 2 degrees, 6 hours prior to events.

2) A **TOU rate** similar to SMUD's SmartSacramento® Pricing Pilot TOU rate, combined with the following features:
   a) Increased ceiling insulation to at least R38
   b) A thermostat that facilitates precooling and peak offset every weekday, to avoid the peak TOU rate. For daily peak reduction, the thermostat *need not be* a communicating thermostat.
   c) Participants with at least R38 insulation should be encouraged to program their thermostat to precool 2 degrees, 6 hours prior to the peak period every weekday.

3) A **TOU-CPP rate** similar to SMUD's SmartSacramento® Pricing Pilot Combined Time of Use and Critical Peak Rate, with the following features:
   a) Increased ceiling insulation to at least R38
   b) A thermostat that facilitates precooling and peak offset every weekday, and also responds to occasional demand response events. For event response, the thermostat *must be* a communicating thermostat.
   c) Participants with at least R38 insulation should be encouraged to program their thermostat to precool 2 degrees, 6 hours prior to the peak period every weekday.

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BACKGROUND

Direct control of air conditioning has been used and studied extensively for decades. To expand upon the existing knowledge in this field, this pilot made use of communicating thermostats to test the potential for AC-based precooling to enhance peak demand response impacts in the residential sector. While there has been some field investigation of precooling in commercial buildings (Xu et al. 2004, Yin et al. 2010), precooling in residential buildings is a subject that has been considered almost exclusively through simulation, which roundly predicts that longer and cooler precooling periods will be followed by increased peak savings (Springer 2007, Turner et al. 2012, Walker & Turner 2012). The goal of this field study was to assess the available technology and to determine the differential effects on load and comfort of multiple precooling strategies with different duration and depth.

Study Overview

Scope and Objectives

The objective of this study was to determine how different precooling strategies prior to direct load control events affect hourly load impacts and participant comfort. In August and September of 2012, two precooling strategies were tested in addition to a business-as-usual scenario of "no precool." One precooling strategy was a "long-shallow" precool of 6 hours at 2°F, and the other was a "short-deep" precool of 2 hours at an offset 4°F below the minimum peak setpoint. This design allowed us to compare precooling strategies of differing length and magnitude to each other, to the business-as-usual case, and also to a baseline case of no precooling, no event.

Experimental Design

Table 1 summarizes the load control strategies applied as treatments in this study.

Table 1. Experimental Treatments

Treatment	Precool Duration*	Precool Offset	Peak Duration*	Peak Offset
P0	0 hours	-0 °F	3 hours	+3 °F
P2	2 hours	-4 °F	3 hours	+3 °F
P6	6 hours	-2 °F	3 hours	+3 °F

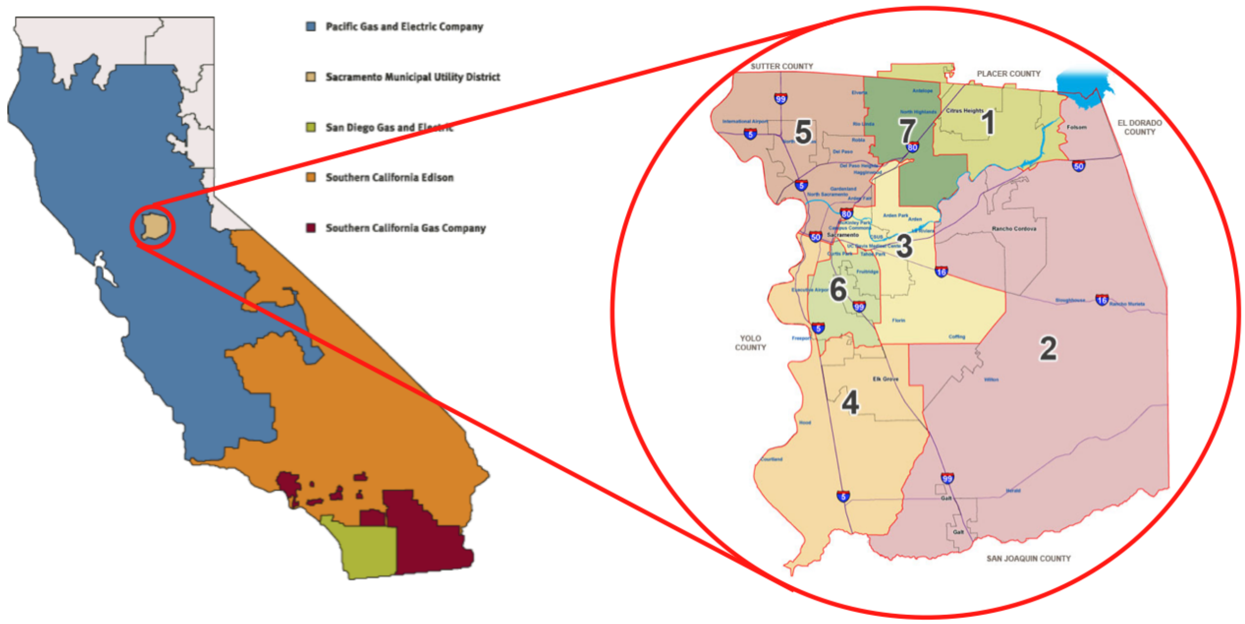
** Peak period for all treatments was 4-7 p.m., and precool periods immediately preceded the peak period.*

Study Area

This study takes place in the in the Sacramento Municipal Utility District (SMUD) service territory, which is located in California's central valley, covering the state capital of Sacramento and surrounding suburban areas (Figure 1). SMUD is currently the sixth largest community-owned electric utility in the nation, spanning 900 square miles and serving over half a million residential customers.

Sacramento weather is characterized by rainy, mild winters and hot, dry summers. On average, the maximum daily temperature exceeds 90 °F on 74 days annually, and exceeds 100 °F on 15 days annually.

Figure 6. SMUD service territory



Metering System

SMUD installed an advanced interval metering system between 2009 and 2012. The new residential and small commercial meters can be configured to collect energy use data at 5, 15, 30, and 60-minute intervals. SMUD's residential meters record energy use hourly and upload the data every four hours.

Peak Load Programs

SMUD's only residential demand response program is Peak Corps, an air-conditioning load control program that uses private VHF communication to signal air-conditioning compressor switches during events. The program is considered an "emergency only" resource, and is not used to manage system peak loads on a regular basis.   More than 93,000 of SMUD's residential customers (about 20%) receive incentives of $2, $4 or $6 per event, depending upon cycling intensity, to allow the District to cycle their air conditioner during critical hours between June 1 and September 30 each year.

In addition to the precooling study described in this document, SMUD is running several other residential pilots to test time-based pricing and real-time information devices intended to lower energy use and peak demand.

SCHEDULE

Table 2 outlines the major phases of project activity in 2012 and corresponding research tasks.

TABLE 2. PROJECT SCHEDULE

Task	Dates	Activities
Field Study Preparation	March 2012 – June 2012	• Project design and planning • Recruitment materials • Website
Recruitment	June 2012	• Invitation mailings and follow-up • Participant database
Installation & Survey	July 2012	• Install thermostats • Inventory database • Pre-treatment surveys
Field Study	August 2012 – September 2012	• Call 8 events • Interim (post-event) surveys • Customer service
Final Evaluation	October 2012 – May 2013	• Satisfaction surveys • Retrieve load database • Data analysis and reporting

Study Components

Participant Benefits and Costs

The 2012 PowerStat Pilot offered customers the following benefits:

- *A smart thermostat*. Customers received a new 7-day programmable thermostat with a large touchscreen display and backlighting. Along with standard thermostat functionality. the thermostat unit provided event notification and automated event response. A supporting Internet website provided remote access to settings, schedules, and event overrides. Paper copies of the UtilityPro user guide were given to participants at installation and were made available on the PowerStat website. The unit and installation were free of cost to participants.
- *Good will*. For many customers, participation makes them feel that they are doing something good for the community: reducing strain on the electric grid during peak times to improve electric reliability and keep system costs down.

Customer costs included:

- Scheduling and being present for the thermostat installation
- Getting a thermostat that they liked less than their old one (this was very uncommon)
- A very slight bill increase due to precooling (generally less than $1 per month)

Thermostats

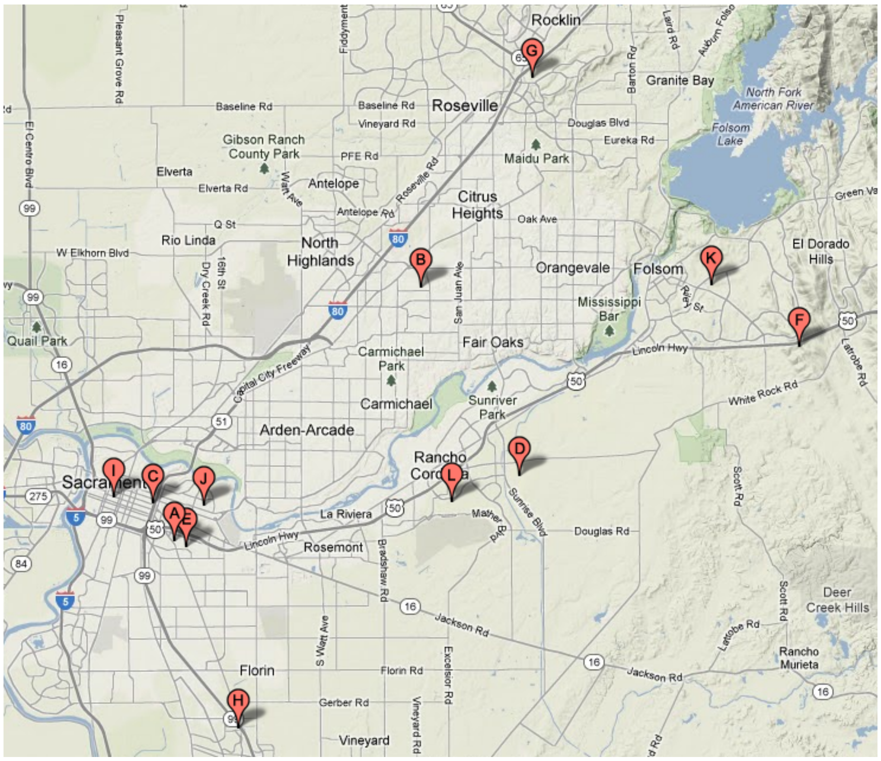
Each participant in the PowerStat Pilot received a Honeywell UtilityPro touchscreen thermostat with the ability to receive control signals and display messages from the load management system. Information in the load management system can be changed through the administrative web portal for all customers by both the installer and the utility. Customers are each provided a password-protected customer web portal to manage their own thermostats.

On event days, the thermostats displayed messages to indicate that a control strategy was in progress. The thermostat displayed “PRE-COOL” when a precooling offset was in effect, “SAVINGS” when the peak offset was in effect, and “RECOVERY” at the end of the event until the customer’s normal temperature setting was attained. During events, adjustments at the thermostat were not possible, but customers could opt out of events through a password protected web portal.

PAGING SYSTEM

There are 12 towers in Sacramento area, as shown in Figure 7.

FIGURE 7. PAGING TOWERS IN THE SACRAMENTO AREA



Field Study Activities

Recruitment, Enrollment, and Participant Sample

Recruitment packages were mailed to 14,221 single-family homes. The final recruitment and enrollment results are provided in Table 3.

Table 3. Recruitment Results

	Single-family Homes	% of Invited	% of Applications
Customers Invited	14,221		
Applications received	771	5.4%	
- Rejected	120		16%
- Enrolled	180		23%
- Waitlisted	471		61%
Clean Applications	651	4.6%	

The 180 enrolled participants were divided into three groups of 60 for the purpose of treatment rotation. Over the course of the summer, five participants dropped out. Upon investigation of the summer load data, 15 Group 2 and 26 Group 3 participants were re-categorized as Group 1 participants. The miscategorization resulted when the thermostats at these 41 participant sites did not receive their group assignment via the paging communication. As a result, these 41 thermostats remained in the default Group 1 rather than being set to Group 2 or 3, as was intended. Another 23 sites were excluded from the analysis because their Group number could not be determined.

Figure 8 maps the locations of the 180 enrolled participants, by status, as follows:

- 111 “good” sites included in the analysis as originally assigned
- 15 “2-to-1” sites assigned to Group 2, but controlled according to the Group 1 schedule
- 26 “3-to-1” sites assigned to Group 3, but controlled according to the Group 1 schedule
- 23 “bad” sites for which the Group number could not be determined
- 5 “drop” sites, who dropped out of the program before the end of the summer

FIGURE 8. MAP OF ORIGINAL 180 POWERSTAT PARTICIPANTS, BY STATUS

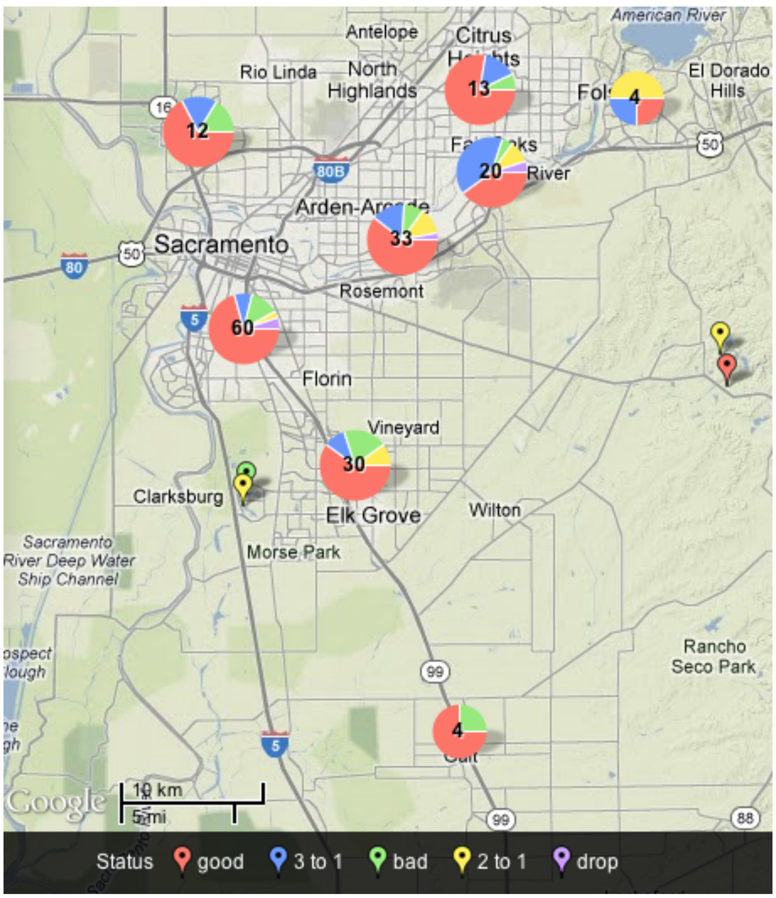
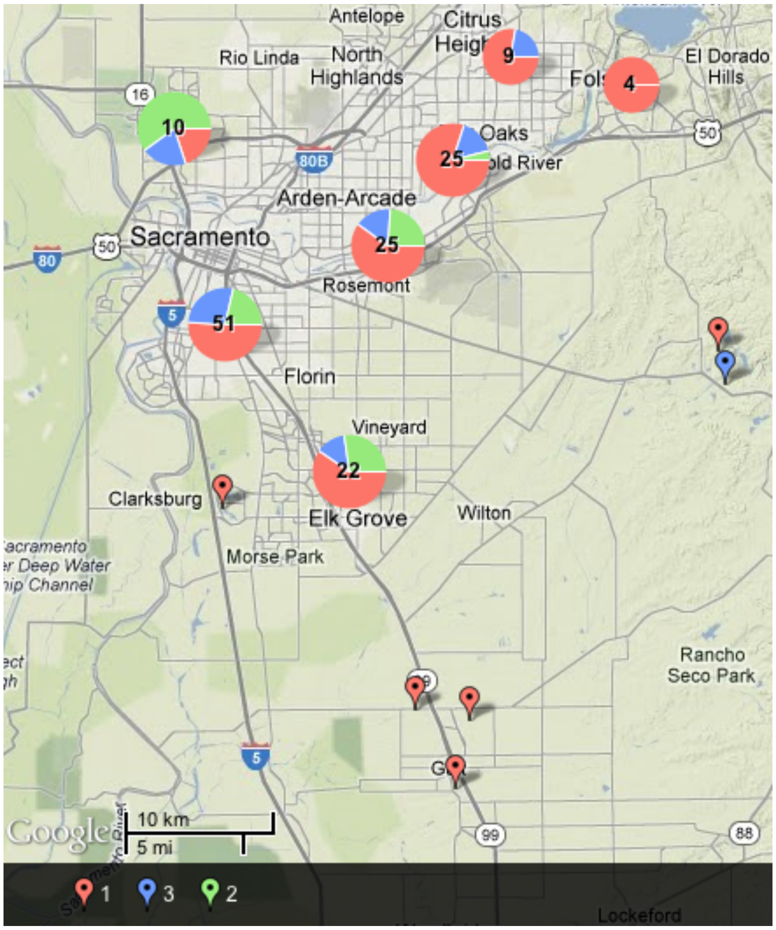


Figure 9 maps the locations of the final 152 participants included in the analysis: 92 participants in Group 1, 30 participants in Group 2, and 30 participants in Group 3.

