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2012 Load Impact Evaluation for Pacific Gas and Electric Company's SmartAC Program

CALMAC ID PGE0322

Prepared for:
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April 1, 2013

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Table of Contents

1 Executive Summary 1
1.1 Residential SmartAC Ex Post Load Impact Summary 1
1.2 Residential SmartAC Ex Ante Load Impact Summary 2
1.3 SMB SmartAC Ex Ante Load Impact Summary 3
1.4 Recommendations 4
2 Overview of SmartAC Program and Evaluation Plan 6
2.1 SmartAC Analytical Overview 8
2.2 Report Organization 9
3 Evaluation Design and Ex Post Methods 10
3.1 Residential Experimental Design and Operations 10
3.2 Residential SmartAC Ex Post Methodology 13
4 Residential Ex Post Load Impact Estimates 15
4.1 SmartAC Primary Test Event Results 15
4.2 Distribution of Impacts Across Customers 20
4.3 Customers with Two SmartAC Devices 22
5 Control Device Success Rates 26
6 Residential SmartAC Ex Ante Methodology 31
6.1 Accounting for Dually-Enrolled Customers 31
6.2 Regression Modeling 36
7 SmartAC Ex Ante Load Impact Results 44
8 Conclusions 48
Appendix A Residential Ex Ante Load Impact Tables Methodology 49
A.1 Estimating Ex Ante Load Without DR 49
A.2 Estimating Ex Ante Snapback 51
Appendix B SmartAC Side-by-side Testing Results 54
Appendix C Event Discomfort Results for Residential Customers 57
Appendix D Temperature Changes During Events 63

1 Executive Summary

This evaluation documents the ex post and ex ante load impact analysis, methodology and results for PG&E's SmartAC™ program for residential and small/medium business (SMB) customers. The SmartAC™ program currently involves the installation of load control switches in households and small/medium businesses with central air conditioning (CAC). The program formerly also offered programmable communicating thermostats (PCTs) and there are still a large number of those in operation. When a SmartAC event is called, the control devices limit the duty cycles of CAC units or adjust thermostat temperature settings, thereby reducing demand.

SmartAC events can be called under several conditions: for limited testing purposes; when the CAISO requests PG&E to operate all or part of the customers on the program when it has publicly issued a Warning notice and has determined that a Stage 1 emergency is imminent consistent with operating procedures E-508B; under emergency or near-emergency situations, when the CAISO day-ahead energy price for the PG&E Default Load Aggregation Point is $1,000/megawatt-hour or more. The program is allowed to be operated May 1 and October 31, up to 6 hours or less in each event, for a maximum of 100 hours per season. Events can be called at any time of day, but are most likely to be called at times near system peak demand, which typically occur in the late afternoon on hot summer days. No emergency events were called in 2012. Several test events were called for subsets of the population as discussed in detail throughout this report and one system-wide test event was called on August 10.

Residential customer enrollment at the end of summer 2012 was roughly 165,000 control devices on roughly 149,000 different premises and SMB customer enrollment was nearly 11,000 control devices on 5,800 premises. More than 26,000 customers with roughly 30,000 devices were dually enrolled in SmartRate and SmartAC. In previous evaluations of SmartAC, this group was a small enough fraction of the population (about 4,000 residential customers) that it could effectively be ignored in evaluating SmartAC; although the group did need to be considered separately in the evaluation of SmartRate. In 2012, the SmartRate program expanded substantially, with a major emphasis on expanding the dually-enrolled population. For this reason, the dually-enrolled population must now be evaluated as a separate group from customers enrolled only on SmartAC. Because the vast majority of load control events for dually-enrolled customers occur coincident with SmartRate events, impact estimates for dually-enrolled customers are reported in the evaluation of SmartRate. After excluding dually-enrolled customers, we are left with about 135,000 devices on 122,000 residential premises in our analysis.

1.1 Residential SmartAC Ex Post Load Impact Summary

Table 1-1 shows the average estimated load impact per customer from 4-5 PM for each 2012 event along with average temperature over the same period for the residential SmartAC population. The table focuses on 4-5 PM because that hour was common to all events, which makes the estimated load impacts comparable with each other without confounding time-of-day effects with other reasons for impact variability. Section 4.1 contains event impact estimates for the full duration of each event. The overall average impact from 4-5 PM was 0.57 kW or about 24% the program performance in 2012 was quite similar to 2011.