FIGURE 9. MAP OF FINAL 152 POWERSTAT PARTICIPANTS, BY ROTATION GROUP



The final three rotation groups, as analyzed, are described in Table 4.

TABLE 4. PARTICIPANT CHARACTERISTICS, BY GROUP

Rotation Group	Homes	Completed surveys	Mean Insulation R-Value	Mean Home Size (ft^2)	Mean # of occupants	# Homes with occupants <2 years old	% Homes occupied 10 am – 4 pm
1	92	77	28.0	1724	2.41	3	75.3
2	30	24	28.2	1754	2.33	0	75.0
3	30	28	26.6	1773	2.21	1	89.3
All	152	129	27.7	1740	2.35	4	78.3

Surveys

Three types of surveys were administered to participants: a pre-treatment survey collected before the first event to capture pre-treatment conditions, four separate event surveys collected the day after each pair of similar events to captured comfort ratings, and a post treatment survey, collected after the final event to capture satisfaction ratings. A summary of survey responses can be found in Appendix E.

Events

Events were called on 5 weekdays in August and 3 weekdays in September, as listed in Table 5. Participants were notified by email on the day before each event.

Table 5. Event dates and temperatures

Date	Day of the Week	Minimum Temperature	Maximum Temperature	AvgTemp24
August 9, 2012	Thursday	59°F	103°F	80°F
August 13, 2012	Monday	65°F	105°F	84°F
August 15, 2012	Wednesday	69°F	96°F	79°F
August 17, 2012	Friday	60°F	95°F	76°F
August 23, 2012	Wednesday	58°F	91°F	73°F
September 4, 2012	Tuesday	56°F	95°F	75°F
September 12, 2012	Wednesday	56°F	91°F	74°F
September 14, 2012	Friday	60°F	92°F	76°F

Before the peak period, thermostats were directed to perform one of the three experimental precooling strategies: P0, P2, or P6, as described previously. These three strategies were evenly rotated among participants in sets of two, such that each participant received the same precooling strategy for two consecutive events, as shown in Table 6.

Table 6. Treatment Schedule

Rotation Group	Event 1 *8/9*	Event 2 *8/13*	Event 3 *8/15*	Event 4 *8/17*	Event 5 *8/23*	Event 6 *9/4*	Event 7 *9/12*	Event 8 *9/14*
1	P6	P6	P2	P2	P0	P0	P6	P6
2	P2	P2	P0	P0	P6	P6	P2	P2
3	P0	P0	P6	P6	P2	P2	P0	P0

Immediately following the precooling strategy, at 4:00 p.m. on event days, participant thermostats were raised 3 degrees higher than the minimum scheduled setpoint for the peak period. This new temperature setting was maintained until 7:00 p.m., when the thermostat returned to its normal customer-programmed temperature schedule.

Data Collection

Multiple types of information were collected from study participants at several points in the project. Initially, basic information was pulled from SMUD's customer database to conduct recruitment efforts. More detailed customer, building, and comfort information was collected through the surveys. Throughout the study, SMUD collected hourly electricity use data. At the end of the study, participant perceptions of the program were documented in their End of Summer Survey answers. A summary of these and other datasets and sources utilized for this study is presented in Table 7.

Table 7. Summary of data collected

Source	Data	Use(s)
SMUD Customer Database	Name, address, etc.	Screening and Recruitment
Installer Checklist	Ceiling R-value	Evaluation: Load impacts
Cooper Power Systems	Log of interactions with website	Evaluation: Overrides
Event Surveys	Comfort ratings	Evaluation: Comfort
Interval Meters	Hourly electricity use	Evaluation: Load impacts Evaluation: Bill impacts
MesoWest.utah.edu	Hourly temperatures	Evaluation: Load impacts
Post-treatment Survey	Satisfaction ratings	Evaluation: Satisfaction

Observed Loads and Temperatures

Hourly electric loads are collected from all residential customers in the SMUD service territory. At the end of the summer 2012, the hourly loads for the 152 participating PowerStat homes were pulled and analyzed to determine the effects of the events on their electricity use. Figure 10 shows the mean hourly loads for all 152 homes combined. Clearly visible are the eight load control events, which are labeled with their corresponding maximum temperature for that day.

Figure 10. Mean hourly loads for PowerStat participants with maximum event temperatures

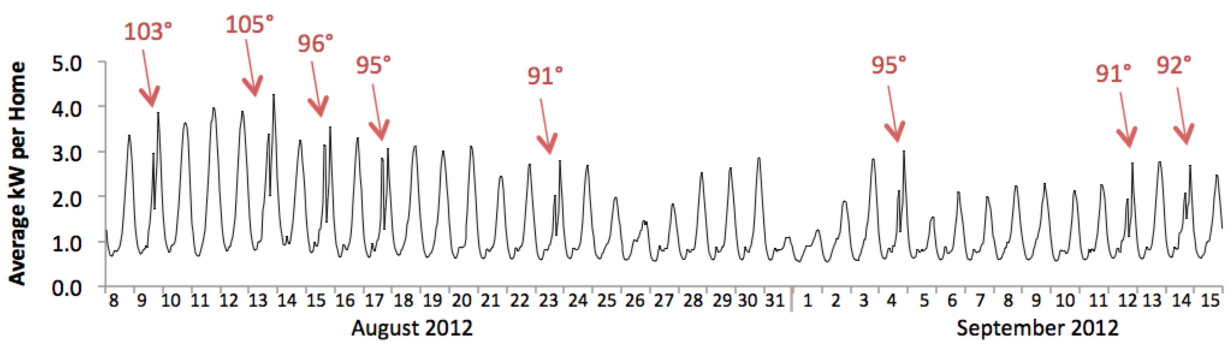
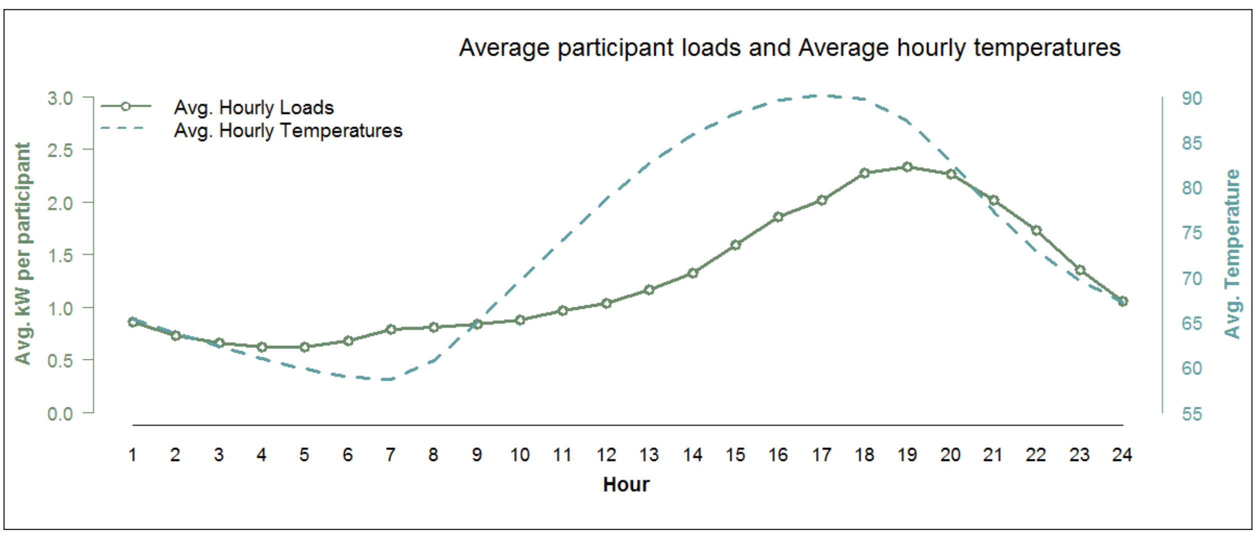


Figure 11 plots the average hourly kW loads in Summer 2012 along with average hourly temperatures – both actual and shifted. Note that shifting actual hourly temperatures by 2-hours increases the correlation between temperature and load from 0.83 to 0.95.

Figure 11. Average hourly temperatures and participant loads



Load Impacts

Following are the results of analyses used to estimate the hourly load impacts for PowerStat participants on event days. All results are presented by precooling treatment – P0, P2, or P6 – to highlight the effects of the different precooling strategies on the pre-peak load increase, peak load shed, and subsequent post-peak rebound.

Hourly kilowatt (kW) values measured at the individual customer level were analyzed using a mixed-effects model, also known as a hierarchical or multilevel model. AvgTemp24 interaction with R-value, hour and treatment is included in the model to capture the effect of the insulation level in the ceiling and the effect of outside temperatures on the load shape and load impacts for different treatments.

$$kw_{ijk} = \beta_{(hour)ijk} hour_{ijk} + \beta_{(CDH)ijk} CDH_{ijk} + \beta_{(AvgTemp24)ijk} AvgTemp24_{ijk} + \beta_{(Rvalue)i} Rvalue_i + \beta_{(hour*AvgTemp24*Rvalue_i*treat)ijk} hour_{ijk} * AvgTemp24 * Rvalue_i * treat + r_i + r_{ij} + \varepsilon_{ijk}$$

kw_{ijk}: kilowatt load for customer i on day j at hour k

$hour_{ijk}$: categorical variables (1-24) indicating the hour of the day, where hour 1 spans the period from midnight to 1:00 a.m. and hour 24 spans the period from 11:00 p.m. to midnight.

CDH_{ijk}: cooling degree hour on day j at hour k (see description below)

$AvgTemp24_{ijk}$: average temperature from noon on day j-1 to noon on day j (see below)

$Rvalue_i$: observed ceiling insulation R-value for customer i

$treat$: categorical variable for treatment with 4 levels (P0, P2, P6, none)

r_i: random effects for customer $\sim N(0, \varphi_1)$, assumed to be independent for i

r_{ij}: random effects for day $\sim N(0, \varphi_2)$, assumed to be independent for different i or j and to be independent of r_i.

ε_{ijk}: error terms $\sim N(0, \delta^2 I)$, assumed to be independent for different i or j and to be independent of random effects.

Cooling Degree Hour (CDH) is the variable used to account for the hourly outside temperature, calculated as the number of degrees above 75°F. CDH is set to zero for all hourly temperature values less than or equal to 75°F. Base 75°F was used for CDH as it was determined that the model produced was the best one to describe the actual data. The resulting CDH values were shifted two hours forward in time to account for the lag in the transfer of outside temperatures into the building.

All impacts are estimated relative to baselines modeled using non-event day loads corrected to reflect event day temperatures. For consistency and ease of comparison, all impacts are presented in units of average kilowatt-hours per hour (kWh/h), abbreviated in most cases to kW. Positive values indicate an increase in energy use relative to the baseline, whereas negative impact values indicate energy savings. Note that the convention for presenting overall energy impacts is kWh rather than kW, but the hourly kW values presented here are easily converted to kWh through multiplication by the number of hours across the desired time period. For detailed output of the mixed model, see Appendix C.

How did precooling and peak offset impact loads?

Figure 12 illustrates the modeled average participant loads and impacts for the three treatments, corrected for the average event-day temperature profile. Load impacts are estimated relative to a weather-corrected non-event day baseline. Error bars represent 95% confidence intervals for the impacts.

Relative to the no-precooling base case (P0), the P6 strategy induces a fairly stable 6-hour load increase from the hour ending 11 am through the hour ending at 4 pm, when the peak period begins. During the load-shed event, the P6 strategy outperforms the base-case by about 25%.

The 2-hour precooling strategy, in comparison, spikes at the hour ending at 3 p.m. and then drops off noticeably in the second hour of precooling. During the peak period, the P2 strategy is nearly identical to the P0 strategy.

FIGURE 12.HOURLY LOADS AND IMPACTS, BY PRECOOLING STRATEGY

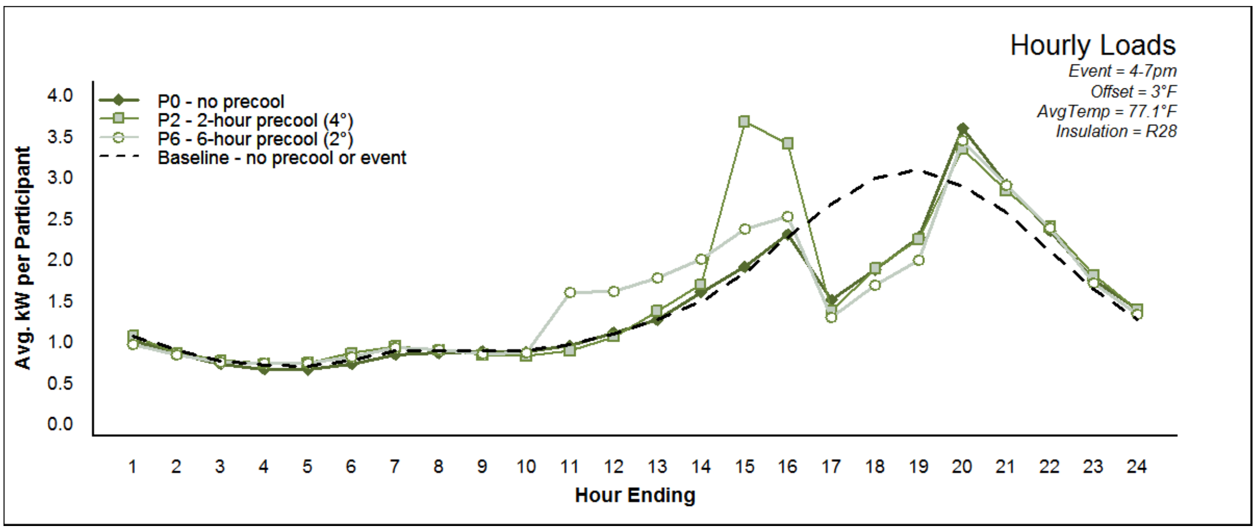


Table 8 represents the estimated load impacts for each of the three treatments for the average event-day temperature profile. Negative kW values indicate the average hourly savings relative to the weather-corrected non-event day baseline. Significant impacts are marked with an asterisk (*).