Table 1-1: Average Residential per Customer Reference Loads, Impacts and Temperatures from 4-5 PM on 2012 Event Days

Event Date	Event Hours	Average Whole-Building Reference Load (kW)	Average Event Impact (kW)	Percent Impact[1]	Average Temperature 4–5 PM (°F)
7/9/12	4-5 PM	2.02	0.50	25%	91
7/10/12	4-5 PM	2.41	0.70	29%	97
7/11/12	4-5 PM	2.86	0.72	25%	100
7/12/12	4-5 PM	2.83	0.69	24%	97
8/2/12	4-5 PM	2.39	0.65	27%	95
8/10/12	4-5 PM	2.88	0.53	19%	99
8/13/12	4-5 PM	3.02	0.73	24%	100
9/13/12	4-5 PM	1.93	0.47	24%	92
9/14/12	4-5 PM	1.91	0.34	18%	90
10/1/12	4-5 PM	2.07	0.38	19%	97
10/1/12*	4-5 PM	2.07	0.52	25%	97
Average	**4-5 PM**	**2.40**	**0.57**	**24%**	**96**

*Two test events were called on 10/1/2012. One lasted from 2-5 PM; the other lasted from 4-6 PM.

1.2 Residential SmartAC Ex Ante Load Impact Summary

Ex ante load impact estimates are meant to represent the expected average and aggregate load impacts for the program if all customers are called simultaneously under normal weather conditions (e.g., 1-in-2 year weather) and extreme weather conditions (e.g., 1-in-10 year weather). The ex post performance of the program was stable between 2011 and 2012, our modeling assumptions were broadly similar, and the program enrollment has been and is expected to be fairly stable. As a result, the ex ante load impact estimates for 2012 are similar to those reported in 2011.

Table 1-2 shows the average ex ante impact estimates for the residential SmartAC population over the resource adequacy window of 1-6 PM. These estimates include the contribution of dually-enrolled customers, whose load impacts were not estimated directly in the ex post analysis, as discussed below. For the 1-in-2 weather year, the highest estimated impact is on the July peak day, with an average impact of 104 MW and a peak hourly impact of 125 MW. The July peak day also shows the highest impacts for the 1-in-10 weather year. The mean impact over the five-hour event is 129 MW and the peak hourly impact is 149 MW.

[1] Impacts are a percentage of whole-building load for residential customers. This must be kept in mind when comparing percent impacts to those in previous evaluations, which were calculated as a percentage of CAC load.

Table 1-2: 2013 Residential SmartAC Ex Ante Load Impact Estimates By Weather Year and Day Type (Event Period 1-6 PM)

Weather Year	Day Type	Mean Hourly Per Customer Impact (kW)	Max. Hourly Per Customer Impact (kW)	Aggregate Mean Hourly Impact (MW)	Aggregate Max Hourly Impact (MW)
1-in-2	Typical Event Day	0.54	0.67	84	105
	May Peak Day	0.38	0.48	59	76
	June Peak Day	0.45	0.58	70	90
	July Peak Day	0.66	0.80	104	125
	August Peak Day	0.52	0.65	81	102
	September Peak Day	0.53	0.66	83	103
	October Peak Day	0.29	0.39	45	61
1-in-10	Typical Event Day	0.70	0.83	110	131
	May Peak Day	0.59	0.73	92	113
	June Peak Day	0.65	0.78	101	123
	July Peak Day	0.82	0.95	129	149
	August Peak Day	0.74	0.86	115	135
	September Peak Day	0.59	0.72	92	113
	October Peak Day	0.51	0.64	80	101

1.3 SMB SmartAC Ex Ante Load Impact Summary

The SMB segment of the SmartAC program is currently not recruiting new customers. No EM&V test events were called for this group during summer 2012 and, therefore, no ex post impacts were estimated. Therefore, no new load impact information is available to alter the per-device ex ante estimates from 2011. The operations of the SMB segment have not changed since 2011, and so the per-device ex ante values for this segment are the same as in the 2011 evaluation. The only source of change in ex ante load impact estimates for SMB customers is a new set of enrollment projections. Table 1-5 shows the average ex ante impact estimates for the non-residential SmartAC population for the resource adequacy window of 1-6 PM.

For the 1-in-2 weather year, the highest estimated impact is on the July peak day, with an average impact of 3.6 MW and a peak hourly impact of 4.3 MW. The July peak day also shows the highest impacts for the 1-in-10 weather year. The mean impact over the five-hour event is almost 4.1 MW and the peak hourly impact is 4.8 MW.

Table 1-5: 2013 SMB SmartAC Ex Ante Load Impact Estimates By Weather Year and Day Type (Event Period 1 to 6 PM)

Weather Year	Day Type	Mean Hourly Per Customer Impact (kW)	Max. Hourly Per Customer Impact (kW)	Aggregate Mean Hourly Impact (MW)	Aggregate Max Hourly Impact (MW)
1-in-2	Typical Event Day	0.55	0.65	2.9	3.4
	May Peak Day	0.37	0.45	2.0	2.4
	June Peak Day	0.47	0.56	2.4	2.9
	July Peak Day	0.69	0.81	3.6	4.3
	August Peak Day	0.55	0.65	2.8	3.4
	September Peak Day	0.51	0.61	2.6	3.1
	October Peak Day	0.32	0.39	1.7	2.0
1-in-10	Typical Event Day	0.72	0.85	3.7	4.4
	May Peak Day	0.63	0.74	3.3	3.9
	June Peak Day	0.66	0.78	3.5	4.1
	July Peak Day	0.79	0.93	4.1	4.8
	August Peak Day	0.76	0.88	3.9	4.6
	September Peak Day	0.61	0.72	3.1	3.7
	October Peak Day	0.50	0.59	2.5	3.0

1.4 Recommendations

The residential SmartAC program has shown quite stable operation over the past two seasons. Due to careful EM&V, its main operations are quite well-understood and the system performs reliably. Due to the use of LCA-level impact estimates for system-wide modeling (as discussed in section 6), there is a relative wealth of information on how the program performs on a system-wide basis during peak weekday hours. These results show a relatively large amount of random variance, but we do not believe that much of this variance is ever likely to be explainable using observable variables. Therefore, we may be reaching the point of diminishing returns for peak period system-wide testing. We believe it is time to expand program testing to understand its capabilities on two new levels.

First, as PG&E is aware, the program may have great value as a transmission and distribution (T&D) resource when called locally. The program is configured so that events can be called for individual substations. This means that at times of T&D congestion, SmartAC events could be used to ease that constraint. Since the constraints are local, such events wouldn't be needed system-wide and would only affect modest numbers of customers. For the past three years PG&E has performed limited testing of the program at the substation level to explore the program's potential as a T&D resource. It may be time now to shift the EM&V effort towards a more systematic evaluation of the program at this level. A first step in this direction would be to re-analyze the 2011 and 2012 ex post data at the sub-station level for all substations to determine which substations have enough customers to support accurate EM&V and to be a potentially useful local resource. Then a more comprehensive model could be developed to estimate impacts at the substation level. A version of this model already exists, but it

should be updated. Finally, the 2013 evaluation plan can emphasize substation testing to a greater degree than in 2011 and 2012.

Second, it would be prudent to conduct testing of the program at times when it is less likely to be needed, such as earlier in the day or on weekends to understand both the load reduction values and the impact on customers. This is important because the program can be called seven days a week at any time of the day and these impacts need to be modeled for forecasting purposes.

2 Overview of SmartAC Program and Evaluation Plan

PG&E's SmartAC™ program currently involves the installation of direct load control switches (switches) in households and small/medium businesses with central (or packaged) air conditioning (CAC). Formerly, the program also offered programmable communicating thermostats (PCTs) as a load control option and many of these are still operational. The control devices allow CAC equipment to be cycled or thermostats to be adjusted when an event is triggered, thereby reducing energy demand associated with AC load.

There are three device types currently used by PG&E to control air conditioners and each has different functional capabilities. LCR5000 and LCR5200 are both load control receivers (referred to hereafter as switches), which attach directly to the premise near or on the central air conditioning units. They control the duty cycle directly using one of several different algorithms.[2] UtilityPro and ExpressStat are each models of PCT, which can control the CAC unit either using duty cycle control like a switch, or by adjusting the temperature on the thermostat.