TABLE 8. AVERAGE LOAD IMPACTS (MODELED)

	N	Off-Peak (hours 1-14)	Pre-peak (hours 15-16)	Peak (hours 17-19)	Post-peak (hours 20-24)	Total (hours 1-24)
P0	152	-0.019 *(-2.0%)*	+0.048 *(+2.4%)*	-1.03* *(-35%)*	+0.30* *(+15%)*	-0.073* *(-4.8%)*
P2	152	+0.017 *(+1.9%)*	+1.48* *(+73%)*	-1.08* *(-37%)*	+0.26* *(+12%)*	+0.052 *(+3.4%)*
P6	152	+0.15* *(+16%)*	+0.39* *(+19%)*	-1.26* *(-43%)*	+0.26* *(+12%)*	+0.016 *(+1.1%)*

- Statistically significant (α = 0.05)

To determine difference between treatments, hourly load data for event days was aggregated into four periods as follows:

- Off-peak = Hours ending 1-14
- Pre-Peak = Hours ending 15-16
- Peak = Hours ending 17-19
- Post-peak = Hours ending 20-24

Contrast analysis was used to compare the effects of the precooling treatments on loads during the four daily periods described above. Table 9 provides results of the between-treatment comparisons for each period. Results show that the P6 treatment shed significantly more load during the peak period than did P0 or P2.

TABLE 9. COMPARISON OF LOAD IMPACTS BY TREATMENT

Treatment Comparison	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-peak (hours 20-24)	Total (hours 1-24)
P2-P0	0.04	1.44*	-0.05	-0.04	0.12*
P6-P0	0.17*	0.35*	-0.23*	-0.04	0.09*
P6-P2	0.13*	-1.09*	-0.18*	0.00	-0.04

* Statistically significant (α = 0.05)

Results further indicate the following:

- In the Off-peak hours, P6 used significantly more energy than P0 or P2.
- In the Pre-peak hours, P2 energy use was the highest, followed by P6 and then P0 as the lowest.
- In the Peak hours, P6 demand was lowest, while P2 and P0 were not significantly different.
- There were no significant differences in the Post-peak hours.
- Total daily energy use was lowest under the P0 treatment, while P2 and P6 were not statistically different.

HOW DID LOAD IMPACTS CHANGE WITH INSULATION LEVEL?

Well-insulated buildings, by definition, slow heat transfer between the interior and exterior of the building. Theoretically then, one might posit that precooling and offset strategies would use less energy and have greater impacts in homes with higher levels of insulation. To test this theory, ceiling insulation R-values were observed from 130 of the 180 homes visited for thermostat installation. The distribution of observed ceiling R-values is provided in Appendix A.

Using the mixed model described previously, hourly impacts by treatment were compared at different insulation levels. The results indicate that homes with higher insulation levels attained deeper load shed and smaller rebound effects than those with the lower insulation levels. Effects of insulation on hourly loads and impacts for P0 are shown in Figure 13 and Table 10, effects for P2 are shown in Figure 14 and Table 11, and effects for P6 are shown in Figure 15 and Table 12

FIGURE 13. EFFECT OF INSULATION ON P0 LOADS

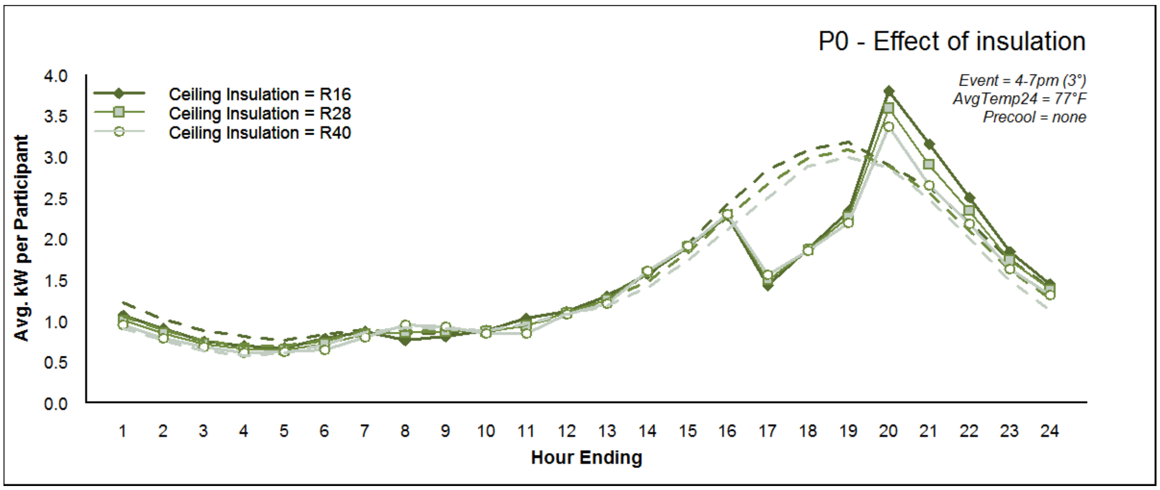


TABLE 10. EFFECT OF INSULATION ON P0 LOAD IMPACTS

Insulation Level	Off-Peak (hours 1-14)	Pre - Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
R16	-0.05	-0.08	-1.15*	0.37*	-0.10*
R28	-0.02	0.05	-1.03*	0.30*	-0.07*
R40	0.01	0.18	-0.91*	0.24*	-0.04

* Statistically significant (α = 0.05)

FIGURE 14. EFFECT OF INSULATION ON P2 LOADS

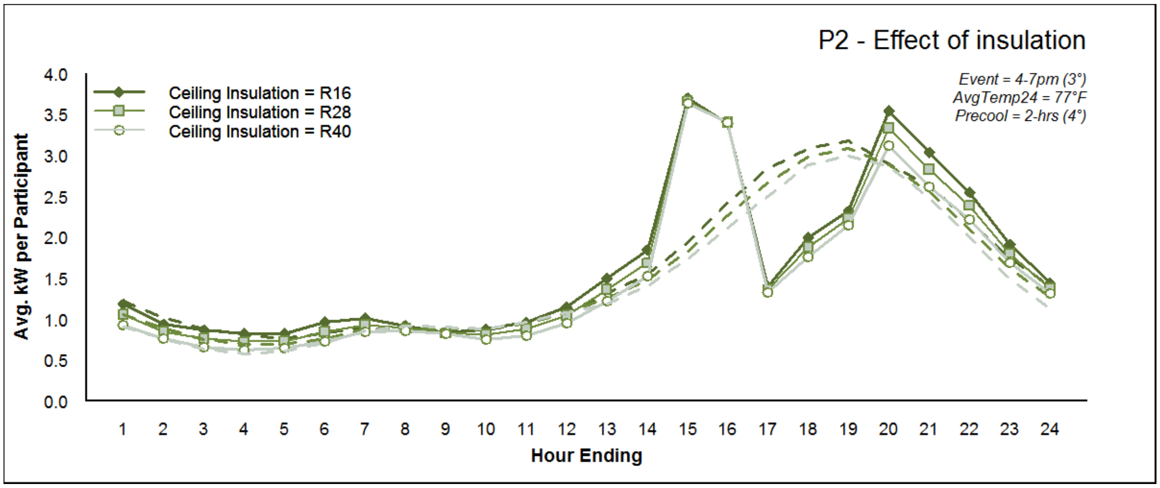


TABLE 11. EFFECT OF INSULATION ON P2 LOAD IMPACTS

Insulation Level	Off-Peak (hours 1-14)	Pre - Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
R16	0.06	1.37*	-1.13*	0.32*	0.07
R28	0.02	1.48*	-1.08*	0.26*	0.05
R40	-0.02	1.59*	-1.04*	0.20*	0.03

* Statistically significant difference (α = 0.05)

FIGURE 15. EFFECT OF INSULATION ON P6 LOADS

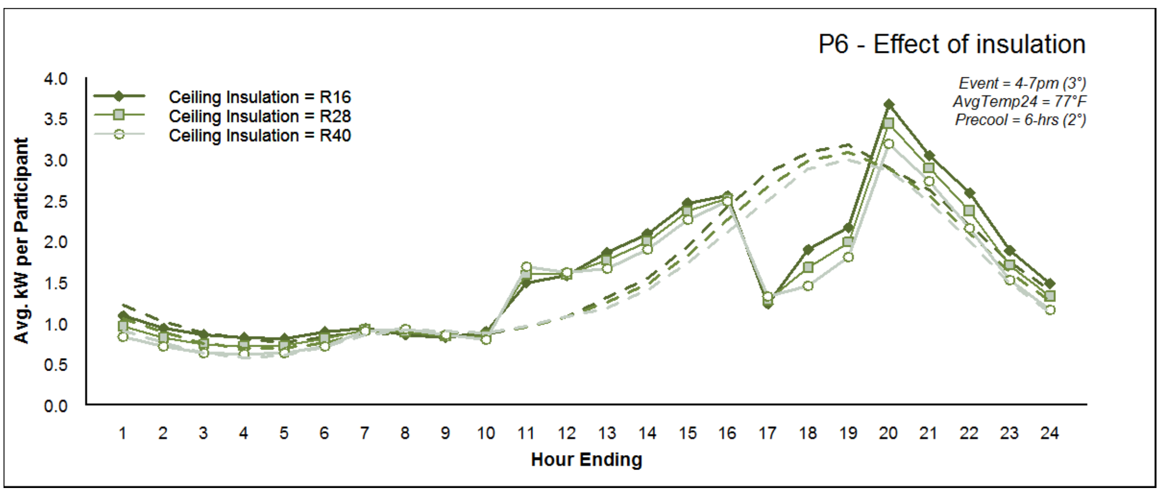


TABLE 12. EFFECT OF INSULATION ON P6 LOAD IMPACTS

Insulation Level	Off-Peak (hours 1-14)	Pre - Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
R16	0.15*	0.34*	-1.27*	0.36*	0.030
R28	0.15*	0.39*	-1.26*	0.26*	0.016
R40	0.15*	0.45*	-1.25*	0.16*	0.002

* Statistically significant (α = 0.05)

HOW DID LOAD IMPACTS CHANGE WITH OUTDOOR TEMPERATURE?

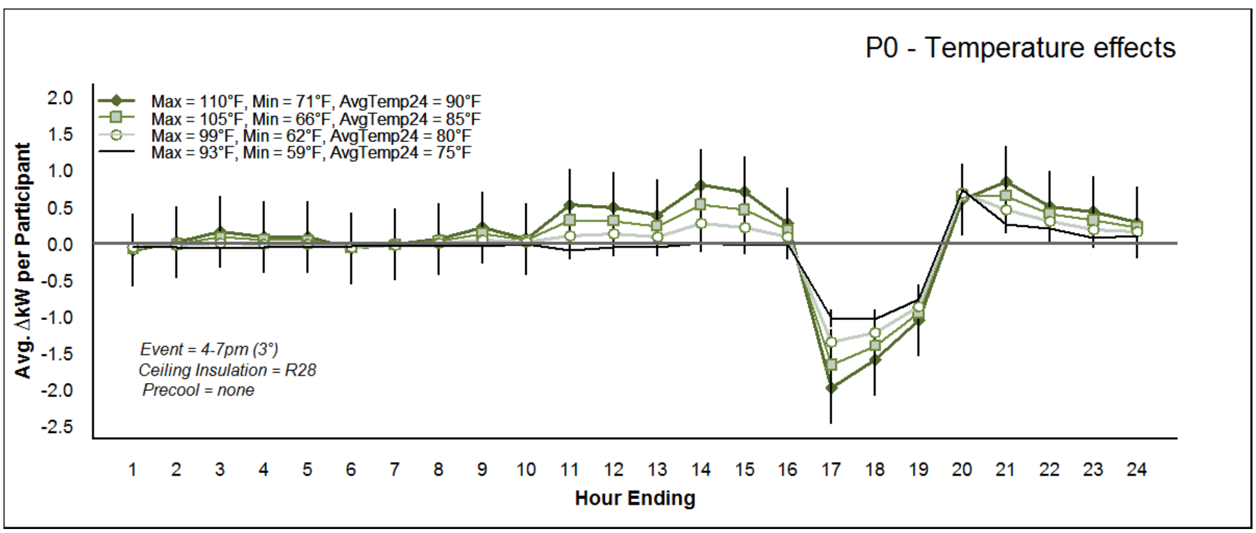
Previous research has shown that higher outdoor temperatures result in higher demand, which translates to greater peak impacts during demand response events (e.g. Herter 2007). This section considers the effect of outdoor temperatures on the hourly loads, and in particular during the pre-peak, peak, and post-peak periods.

To model these results, the mixed model for both event and non-event days was populated with 4 different temperature profiles, defined by maximum and minimum hourly temperatures along with the variable *AvgTemp24*.[1] In all cases, results show that higher temperatures increase pre-peak and post peak loads and lower peak loads relative to the baseline loads.

Results for 1-in-2, 1-in-5 and 1-in-10 peak days can be found in Appendix D.

Figure 16 plots the modeled hourly impacts for P0, with separate lines for days with maximum temperatures ranging from 93 °F to 110 °F. In general, higher temperatures result in deeper load shed and higher post-peak rebound, as expected. Unexpected, however, are the positive impacts (increased loads) prior to the peak period at hotter temperatures. Since precooling was not supposed to be initiated at all for P0, the source of these positive impacts is unknown. Reviewing the actual loads for each event, it appears that the hottest two events, on 8/9 and 8/13, are the source of this pre-peak load increase (see Appendix B). One possible explanation is that some customers chose to precool manually on the hottest days.

FIGURE 16. EFFECTS OF TEMPERATURE ON HOURLY P0 IMPACTS



[1] As described previously, AvgTemp24 is calculated as the average 24-hour temperature from noon on the previous day to noon on the current day, and is used as a basic indicator of heat gain in the building mass.

Table 13 summarizes the P0 impacts for the pre-peak, peak, and post-peak periods, as well as the total daily impact. Note that on cooler days, where AvgTemp24 is 75, the P0 treatment significantly reduced overall energy use on event days.