Duty cycle control, not temperature control, was used exclusively during the 2012 season for all control devices. The exact type of cycling varies depending on the control device and type of customer, as shown in Table 2-1. As the table shows, there are two basic kinds of cycling, indexed by a percentage value. Under simple cycling, the CAC compressor's duty cycle is capped at the percentage value for each hour. For example, under 50% TrueCycle2, a unit's compressor could run for no more than half a given hour. Under TrueCycle2, a baseline methodology is used to limit the compressor to run no more than the given percentage of what it would have been expected to run without the event. For example, under 33% TrueCycle2, a compressor is constrained to run for no more than 33% of its expected run time each hour.

Table 2-1: Control Strategies by Segment and Device Type

Segment	Control Device		
	LCR (Switch)	UtilityPRO	Express Stat
Residential	50% TrueCycle2	50% TrueCycle2	50% Simple Cycling
SMB	33% TrueCycle2	33% TrueCycle2	33% Simple Cycling

Table 2-2 shows the number of enrolled control devices by customer type, device type and local capacity area (LCA). It is important to distinguish between enrolled customers and enrolled devices, as many customers, especially SMB customers, have multiple CAC units and, therefore, multiple control devices. Some accounts even have both kinds of control device associated with separate CAC units. Residential customer enrollment at the end of summer 2012 was 149,165[3] accounts and SMB customer enrollment was 4,801 accounts. There were 164,859 active installed devices among residential accounts and 9,178 devices for SMB accounts. More than 26,000 residential customers

[2] Duty cycle is the fraction of time that an air conditioning compressor is active. Duty cycles vary significantly with temperature. The hotter the temperature across the hours of a day, the longer the duty cycle.

[3] An additional 1,612 customers with 1,872 devices had interval data but did not match PG&E's residential population database, and were thus left out of the analysis.

with roughly 30,000 devices were dually enrolled in SmartRate and SmartAC, leaving about 135,000 devices on 122,000 premises in our analysis.

As seen in Table 2-2, the majority of SmartAC devices are associated with residential households. Indeed, the residential segment comprises 94% of all SmartAC devices, 99% of switches and 72% of PCTs. Among residential customers, the majority of devices are switches, while among SMB customers the majority are PCTs. SMB accounts have roughly 1.9 devices per customer, whereas residential accounts average 1.1 devices per customer.

Table 2-2: SmartAC Active Control Devices as of the October 1, 2012 Event Day

Customer Class	Local Capacity Area	Enrolled Customers	PCTs	Switches	Total Devices
SMB	Greater Bay Area	2,010	3,412	214	3,626
	Greater Fresno	852	1,599	223	1,822
	Kern	252	424	27	451
	Northern Coast	673	951	110	1,061
	Other	1,135	2,026	202	2,228
	Sierra	465	758	90	848
	Stockton	440	758	143	901
	Total	**5,827**	**9,928**	**1,009**	**10,937**
Residential – SmartAC-only	Greater Bay Area	41,142	6,181	39,982	46,163
	Greater Fresno	23,044	5,222	20,026	25,248
	Kern	4,764	1,370	3,909	5,279
	Northern Coast	7,685	1,132	6,975	8,107
	Other	20,755	3,454	18,760	22,126
	Sierra	14,172	1,788	14,338	16,126
	Stockton	10,850	1,839	9,823	11,662
	Total	**122,412**	**20,986**	**113,813**	**134,799**
Residential – Dually-Enrolled (SmartAC and SmartRate)	Greater Bay Area	10,848	1,463	10,966	12,329
	Greater Fresno	3,114	768	2,795	3,563
	Kern	1,460	870	801	1,671
	Northern Coast	1,574	178	1,463	1,641
	Other	4,157	705	3,802	4,507
	Sierra	3,190	341	3,376	3,717
	Stockton	2,410	426	2,206	2,632
	Total	**26,753**	**4,751**	**25,309**	**30,060**

2.1 SmartAC Analytical Overview

The basic analytical requirement for SmartAC impact evaluation is the estimation of a reference load during event periods. This requires an experimental design. The experimental design for measuring load control impacts took the form of randomized controlled trial (RCT), which was almost identical to the design for 2011. In this design, approximately 1/10 of the residential SmartAC population was called for an event on each of 10 test event days. The remaining 9/10 — the control group — was not called for an event, and observed loads from that 9/10 provided a reference load. The group called for an event rotated for each event so that each customer in the program was subjected to a maximum of one test event; each customer was also subjected to the system-wide test event on August 10.

The advantages of this evaluation design are discussed extensively in the 2011 evaluation.[4] Briefly, this method removes virtually all uncertainty from the ex post half of the evaluation. The groups are large and random within the population (as demonstrated below), which means that reference loads, estimated loads during events, and ex post load impacts are measured with very small variance and no selection bias or specification bias.