TABLE 13. EFFECT OF OUTDOOR TEMPERATURE ON P0 IMPACTS

AvgTemp24 (°F)	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
75	-0.05	-0.02	-0.95*	0.27*	-0.10*
80	0.03	0.15	-1.15*	0.35*	-0.04
85	0.11	0.31*	-1.35*	0.44*	0.01
90	0.19	0.48*	-1.54*	0.53*	0.07

* Statistically significant (α = 0.05)

Figure 17 illustrates the P2 precooling case for the four different temperature profiles.

FIGURE 17. EFFECTS OF TEMPERATURE ON HOURLY P2 IMPACTS

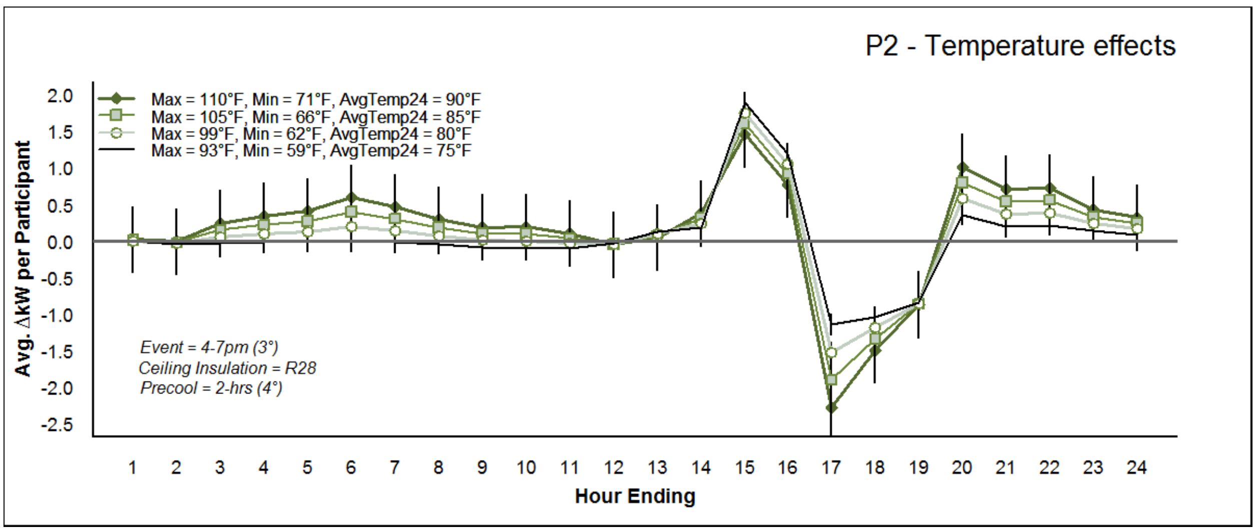


Table 14 summarizes the P2 impacts for the pre-peak, peak, and post-peak periods, as well as the total daily impact. At all temperatures, P2 uses significantly more energy pre-peak and post-peak, and significantly less energy during the peak.

TABLE 14. EFFECT OF OUTDOOR TEMPERATURE ON P2 LOADS

AvgTemp24 (°F)	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
75	-0.02	1.54*	-1.01*	0.20*	0.03
80	0.06	1.40*	-1.19*	0.34*	0.08*
85	0.15	1.26*	-1.37*	0.49*	0.12
90	0.23	1.12*	-1.55*	0.64*	0.16

* Statistically significant (α = 0.05)

Figure 17 illustrates the P6 precooling case for the four different temperature profiles. Once again, higher temperatures are associated with higher pre-peak loads, deeper load sheds, and higher post-peak rebound.

FIGURE 18. EFFECTS OF TEMPERATURE ON HOURLY P6 IMPACTS

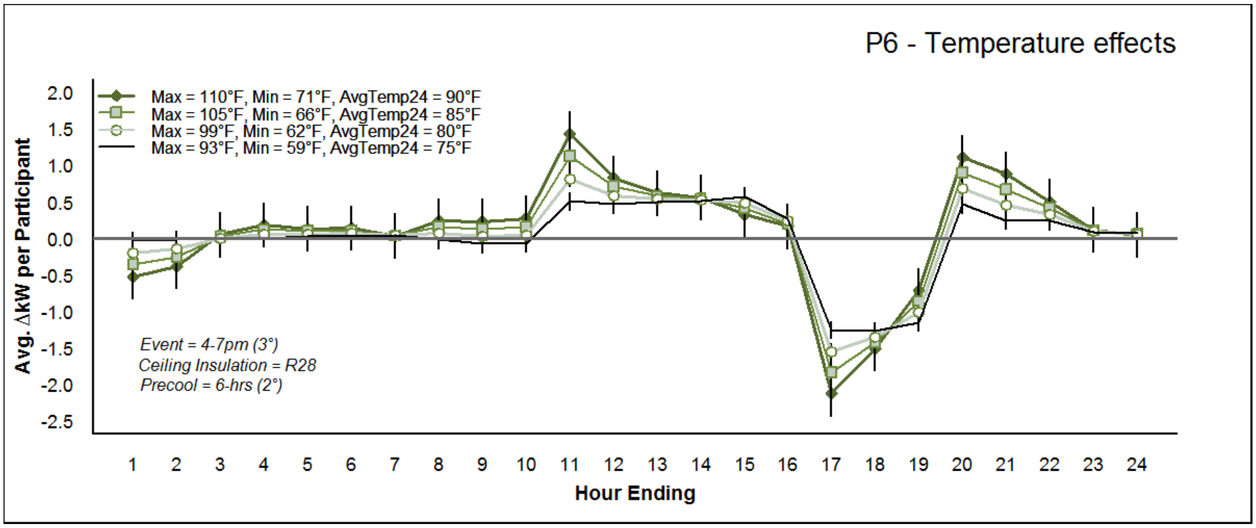


Table 15 summarizes the P6 impacts for the pre-peak, peak, and post-peak periods, as well as the total daily impact.

TABLE 15. EFFECT OF OUTDOOR TEMPERATURE ON P6 IMPACTS

AvgTemp24 (°F)	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
75	0.13*	0.42*	-1.23*	0.22*	0.00
80	0.18*	0.36*	-1.30*	0.32*	0.04
85	0.22*	0.30*	-1.38*	0.42*	0.07
90	0.27*	0.24	-1.45*	0.53*	0.11

* Statistically significant (α = 0.05)

How did load impacts change with customer characteristics?

Table 16 provides correlation coefficients for precooling treatments and customer-specific peak impacts on event days. For all treatments, homes occupied between 10 am and 4 pm provided deeper load sheds than homes that were unoccupied during that time, but this effect was statistically significant only for P0 and P6. In general, homes with more occupants shed more load during peak events, but this effect was statistically significant only for P6.

Table 16. Pearson's product-moment correlations with event impacts

	Square footage of home	People living in home	Occupant <2 yrs old	Occupant >65 yrs old	Home occupied 10am-4pm
P0	-0.15	-0.17	0.05	-0.09	-0.20*
P2	-0.11	-0.12	0.00	-0.15	-0.11
P6	-0.15	-0.21*	0.07	0.09	-0.22*

* Statistically significant (α = 0.05)

How did comfort change with load impacts?

Table 17 shows the correlations between peak impacts and comfort levels for different treatments. In general, more savings during the peak hours were correlated with colder pre-peak hours and hotter peak hours.

Table 17. Impacts and comfort correlations, by treatment

Treatment	Time Period	correlation
P0	2-4 pm	0.05
P0	4-7 pm	**-0.30***
P2	2-4 pm	0.06
P2	4-7 pm	**-0.23***
P6	2-4 pm	**0.21***
P6	4-7 pm	-0.03

* Statistically significant (α = 0.05)

BILL IMPACTS

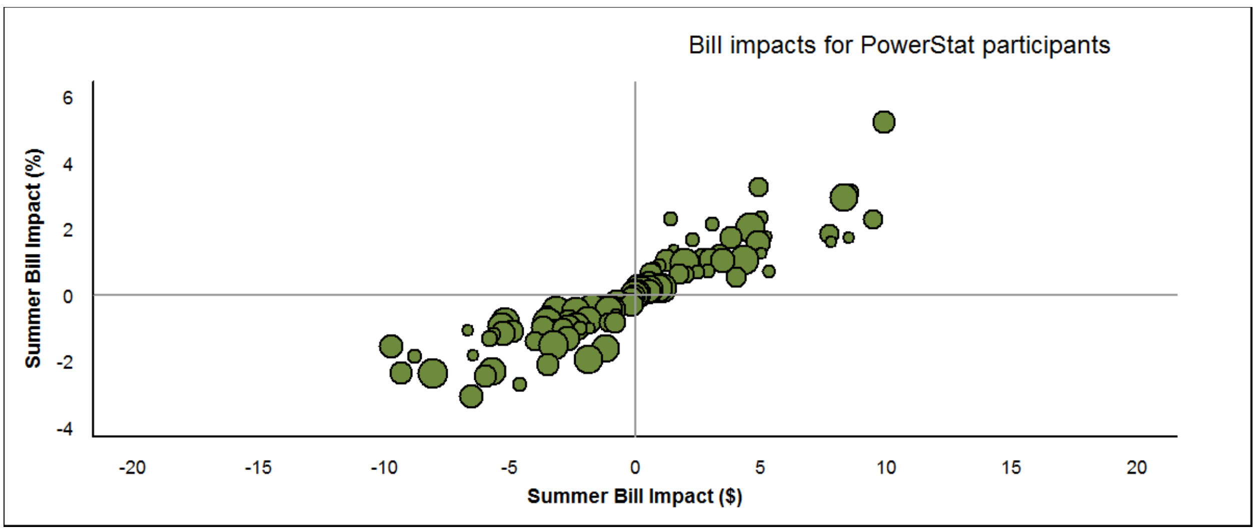
Average monthly bill impacts for PowerStat participants were not statistically significant, ranging from a $2 monthly bill savings (-1.2%) to a $0.55 monthly bill increase (+0.5%), as shown in Table 18.

TABLE 18. AVERAGE MONTHLY BILL IMPACTS

Treatment	Average Monthly Bill Impact ($)	% Bill Impact
P0	- $2.03	- 1.2 %
P2	+ $0.55	+ 0.5 %
P6	- $0.20	- 0.1 %

Figure 19 plots the bill impact estimates for the 152 particpants for August and September of 2012. Excluding the two outliers at the high and low ends, bill impact estimates ranged from -$10 to $10 for the summer, representing between -3% and +5% of the August-September bills.

FIGURE 19. DISTRIBUTION OF ESTIMATED 2012 POWERSTAT BILL IMPACTS



COULD CUSTOMERS ON A TIME-OF-USE RATE SAVE MONEY BY PRECOOLING EVERY WEEKDAY?

All PowerStat participants were on SMUD's standard residential rate, which provides no incentive to shift electricity use out of the peak period on non-event days. Under a time-of-use rate like SMUD's SmartSacramento® Pricing Pilot TOU rate (Table 19), customers have the opportunity to use precooling and peak offset to save money every weekday, not just on event days.

TABLE 19. STANDARD RESIDENTIAL RATE AND THE SPO TOU RATE

Period	Schedule	Tier	Standard Summer Rate ($/kWh)	SmartSacramento Summer TOU Rate ($/kWh)	% of Time
On-peak	4:00 - 7:00 p.m. Non-holiday weekdays	Base Plus	$ 0.1859	$0.2700	9%
		Base	$ 0.1045		
Off-peak	All other hours	Base Plus	$ 0.1859	$ 0.1660	91%
		Base	$ 0.1045	$ 0.0846	

A program that supplied customers with a thermostat that could be easily programmed to avoid peak prices every weekday could have significant impacts, not only on hourly loads, but also on bills. Results would depend on the weather, the precooling strategy, and the insulation level of the home.

Figure 20 shows the average monthly bill impacts for customers who practice the P0, P2 or P6 air-conditioning control strategy every weekday on the Standard rate (left) and on the TOU rate (right). These charts imply that customers on the Standard rate save money only if they shed load during peak without precooling, regardless of their insulation level. In contrast, customers on the TOU rate save more than 5% on their monthly bills in all cases except the P2 case. With a ceiling insulation level of R40, bill savings are roughly the same for peak load shed under P0 or P6 – meaning precooling is worth it to the customer if they find that it improves their comfort during the peak.

FIGURE 20. AVERAGE MONTHLY BILL IMPACTS - PRECOOLING PLUS PEAK LOAD SHED EVERY WEEKDAY

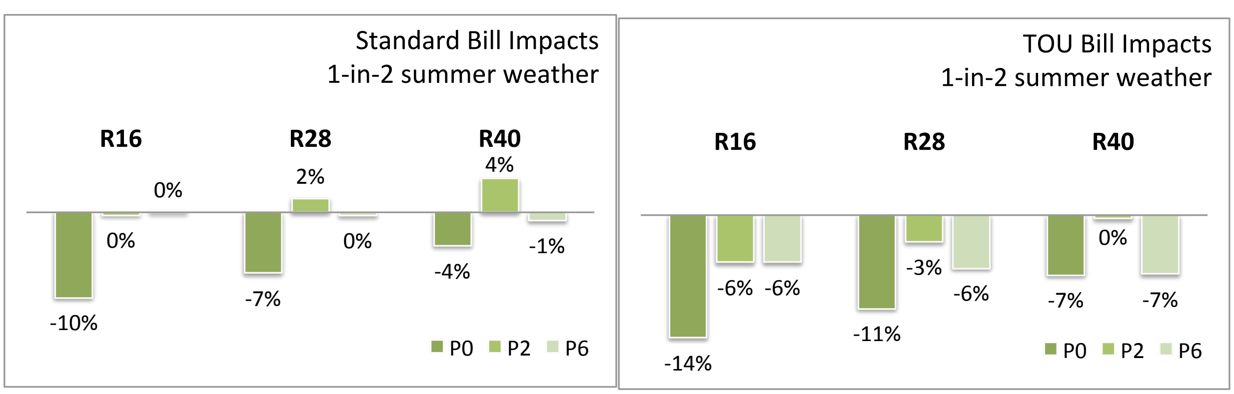
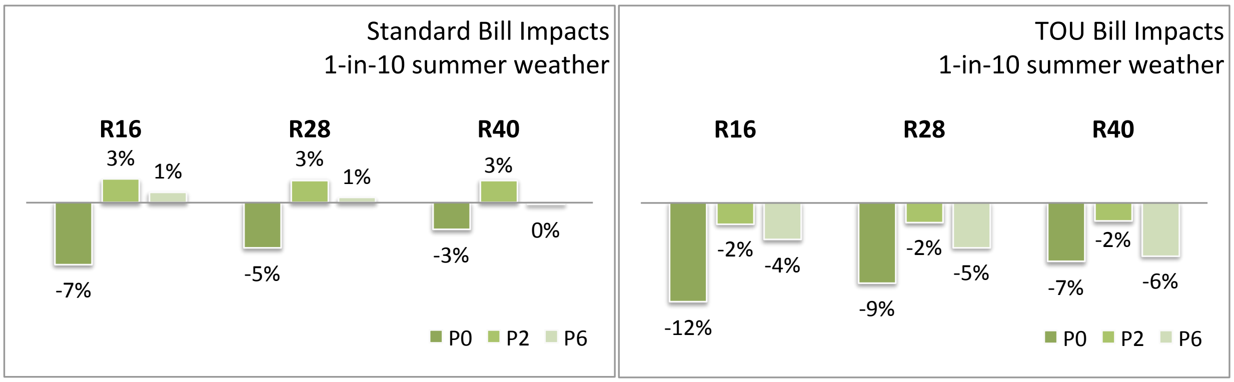


Figure 21 also shows average monthly bill impacts for the Standard and TOU rates under different precooling and insulation scenarios, but this time, for a very hot summer – one that happens only once in 10 years. While results do not change substantially, impacts are generally reduced compared to the average 1-in-2 temperature scenario.