Test events varied in length between two and three hours, and were called in the mid-to-late afternoon and early evening. Each of these test events included the hour from 4-5 PM, which is an important detail for ex ante estimation. There were also four notch tests in September, all called on the same group of customers for the purpose of increasing the data available on control device communication.

Ex ante estimation is based on a model of ex post load impacts as a function of event day weather. Load impacts from 4-5 PM are modeled as a function of the average temperature from midnight to 5 PM on each event day, and this model is used to predict ex ante load impacts from 4-5 PM under ex ante weather conditions. Ex ante impacts for the remaining resource adequacy hours of 1-4 PM and 5-6 PM are then modeled as proportions of the 4-5 PM impacts based on a model of the relative size of load impact across event hours as a function of weather. The details of these models are discussed in Section 6.

In addition to estimating load impacts, FSC also analyzed the degree to which SmartAC control devices received the signal to activate and if they successfully reduced load according to the indicated control strategy. These issues were identified as a major source of smaller than expected load impacts in the 2010 SmartAC evaluation, which led to the elimination of thermostat temperature adjustment and a mass push of the TrueCycle2 control strategy to devices in 2011. Communication success appears fairly similar between 2011 and 2012, although operational issues continue to lead to signals not being sent for some customers on some days. This is discussed further in Section 5.

FSC also conducted a survey of SmartAC customers following a test event to assess the degree to which customers felt discomfort due to the event. A control survey on SmartAC customers who did not experience the event was also conducted. Results from this survey showed that customers who were called for a two-hour event did not report more discomfort than customers who were not called

[4] See "2011 Load Impact Evaluation for Pacific Gas & Electric's SmartAC Program" prepared by FSC. Available at http://fscgroup.com/reports/2011-pge-smartac-evaluation.pdf

for an event. Additionally, customers reported a high degree of satisfaction with the program, with the median value being 9 out of 10.

2.2 Report Organization

The remainder of this evaluation is organized as follows. Section 3 describes the evaluation design and the methods used to calculate ex post impact estimates. Section 4 provides residential load impact results. Section 5 has our findings on control device success rates — an important operational issue for the program. Section 6 describes the methods used to estimate ex ante load impacts and Section 7 shows those results, as well as ex ante results for SMB customers. Section 8 concludes with a summary and recommendations. Following the main body of the paper are four appendices that go into greater technical detail on the following topics: residential ex ante methodology for producing whole building loads;[5] side-by-side testing results; discomfort survey results; and how much building temperatures rise during SmartAC events.

[5] The methodology used to estimate ex ante load impacts does not require estimation of a reference load. However, the load impact protocols that guide this evaluation require reporting reference loads along with load impacts. As such, it is necessary to produce a reference load even though it is not required to obtain load impacts. The approach to dealing with this is discussed in the appendix.

3 Evaluation Design and Ex Post Methods

This section details the evaluation design and numerical methods used to estimate ex post load impacts for residential customers.

3.1 Residential Experimental Design and Operations

The ultimate goal of the experimental design of this evaluation is to provide a source of reference load for each test event. During each test event, it is straightforward to determine average loads among customers affected by the event through the use of hourly interval data collected from SmartMeters, which are present on the vast majority of premises in the SmartAC population. Estimating load impacts requires a comparison between those observed loads and an estimate of what the loads would have been among affected customers if the event had not occurred — a reference load. In this design, the reference load is estimated by computing the average load among a representative group of customers who are on the program, but not called for the event, as described below.

The evaluation is based on a large-scale RCT in which 1/10 of the population is called for each test event. The average load among the 9/10 of the population not called is used as a reference load; so in each case, 10% of the population constitutes the test group and the remaining 90% constitutes a control group which provides reference load. This provides a highly accurate and precise reference load because this group is quite large and highly representative of the SmartAC population. Similarly, the group subjected to the test event is also quite large and highly representative of the SmartAC population.