FIGURE 21. AVERAGE MONTHLY BILL IMPACTS - PRECOOLING PLUS PEAK LOAD SHED EVERY WEEKDAY



COMFORT

Surveys collected just after each event – including a “benchmark” event where no temperature changes were initiated – asked participants about their comfort during the precooling and peak time periods by asking:

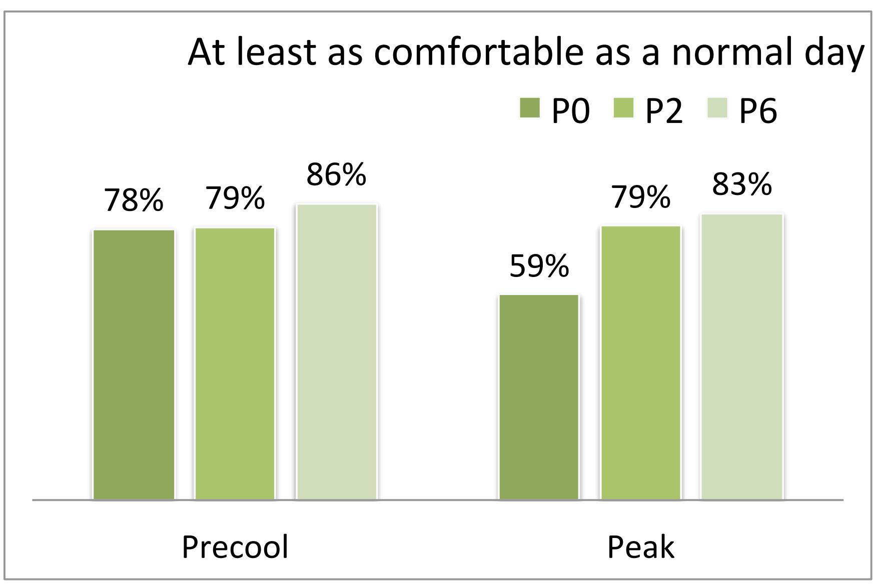
1. How would you rate the temperature in your home on [event day] between 2PM and 4PM?
2. How would you rate the temperature in your home on [event day] between 4PM and 7PM?

Participants were directed to choose from the following possibilities:

- Much too cold
- A bit too cold
- About right/comfortable
- A bit too hot
- Much too hot

Figure 22 summarizes the comparison between the survey responses from the benchmark event and the actual events. Overall, PowerStat participants under the P6 precooling strategy were most likely to say that they were as or more comfortable than they were on the benchmark event day. Statistical analysis showed that participant comfort under the P6 precooling strategy was statistically similar to a normal non-event day, while comfort under the P2 and P0 precooling strategies were significantly worse. The P6 precooling strategy was also the least likely to elicit negative comments from other household occupants (TrueNorth 2013).

FIGURE 22. MORE PARTICIPANTS SAID THEY WERE COMFORTABLE ON P6 EVENT DAYS



Source: TrueNorth 2013

SATISFACTION

Of the 152 participants who were included in this load impact analysis and responded to the post-pilot survey, 94% indicated they were somewhat or very satisfied with their PowerStat program experience, and 85% said they would recommend the PowerStat program to a friend. About 30% of respondents said they would definitely sign up for PowerStat again next summer, and about 40% said they would probably sign up again next summer.

Conclusions and Recommendations

SMUD's Residential Direct Load Control Precooling study tested three different AC precooling and load shed strategies in the summer of 2012. Hourly loads and survey results from 152 residential customers were analyzed to determine the effects of precooling on peak load shed and customer comfort.

The peak load shed consisted of a 3 °F setpoint increase from 4:00 to 7:00 p.m. Prior to this peak period, one of the following three precooling strategies was initiated:

- P0: no precooling
- P2: a 2-hour, 4-degree precool
- P6: a 6-hour, 2-degree precool

These precooling strategies were rotated among the three groups of participants in an attempt to limit pre-treatment load bias.

The evaluation considered hourly load impacts, overall energy use, bill impact, and participant comfort. Based on eight events during August and September, a regression model and corresponding spreadsheet-based simulation tool were developed for the two pre-cooling strategies and the no precooling baseline.

Load impact results for the event days were promising, with the 1-in-2 Peak day regression model showing average load reductions of over 1 kW per participant for all three precooling strategies. Interactions between precooling treatment, outdoor air temperatures, and ceiling insulation levels significantly affected hourly loads. On average, P0 and P2 had statistically similar peak impacts of -1.0 kW and -1.1 kW, respectively, while P6 showed a peak impact of -1.3 kW. The difference between this and the other two treatments was statistically significant.

In general, higher temperatures elicited larger peak load shed, while higher insulations levels reduced energy use, peak loads, and customer bills. Higher insulation levels also extended the time that the AC unit stayed off during the peak, and reduced the rebound effect directly following the peak. Despite these promising results, precooling is not for everyone. Those with the lower insulation levels (R16) increased overall energy use as a result of precooling under the P2 and P6 precooling strategies, and had higher energy bills than they would have had if they had not precooled (P0).

Based on these results, participants who initiated a 3°F peak offset every weekday during a 1-in-2 weather summer would save between 7% and 14% on their monthly electricity bills under a TOU rate. Participants who initiated P6 precooling in addition to the 3°F peak offset would save between 6% and 7% on their monthly electricity bills under a TOU rate.

The main findings of this study are as follows.

1. **Hourly load impacts**
   a. Precooling significantly increased loads prior to the event period. In the 2 hours before the event, P2 increased average participant loads by 1.5 kW (+73%), and P6 increased average loads by 0.39 kW (+19%).
   b. Load shed – averaging 1.0 kW for P0 (-35%), 1.1 kW for P2 (-37%), and 1.3 kW for P6 (-43%) – was statistically significant in all 3 event-hours for all 3 treatments. P6 precooling, higher insulation levels, and higher temperatures increased this effect. At lower temperatures, load shed following P6 was significantly deeper than the load sheds following P2 or P0. At higher temperatures, precooling did not affect peak load shed.
   c. Post-peak rebound – averaging 0.30 (+15%) for P0 and 0.26 kW (+12%) for the precooling treatments – was statistically significant in the five hours after the event ended for all treatments. Precooling, higher insulation levels, and lower temperatures reduced this effect.

2. **Energy, comfort and bill impacts**
   a. On average, P0 reduced energy use while P2 and P6 increased energy use; however, P6 precooling reduced overall energy use for participants with higher levels of ceiling insulation (at least R38).
   b. Participants were most comfortable under the P6 precooling strategy. Compared to a benchmark day with no precooling or offset, the P6 comfort levels were statistically similar, whereas comfort ratings for P0 and P2 precooling strategies were significantly worse than the benchmark ratings.
   c. The eight events did not significantly affect monthly energy use or bills for PowerStat participants, who were all on SMUD's standard residential rate.
   d. Under SMUD's SmartSacramento® Pricing Pilot TOU rate, customers with higher insulation levels could precool <u>every weekday</u> to achieve energy and bill savings without discomfort.

Based on the findings of this study, we recommend the following for future demand response programs at SMUD:

1. **A Demand Response program** combined with the following features:
    a. Increased ceiling insulation to at least R38
    b. A thermostat that facilitates precooling and peak offset, to avoid occasional demand response events. For event response, the thermostat *must be* a communicating thermostat.
    c. Participants with at least R38 insulation should be encouraged to program their thermostat to precool 2 degrees, 6 hours prior to events.

2. A **TOU rate** similar to SMUD's SmartSacramento® Pricing Pilot TOU rate, combined with the following features:
    a. Increased ceiling insulation to at least R38
    b. A thermostat that facilitates precooling and peak offset every weekday, to avoid the daily peak TOU rate. For daily peak reduction, the thermostat *need not be* a communicating thermostat.
    c. Participants with at least R38 insulation should be encouraged to program their thermostat to precool 2 degrees, 6 hours prior to the peak period every weekday.

3. A **TOU-CPP rate** similar to SMUD's SmartSacramento® Pricing Pilot Combined Time of Use and Critical Peak Rate, with the following features:
    a. Increased ceiling insulation to at least R38
    b. A thermostat that facilitates precooling and peak offset every weekday, and also responds to occasional demand response events. For event response, the thermostat *must be* a communicating thermostat.
    c. Participants with at least R38 insulation should be encouraged to program their thermostat to precool 2 degrees, 6 hours prior to the peak period every weekday.

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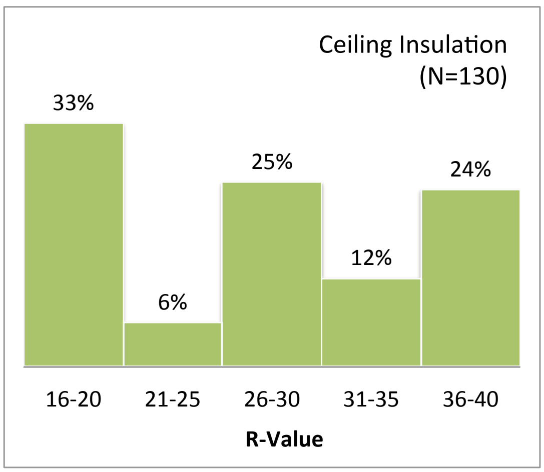
Appendices

Appendix A. Household information

R-value

Where possible, ceiling insulation levels for participant homes was documented at the time of thermostat installation. The 130 values collected ranged from R16 to R40, with a mean and median value of R28. Figure 5 shows the distribution of ceiling R-values for these 130 participants.

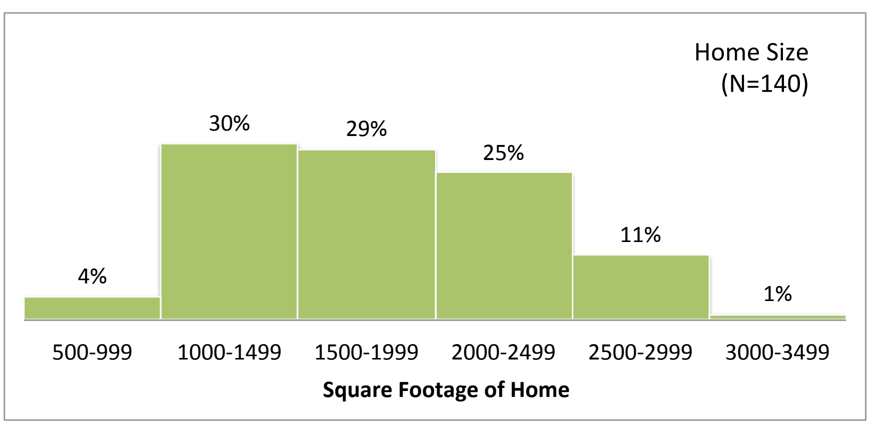
Figure 23. Distribution of Ceiling R-values



Square footage

The square footage of participant homes was requested in the pre-treatment survey. The 140 responses ranged from 825 to 3076, with a mean of 1753 and median value of 1667 ft^2. Figure 24 shows the distribution of home square footage for these 140 participants.

Figure 24. Distribution of square footage of houses



OCCUPANCY

The number of people in the home was requested in the pre-treatment survey. The 148 responses ranged from 1 to 5, with a mean of 2.3 and median value of 2. Figure 25 shows the distribution of home square footage for these 148 participants.

FIGURE 25.DISTRIBUTION OF NUMBER OF PEOPLE IN THE HOUSEHOLD

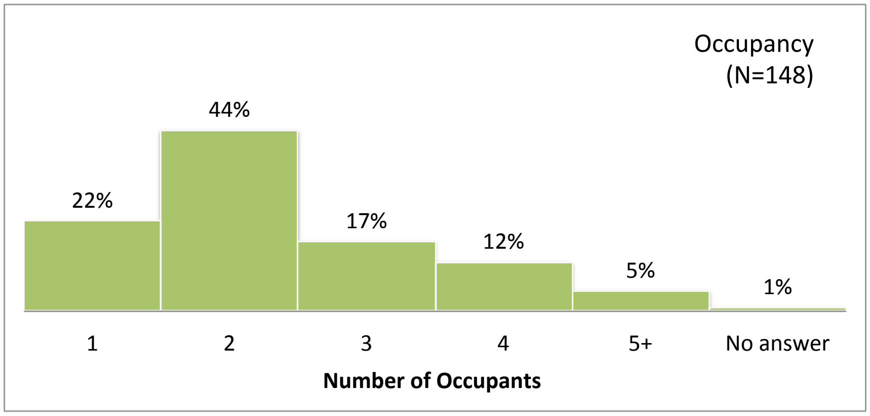


Table 7 provides summary for Q24-Q26 pre-treatment survey responses. Only 116 participants responded to question 24

TABLE 20. OCCUPANCY BY AGE, TIME OF DAY

	Question	Yes	No	Other
Q24	Is anyone in your home less than two years old?	4%	73%	24%
Q25	Is anyone in your home over the age of 65?	26%	72%	1%
Q26	During the typical summer weekday, is there at least one person in your home for at least one hour between 10AM and 4PM?	79%	18%	3%

APPENDIX B. OBSERVED LOADS (NOT MODELED)

BY ROTATION GROUP

Figure 26 and Figure 27 show that the average load shapes for the three rotation groups on non-event weekdays were similar, but not identical.