In general, designating groups of customers to be called for particular events — while excluding others — requires an operation known as re-addressing within Yukon, the head-end device control software by Cooper Power Systems. This operation sends pages to the devices and assigns them to groups that determine which load control signals they will respond to. This process is time consuming due to software constraints and daily paging limits with surcharges for overages. Re-addressing the entire SmartAC residential population would therefore have a substantial associated cost and would be an endeavor that would take at least a month due to the complexity of the addressing within Yukon. One alternative is to use less than the whole population in the evaluation. However, each SmartAC control device happens to be pre-addressed based on the last digit of its serial number when it is manufactured.[6] This results in 10 random groups of devices — each group corresponding to a different final digit of the serial number (0-9). FSC's testing showed that this addressing scheme resulted in a valid randomization with no significant differences in population characteristics between any of the 10 random groups of devices. Table 3 shows that each randomized group has approximately the same proportion of customers in each LCA and that each group has roughly the same average usage.

[6] The exception to this was the group of Express Stat PCTs, which comprise about 6% of all customer control devices. This set of devices was re-addressed as part of the 2011 evaluation based on the last digit of the device serial number.

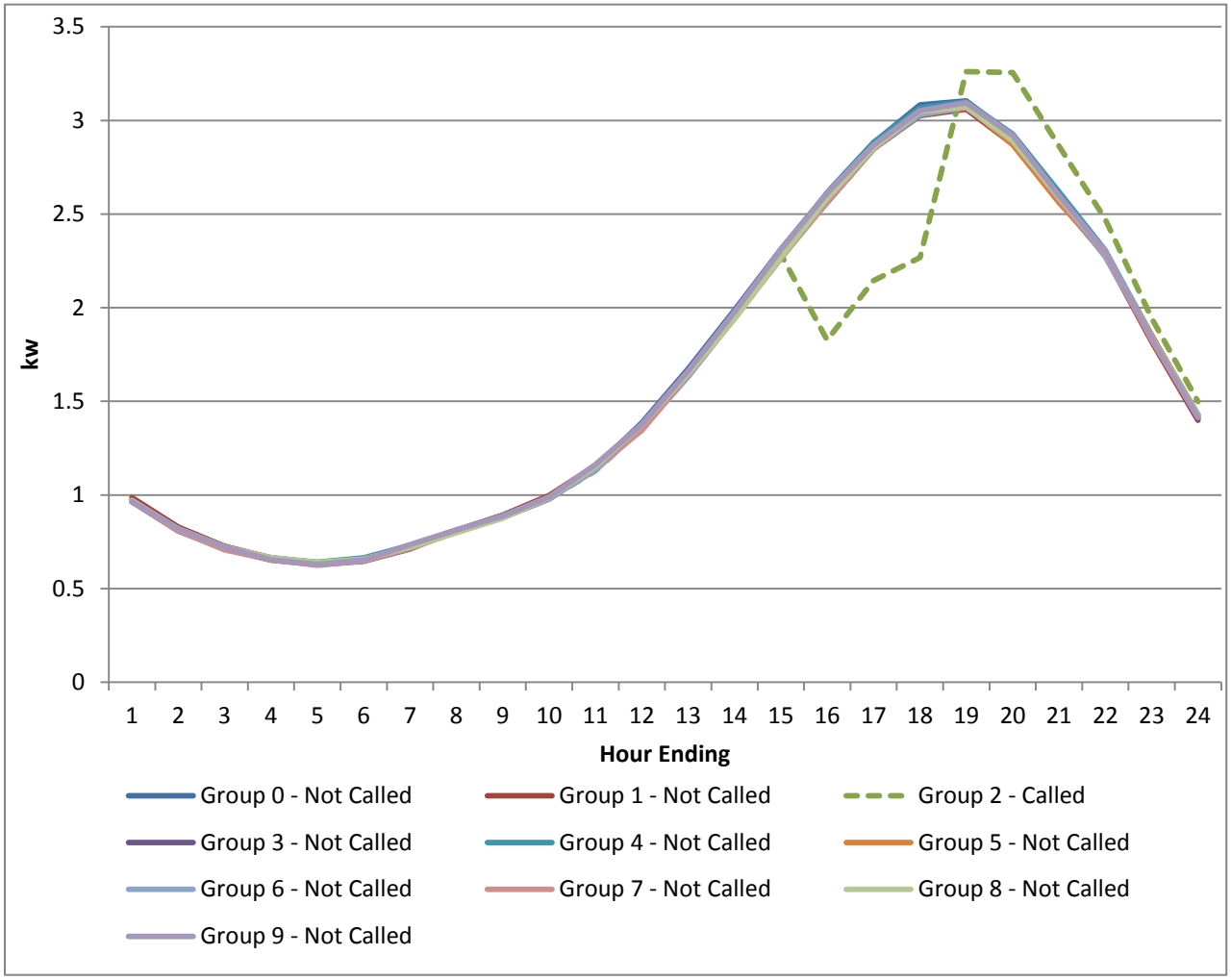
Table 3-1: Comparison of Randomized Groups