FIGURE 26.EVENT DAY ACTUAL LOADS, BY GROUP

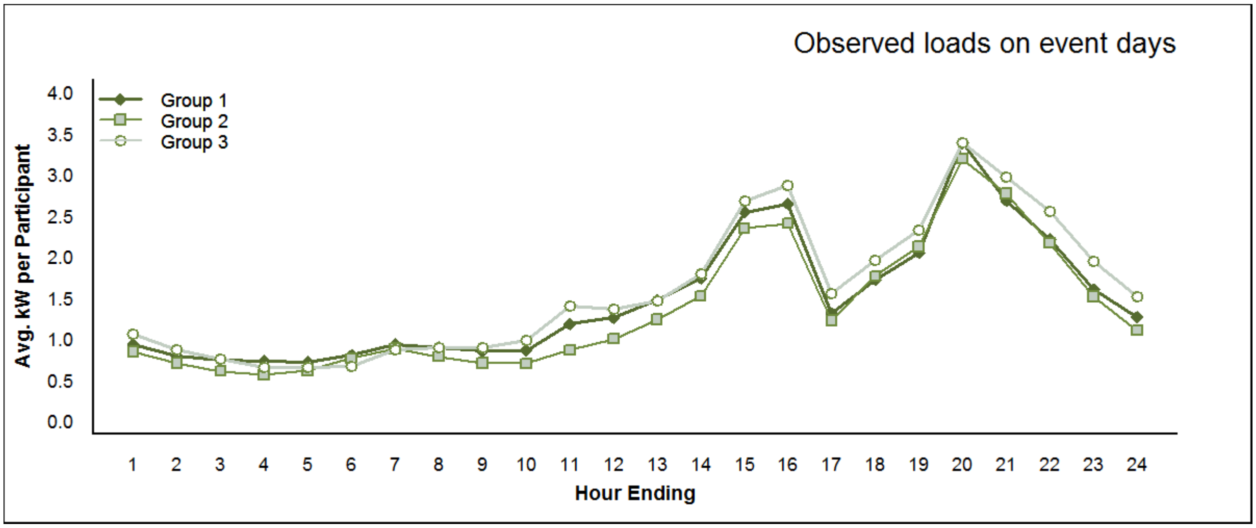
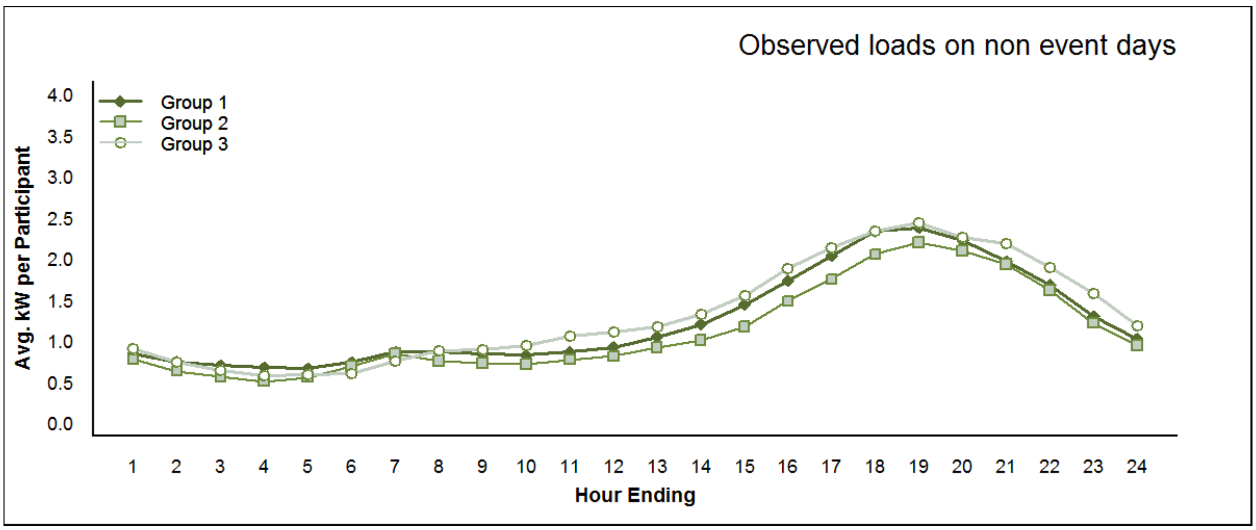


FIGURE 27.NONEVENT DAY ACTUAL LOADS, BY GROUP



Individual Event Day Loads

The following figures (Figure 28 through Figure 35) are plots of the observed hourly load values for each individual event day (8/9/12 through 9/14/12). For comparison, each plot also includes a modeled baseline, adjusted for the temperature profile of that particular day.

Figure 28. Observed loads on 8/9/12

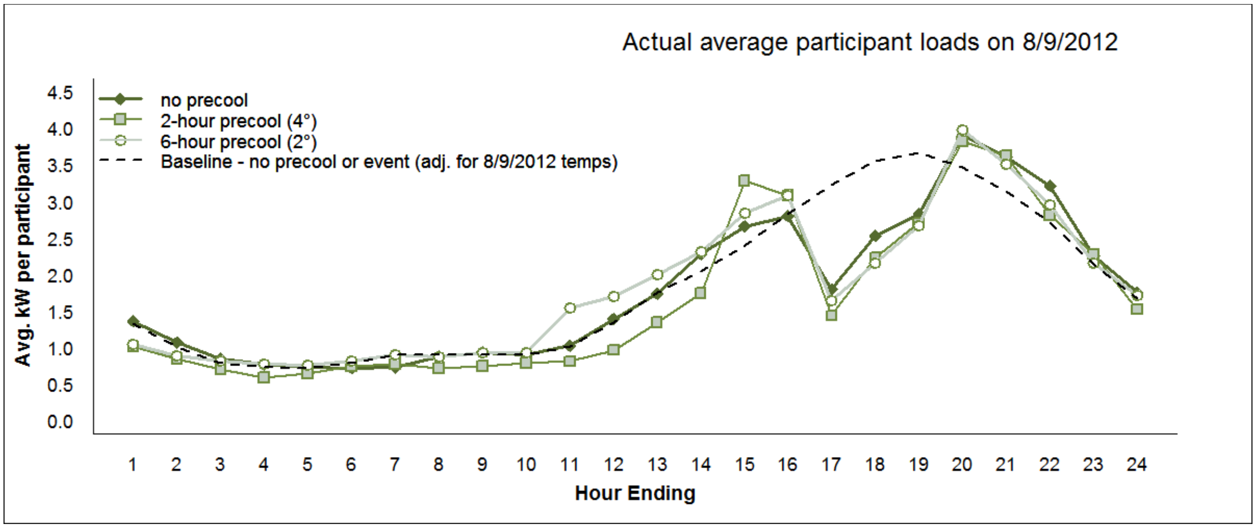


Figure 29. Observed loads on 8/13/12

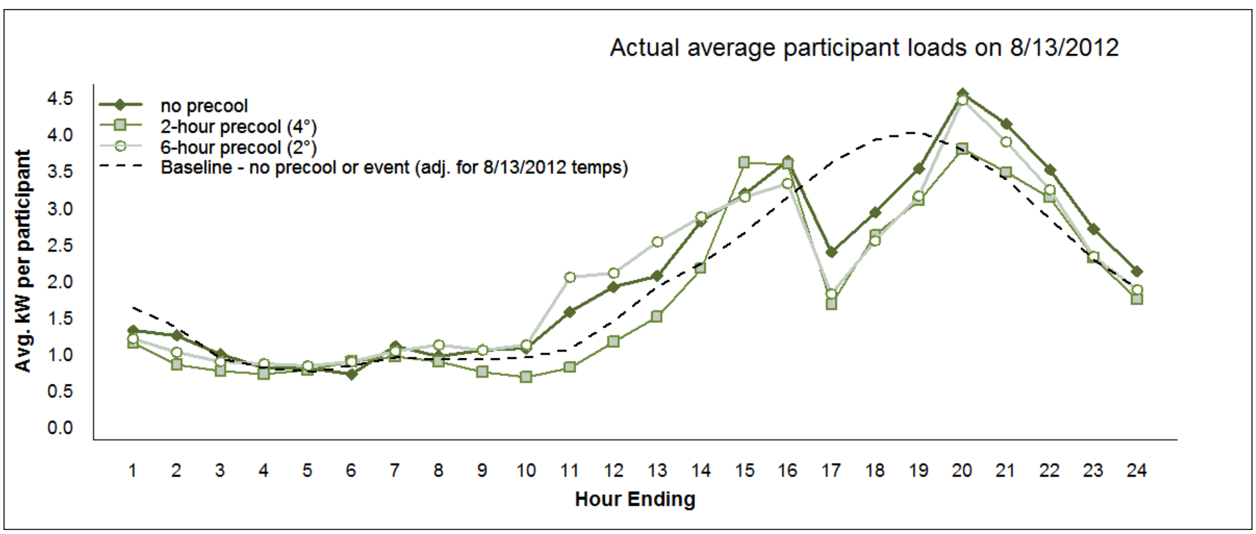


FIGURE 30. OBSERVED LOADS ON 8/15/12

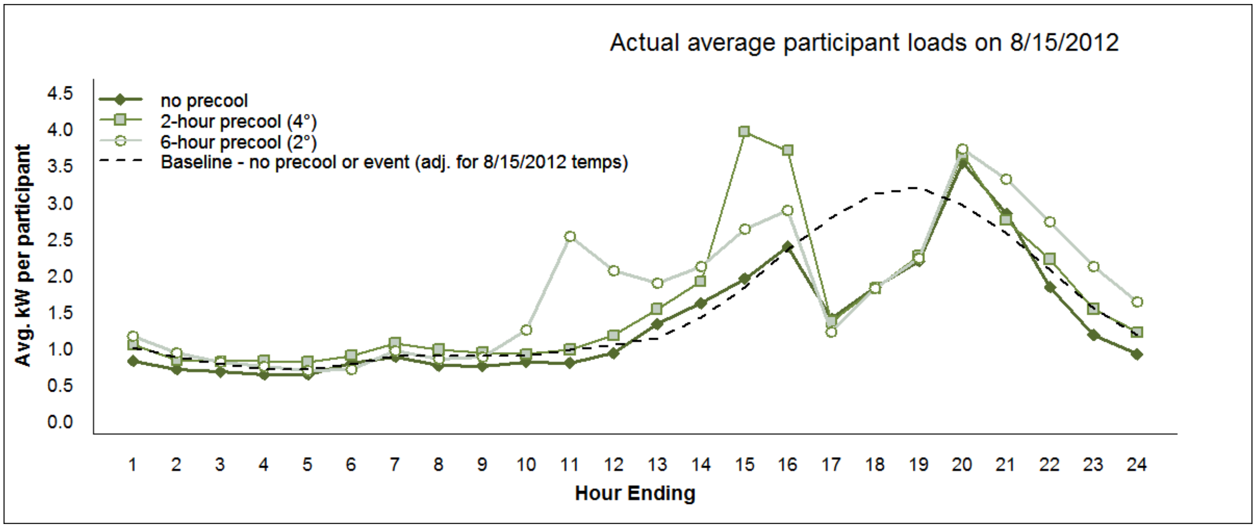


FIGURE 31. OBSERVED LOADS ON 8/17/12

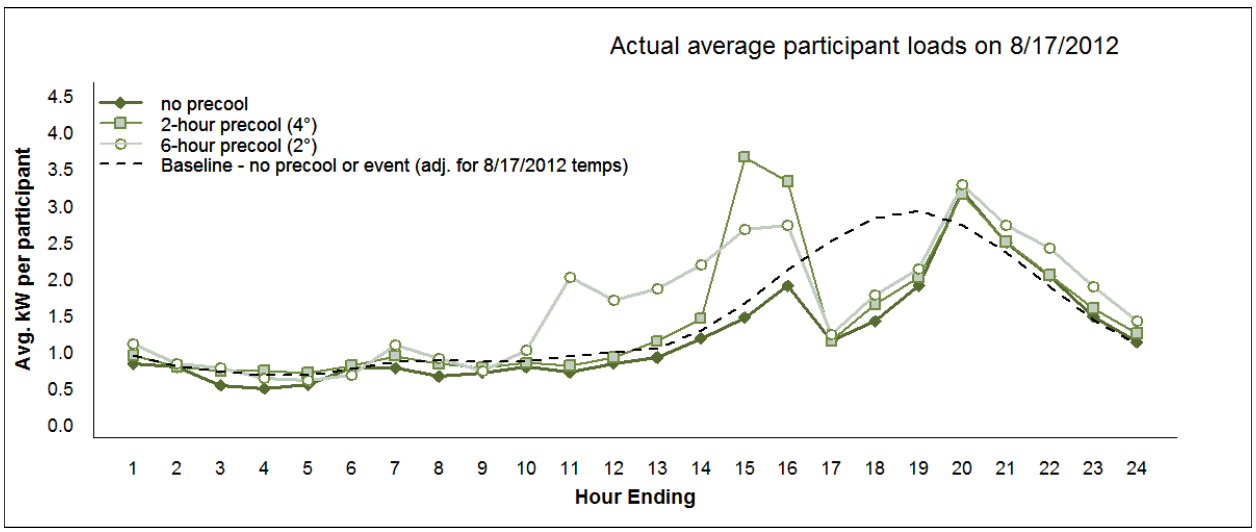


FIGURE 32. OBSERVED LOADS ON 8/23/12

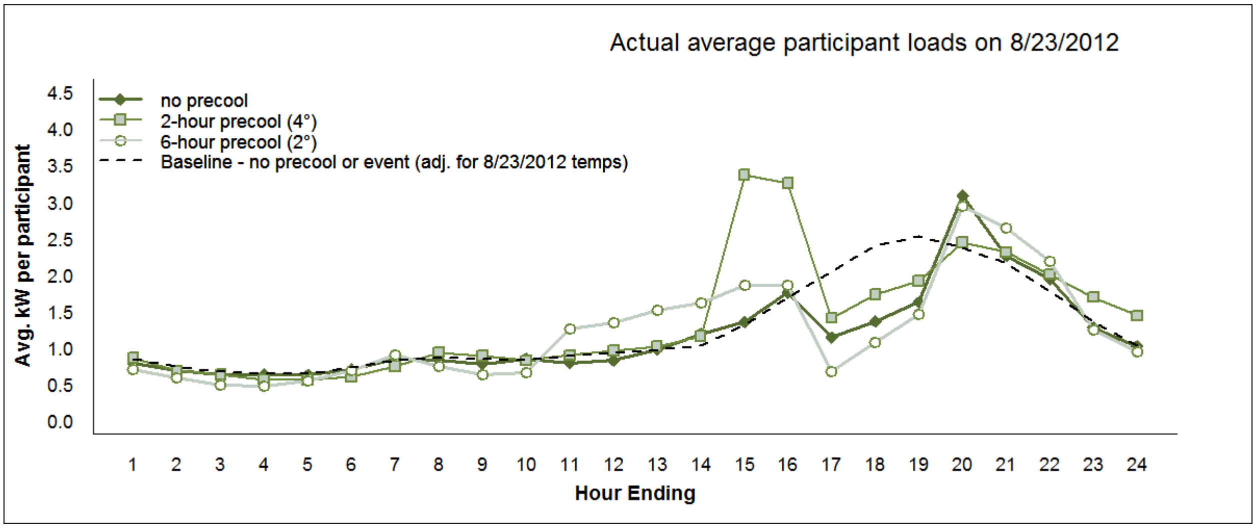


FIGURE 33. OBSERVED LOADS ON 9/4/12

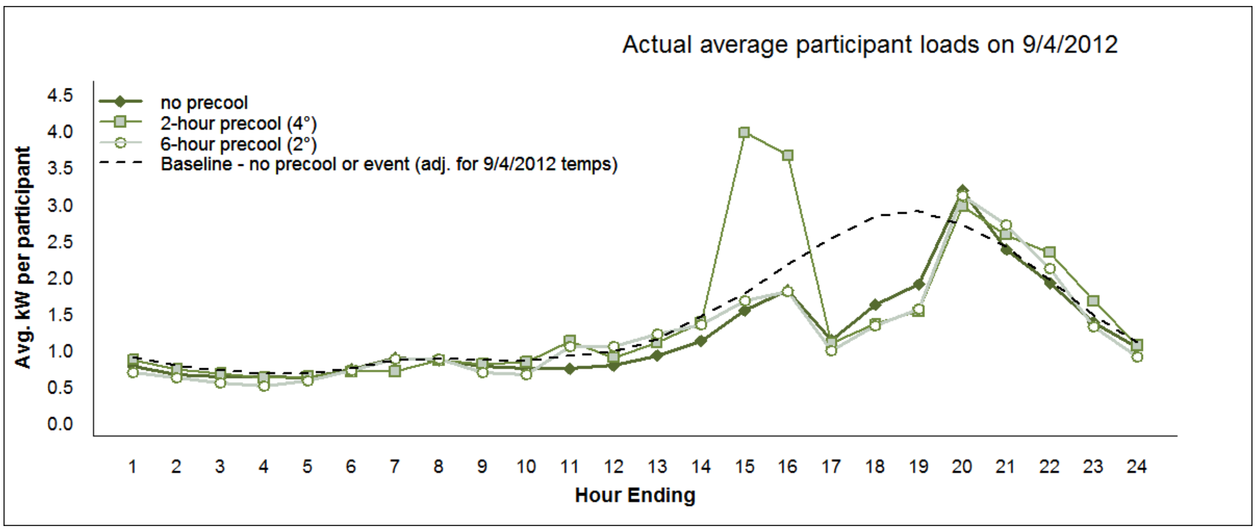


FIGURE 34. OBSERVED LOADS ON 9/12/12

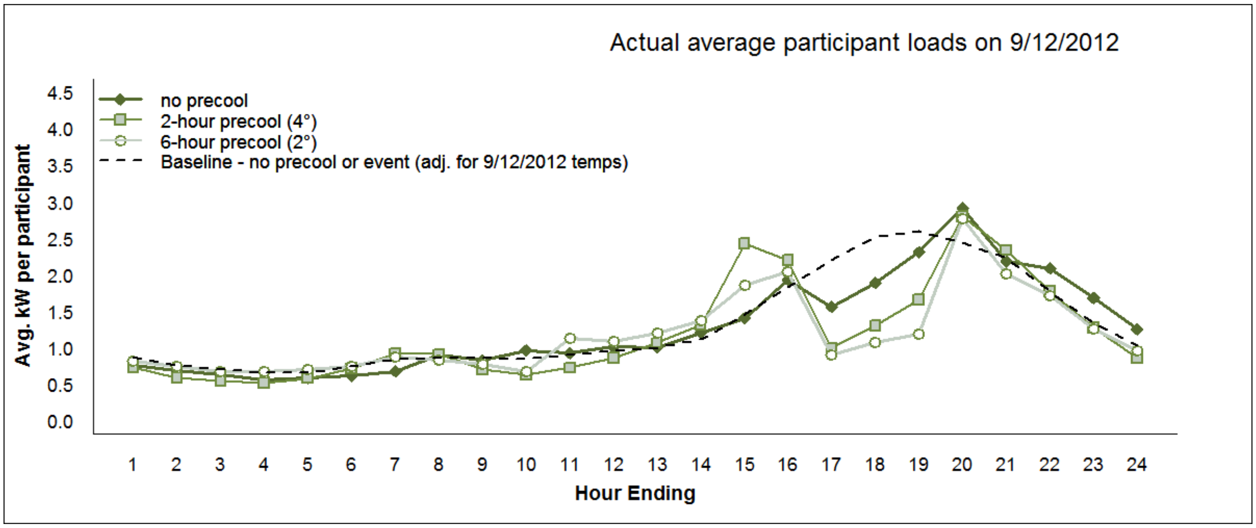
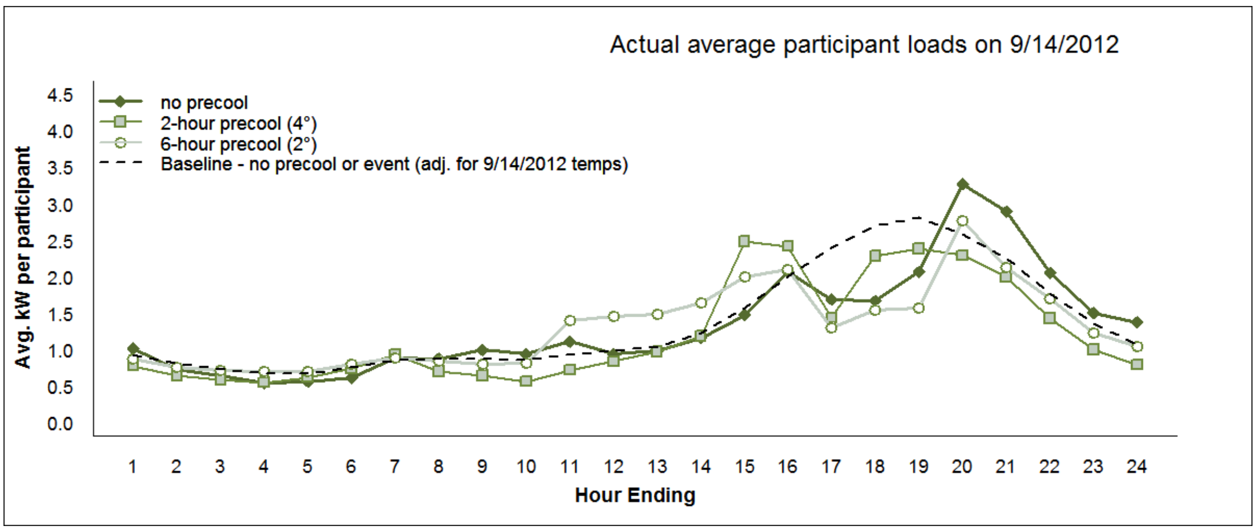


FIGURE 35. OBSERVED LOADS ON 9/14/12



Appendix C. Load Impact Regression Analysis Detail

Based on AIC and BIC criteria and a log likelihood ratio test, it was determined that inclusion of random effects for both customers and days produced a better model for the data than did a model with random effect for customers only. Table 21 provides detailed information about the comparison of the two models. Note the p-value of < 0.0001, which is an indication of significant improvement in the model when both random effects are included. Table 22 contains results for type III test for fixed effects, and Table 23 provides details for average daily and peak impacts on event days.

Table 21. Model comparison

Model	Random effects	DF	AIC	BIC	logLik	Test	L.Ratio	p-value
1	Customer	387	581541	585523	-290384			
2	Customer, Days	388	568187	572180	-283706	1 vs 2	13356	<0.0001

Table 22. Type III test of fixed effects

Variable	Numerator DF	Denominator DF	F-value	p-value
CDH	1	208586	7638.19	<0.0001
AvgTemp24	1	8957	23.74	<0.0001
Rvalue	1	114	0.00	0.99
hour	24	208586	8.72	<0.0001
treat	3	8957	0.32	0.81
AvgTemp24:Rvalue	1	8957	0.61	0.44
AvgTemp24:hour	23	208586	12.13	<0.0001
Rvalue:hour	23	208586	1.50	0.06
AvgTemp24:treat	3	8957	0.37	0.77
Rvalue:treat	3	8957	0.08	0.97
hour:treat	69	208586	0.97	0.55
AvgTemp24:Rvalue:hour	23	208586	1.73	0.02
AvgTemp24:Rvalue:treat	3	8957	0.09	0.96
AvgTemp24:hour:treat	69	208586	0.98	0.52
Rvalue:hour:treat	69	208586	1.34	0.03
AvgTemp24:Rvalue:hour:treat	69	208586	1.34	0.03

Table 23. Daily and peak impacts, by treatment

Period	Treatment	Impact	SE	Lower	Upper	testStat	df	Pvalue
Daily	P0	-0.073	0.023	-0.12	-0.028	-3.18	217652	0.0092
	P2	0.052	0.022	-0.009	0.095	2.37	217652	0.1046
	P6	0.016	0.019	0.002	0.054	0.83	217652	0.4091
Peak	P0	-1.03	0.038	-1.11	-0.96	-27.36	217652	<0.0001
	P2	-1.08	0.036	-1.16	-1.01	-29.99	217652	<0.0001
	P6	-1.26	0.032	-1.32	-1.20	-39.25	217652	<0.0001

APPENDIX D. 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

FIGURE 36. P0 LOADS FOR 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

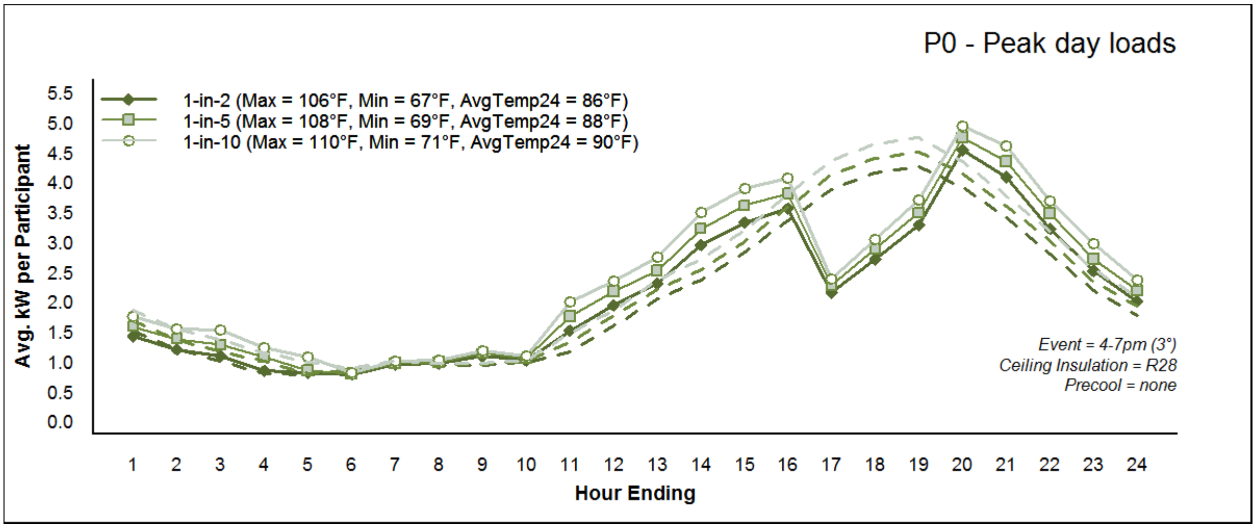


TABLE 24. P0 IMPACTS ON 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

Peak Day Type	AvgTemp24 (°F)	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
1-in-2	86	0.12	0.35*	-1.38*	0.46*	0.02
1-in-5	88	0.16	0.42*	-1.46*	0.49*	0.04
1-in-10	90	0.19	0.48*	-1.54*	0.53*	0.07

* Statistically significant (α = 0.05)

FIGURE 37. P2 LOADS FOR 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

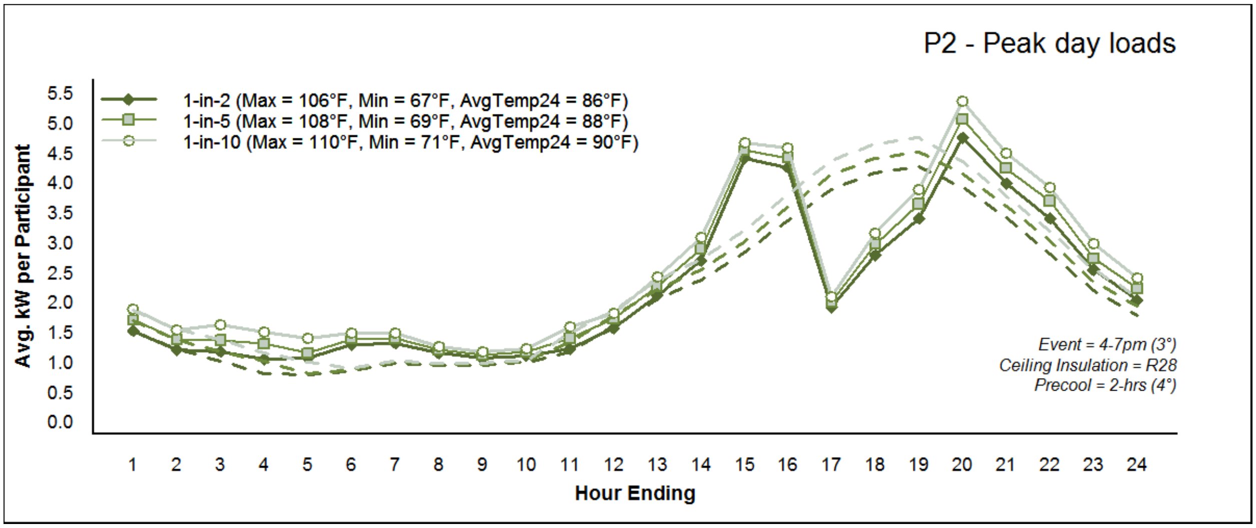


TABLE 25. P2 IMPACTS ON 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

Peak Day Type	AvgTemp24 (°F)	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
1-in-2	86	0.16	1.23*	-1.40*	0.52*	0.13
1-in-5	88	0.19	1.17*	-1.48*	0.58*	0.15
1-in-10	90	0.23	1.12*	-1.55*	0.64*	0.16

* Statistically significant (α = 0.05)

FIGURE 38. P6 LOADS ON 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

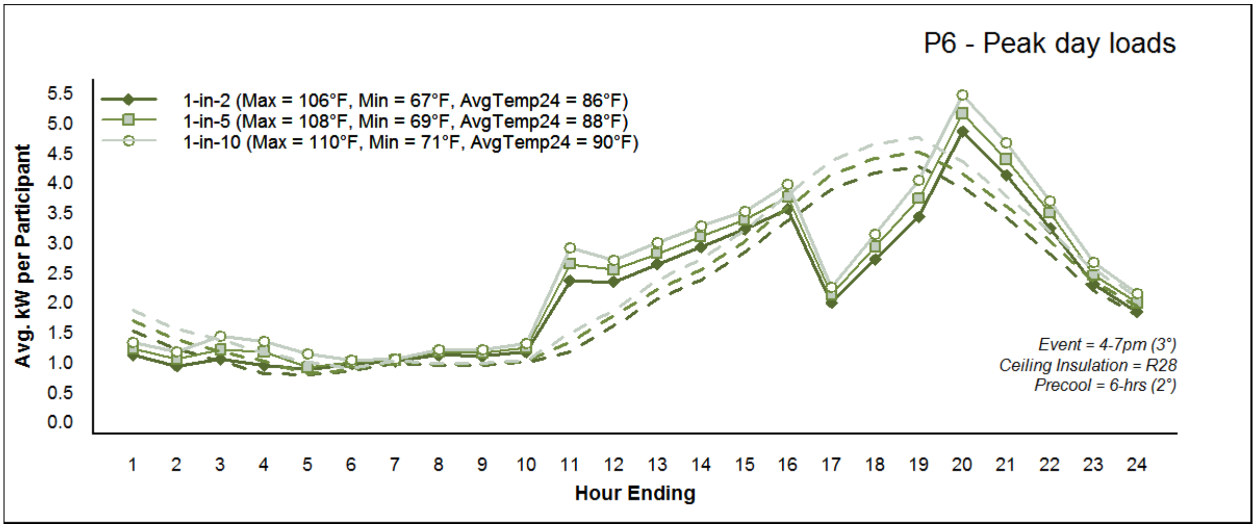


TABLE 26. P6 IMPACTS ON 1-IN-2, 1-IN-5, AND 1-IN-10 PEAK DAYS

Peak Day Type	AvgTemp24 (°F)	Off-Peak (hours 1-14)	Pre-Peak (hours 15-16)	Peak (hours 17-19)	Post-Peak (hours 20-24)	Total (hours 1-24)
1-in-2	86	0.23*	0.29*	-1.39*	0.45*	0.08
1-in-5	88	0.25*	0.26*	-1.42*	0.49*	0.09
1-in-10	90	0.27*	0.24	-1.45*	0.53*	0.11

* Statistically significant (α = 0.05)

Appendix E. Survey responses

Table 27. Survey response rates, by survey

	Invites sent	Completed surveys	Response rate (%)
Pre	152	129	85%
Post	152	119	78%
Wave 1	152	135	89 %
Wave 2	152	117	77 %
Wave 3	152	118	78 %
Wave 4	152	96	63 %

Table 28. In your own words, what would you say was the main reason you signed up to participate in the Powerstat pilot program?

	Pre 1	Percent
1	Save, conserve energy	36%
2	Save money	22%
3	Free upgraded thermostat	21%
4	Opportunity to learn new	8%
5	Help SMUD	5%
6	NA	4%
7	Control thermostat remotely	2%
8	Help protect environment	1%
9	Other	1%

Table 29. By participating in this program, do you expect to _____?

	Pre2A-2F	Yes, Definitely	Yes, Probably	No, Probably Not	No, Definitely Not	Not Sure	Prefer not to Answer	NA
1	Save money	43%	39%	12%	0.0%	5.4%	0%	0%
2	Help protect the environment	32%	43%	12%	0.8%	12%	0%	0%
3	Learn how to better conserve electricity	48%	45%	3.9%	0.0%	3.1%	0%	0%
4	Actually use less electricity	41%	43%	7.0%	0.0%	8.5%	0%	0%
5	Have more control over your electricity bill	45%	44%	3.9%	0.8%	6.2%	0%	0%
6	Keep your home at a comfortable temperature	43%	49%	3.9%	0.0%	4.7%	0%	0%

Table 30. In your opinion, how much has participating in the PowerStat® pilot program __________?

	Post4A-4F	A lot	Some	A little	None	Not Sure	Prefer not to Answer	NA
1	Helped you save money on your electric bill	10%	24%	18%	22%	27%	0%	0%
2	Helped you protect the environment	13%	30%	14%	13%	29%	0%	0%
3	Improved your knowledge about ways you can reduce your household's electricity use	24%	29%	24%	16%	7.6%	0%	0%
4	Reduced the amount of electricity your household uses	11%	30%	19%	21%	19%	0%	0%
5	Given you more control over your electricity bill	23%	27%	16%	16%	18%	0%	0%
6	Motivated you to change your electricity use habits	22%	29%	21%	24%	4.2%	0%	0%

Table 31. In general, how would you rate your overall experience participating in the PowerStat® pilot program?

	Int14 Post1	Very satisfied	Somewhat satisfied	Somewhat dissatisfied	Very dissatisfied	Not sure	Prefer not to answer	NA
1	P0	64%	31%	3.6%	0%	2.1%	0%	0%
2	P2	58%	32%	3.6%	0%	6.4%	0%	0%
3	P6	59%	34%	3.8%	1.1%	2.7%	0%	0%
4	Post-Treat	69%	25%	3.4%	0.8%	1.7%	0%	0%

Table 32. If a friend asked you about the PowerStat® pilot program, would you recommend that they participate?

Post6	Yes	Not sure	No	Prefer not to answer	NA
1	85%	12%	3.4%	0%	0%

Table 33. Thinking ahead to next summer (2013), would you sign up again to allow SMUD to occasionally adjust your thermostat settings to reduce your household's peak-period electricity use?

Post7	Definitely yes	Not sure	Probably yes	Probably no	Definitely no	NA
1	31%	13%	39%	16%	0.8%	0%

TABLE 34. PLEASE INDICATE THE EXTENT TO WHICH YOU AGREE OR DISAGREE WITH THE FOLLOWING STATEMENTS ABOUT THE INSTALLATION PROCESS.

	Pre4A-4I	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	Not sure	Doesn't Apply	NA
1	I was able to select an installation appointment time that worked best for my schedule	74%	17%	1.6%	0.8%	0%	0.8%	6.2%
2	The technician arrived on-time for the appointment	84%	8.5%	0%	0%	0%	0.8%	6.2%
3	The technician explained the installation process prior to starting the work	85%	7.0%	0%	0%	1.6%	0%	6.2%
4	The length of time it took to install the device was reasonable	90%	3.9%	0%	0%	0%	0%	6.2%
5	The work site was left clean after the installation was complete	93%	0.8%	0%	0%	0%	0%	6.2%
6	There was no damage to my property during the installation process	92%	1%	0%	0%	0%	1%	6%
7	The technician explained to me the basics of how to use the thermostat	90%	4%	0%	0%	0%	0%	6%
8	The technician explained how to log-on to the PowerStat website	65%	18%	4%	1%	6%	0%	6%
9	I was provided a clear explanation of what I was expected to do during the program	60%	28%	4%	0%	1%	1%	6%

TABLE 35. OVERALL, WERE YOU SATISFIED OR DISSATISFIED WITH THE INSTALLATION PROCESS FOR YOUR NEW THERMOSTAT?

Pre5	Very satisfied	Somewhat satisfied	Somewhat dissatisfied	Very dissatisfied	Not sure	Prefer not to answer	NA
1	89%	4.7%	0%	0%	0%	0%	6.2%

TABLE 36. OVERALL, HOW WOULD YOU RATE YOUR SATISFACTION WITH THE NEW THERMOSTAT?

		Very satisfied	Somewhat satisfied	Somewhat dissatisfied	Very dissatisfied	Not sure	Prefer not to answer	NA
1	Pre7	74%	22%	0.8%	0%	3.9%	0%	0%
2	Post8	78%	19%	2.5%	0%	0.8%	0%	0%

Table 37. Please rate the new thermostat on the following attributes.

	Pre9A-9H	Excellent	Good	Fair	Poor	Very Poor	Not sure/ Doesn't Apply	NA
1	Easy of use	52%	39%	3.9%	0.8%	0%	5.4%	0%
2	Clarity of thermostat operation manual	39%	43%	6.2%	0%	0%	12.4%	0%
3	Readability of display	72%	23%	3.1%	1.6%	0.8%	0%	0%
4	Availability of technical support	15%	25%	1.6%	0%	0%	59%	0%
5	Appearance	71%	26%	1.6%	0%	0%	0.8%	0%
6	Keeping my home at a comfortable temperature	58%	35%	2.3%	0%	0%	4.7%	0%
7	Ability to program the thermostat using the PowerStat website	20%	19%	1.6%	3.1%	0%	56.6%	0%
8	Overall Performance	53%	40%	2.3%	0%	0%	4.7%	0%
	Post10A-10H							
1	Easy of use	56%	39%	5.0%	0%	0%	0%	0%
2	Clarity of thermostat operation manual	38%	46%	7.6%	0%	0%	8.4%	0%
3	Readability of display	63%	32%	3.4%	0%	0.8%	0.8%	0%
4	Availability of technical support	15%	23%	2.5%	0%	0%	60%	0%
5	Appearance	64%	34%	1.7%	0%	0%	0%	0%
6	Keeping my home at a comfortable temperature	45%	50%	4.2%	0%	0%	0.8%	0%
7	Ability to program the thermostat using the PowerStat website	18%	27%	10%	3%	0%	42%	0%
8	Overall Performance	53%	44%	3%	0%	0%	0%	0%

Table 38. Since enrolling in the PowerStat program and receiving your new thermostat, how easy or difficult has it been to keep your home at a comfortable temperature?

	Very easy	Somewhat easy	Somewhat difficult	Very difficult	Not sure	Prefer not to answer	NA
Pre10	68%	24%	0%	0%	7.8%	0%	0%
Post12	64%	35%	0.8%	0%	0%	0%	0%

Table 39. When compared to your prior thermostat, would you say that the new thermostat you received through the PowerStat Pilot performs better, worse or about the same overall?

	Much better	Somewhat better	About the same	Somewhat worse	Much worse	Not sure	Prefer not to answer	NA
Pre15	49%	25%	22%	0.8%	0%	3.1%	0%	0%
Post11	52%	26%	22%	0%	0%	0%	0%	0%

TABLE 40. PRIOR TO RECEIVING YOUR NEW THERMOSTAT, HOW EASY OR DIFFICULT WAS IT TO KEEP YOUR HOME AT A COMFORTABLE TEMPERATURE WHEN THE TEMPERATURE OUTSIDE WAS 100 DEGREES OR HOTTER?

	Very easy	Some-what easy	Some-what difficult	Very difficult	Not sure	Prefer not to answer	NA
Pre16	26%	47%	21%	3.1%	3.1%	0%	0%

TABLE 41. PLEASE INDICATE THE EXTENT TO WHICH YOU AGREE OR DISAGREE WITH THE FOLLOWING STATEMENTS ABOUT YOUR EXPERIENCE PARTICIPATING IN THE POWERSTAT® PILOT PROGRAM.

	Post21	Strongly Agree	Some-what Agree	Some-what Disagree	Strongly Disagree	Not sure	Doesn't Apply	NA
1	SMUD clearly explained the goals of the program	60%	34%	5.0%	0%	0.8%	0.8%	0%
2	SMUD clearly explained what I was expected to do during the program	70%	25%	4.2%	0%	0%	0.8%	0%
3	I was satisfied with how SMUD answered my questions	54%	24%	1.7%	0%	2.5%	17%	1.7%
4	The information SMUD made available was informative and helpful	64%	30%	0.8%	0%	2.5%	1.7%	0.8%

TABLE 42. GENERALLY SPEAKING, ARE YOU SATISFIED OR DISSATISFIED WITH THE JOB SMUD IS DOING TO PROVIDE ELECTRICITY SERVICES TO YOUR HOUSEHOLD?

		Very satisfied	Some-what satisfied	Some-what dissatisfied	Very dissatisfied	Not sure	Prefer not to answer	NA
1	Pre19	78%	21%	0.8%	0%	0.8%	0%	0%
2	Post26	71%	28%	0.8%	0%	0%	0%	0%

TABLE 43. WOULD YOU SAY THAT YOUR PARTICIPATION IN THE POWERSTAT PILOT PROGRAM HAS POSITIVELY IMPACTED YOUR OPINION OF SMUD, NEGATIVELY IMPACTED YOUR OPINION OF SMUD, OR HAS IT NOT CHANGED YOUR OPINION EITHER WAY?

		Positively impacted opinion about SMUD	Negatively impacted opinion about SMUD	No impact	Not sure	Prefer not to answer	NA
1	Pre20	74%	0%	18%	7.8%	0.8%	0%
2	Post26	78%	1.7%	18%	0.8%	0.8%	0%

Table 44. Have you visited SMUDs PowerStat website: www.SMUD.org/powerstat?

		Yes	No	Prefer not to answer	NA
1	Pre11	29%	71%	0%	0%
2	Post13	52%	48%	0%	0%

Table 45. How frequently did you visit the SMUD's PowerStat® website since you enrolled in the pilot program?

	At least two times per week	Once per week	Two to three times per month	Once per month	Less often than once per month	Not sure	Prefer not to answer	NA
Post14	0%	8.1%	27%	23%	32%	10%	0%	0%

Table 46. Have you used the PowerStat website to do the following?

	Pre12	Yes	No	Prefer not to answer	NA
1	Learn more about the PowerStat program	78%	22%	0%	0%
2	Program your thermostat	62%	38%	0%	0%
3	Review the thermostat operation manual	19%	81%	0%	0%
4	Review the frequently asked questions (FAQ's)	49%	51%	0%	0%
	Post15				
1	Learn more about the PowerStat program	69%	31%	0%	0%
2	Program your thermostat	65%	36%	0%	0%
3	Review the thermostat operation manual	24%	76%	0%	0%
4	Review the frequently asked questions (FAQ's)	58%	42%	0%	0%

Table 47. How would you rate the ability to schedule the wake, leave, return and sleep temperature settings for your thermostat on the PowerStat® website?

	Excellent	Good	Fair	Poor	Very Poor	Not sure	Prefer not to answer	NA
Post16	31%	11%	11%	0%	1.6%	6.5%	3.2%	35%

Table 48. How would you rate the ability to use the PowerStat® website to make temporary adjustments to the current temperature in your home?

	Excellent	Good	Fair	Poor	Very Poor	Not sure	Prefer not to answer	NA
Post17	23%	26%	6.5%	0%	3.2%	6.5%	0%	35%

Table 49. When you have visited the PowerStat website, were you most often doing so from home, while at work, or from a different location?

		Home	Work	Different Location	Prefer not to answer	NA
1	Pre13	81%	14%	5.4%	0%	0%
2	Post18	73%	16%	8.1%	3.2%	0%

Table 50. How would you rate the overall quality of the PowerStat website?

		Excellent	Good	Fair	Poor	Very Poor	Not sure	Prefer not to answer	NA
1	Pre14	27%	65%	5.4%	0%	0%	2.7%	0%	0%
2	Post19	24%	60%	13%	0%	0%	3.2%	0%	0%

Table 51. Did you contact SMUD and/or the installation company (GoodCents) during the past three months about any issue(s) related to the PowerStat® pilot program?

	Yes, called SMUD	Yes, called GoodCents	Yes, called SMUD and GoodCents	No	Prefer not to answer	NA
Post22	9.2%	4.2%	5.0%	80%	1.7%	0%

Table 52. Was SMUD/GoodCents able to help resolve the issue(s) to your satisfaction?

	Post24-25	Yes	No	Yes for some issues, no for others	Prefer not to answer	NA
1	SMUD	81%	13%	6.3%	0%	0%
2	GoodCents	73%	18%	9.1%	0%	0%

Table 53. During the summer, what temperature is your thermostat normally set at between noon and 4PM/ 4PM and 7PM?

	Pre17-18	Average Temperature
1	noon - 4PM	78.6
2	4PM-7PM	77.4

Appendix F. Residential Rates

Period	Schedule	Tier	Standard Summer Rate *($/kWh)*	SmartSacramento TOU Rate *($/kWh)*	SmartSacramento TOU-CPP Rate *($/kWh)*	% of Time
Event	4:00 - 7:00 p.m.	>700 kWh	$ 0.1859	$ 0.2700	$ 0.7500	1%
		<700 kWh	$ 0.1045			
On-peak	4:00 - 7:00 p.m. Non-holiday weekdays	>700 kWh	$ 0.1859		$ 0.2700	8%
		<700 kWh	$ 0.1045			
Off-peak	All other hours	>700 kWh	$ 0.1859	$ 0.1660	$ 0.1411	91%
		<700 kWh	$ 0.1045	$ 0.0846	$ 0.0721	