Randomized Group	Greater Bay Area	Greater Fresno	Kern	Northern Coast	Other	Sierra	Stockton	Mean Daily Usage (kW)7
0	33%	19%	4%	7%	17%	11%	9%	32.9
1	33%	19%	4%	7%	17%	12%	9%	32.2
2	33%	19%	4%	7%	17%	12%	9%	31.8
3	33%	19%	4%	7%	17%	12%	9%	31.7
4	32%	19%	4%	7%	17%	12%	9%	32.7
5	33%	19%	4%	7%	17%	12%	9%	31.4
6	33%	19%	4%	7%	17%	12%	9%	33.1
7	33%	19%	4%	6%	17%	12%	10%	32.9
8	33%	19%	4%	7%	17%	12%	9%	33.1
9	33%	19%	4%	7%	17%	11%	9%	33.1

Additional evidence of the comparability of the 10 groups is shown in Figure 3-1, which shows the loads of each group on the July 11 test event day. The loads are virtually identical prior to the event, and 9 of the 10 loads remain identical during the event, with the test event group (Group 2), shown as the green dotted line, being the only exception.

[7] Calculated over days when the group was in the control group — meaning that each group's average is calculated over a slightly different set of days. Nevertheless, the values are quite close.

Figure 3-1: Comparison of Loads of Randomized Groups on July 11, 2012 Event Day



Ideally, the SmartAC population would have been divided into a greater number of smaller groups. This would have allowed for greater flexibility to call more events without affecting customer comfort too much. Moreover, randomized groups that were even one-third the size of the groups that were used would have still been sufficient to produce highly accurate impact estimates. However, re-addressing the entire SmartAC population into 20-30 randomized groups would have been a time-consuming and logistically difficult process with the potential for many problems. It was decided that avoiding re-addressing was worth a small compromise in experimental design.

The residential test event protocol prescribed events to be called based on a trigger algorithm intended to lead to an expected value of 10 test events during the summer, with the trigger based on a weighted average of the daily high temperature at 5 weather stations in the PG&E territory. Although the algorithm is dynamic, leading to different trigger temperatures throughout the summer depending on the number of events that have occurred so far, it can be summed up fairly simply. All days where the weighted average temperature experienced by the SmartAC population was expected to exceed 95°F were called for events, and some days where that temperature was expected to

exceed 90°F were called. The test event protocol called for a mixture of 2 and 3-hour events, covering a variety of times of day, but always including the hour 4-5 PM, as a basis for modeling.

Each control device was subjected to exactly one EM&V test event during the summer, as well as the system-wide event. EM&V test events occurred over the course of 10 days. On each of those days, one group was activated using the standard SmartAC test event control strategies for 2012. On one of the days — October 1 — more than one group of customers was called on the same day for side-by-side testing. One randomized group of customers was operated from 2-5 PM; while another randomized group was operated from 4-6 PM. This provided further information on the degree to which load impacts vary as a function of the duration of the event. Results from this test are discussed in Appendix B.

3.2 Residential SmartAC Ex Post Methodology

On October 1, the final event day of 2012, there were approximately 165,000 installed residential SmartAC devices. These devices were installed at about 149,000 customers' homes. Due to the pre-existing addressing and the need for SmartMeter data from each participating customer, not all SmartAC customers are included in the design.

Of the residential program population, 26,753 customers with 30,060 devices were dually enrolled in SmartRate and SmartAC and were excluded from the primary ex post analysis. These customers are excluded because they are subjected to load control events on all SmartRate event days, which overlap with SmartAC events at some times and not others. Additionally, none are excluded from load control for the sake of providing a reference load during SmartRate events and because they are also subject to higher prices, the load impacts observed during SmartRate events are due to more than just load control. Finally, a separate analysis of load impacts for those customers is provided in the evaluation of SmartRate. For an analysis of the incremental impact of a SmartRate event on a SmartAC event and vice versa for comparable populations, see the 2011 evaluation of SmartAC.[8]

The dually-enrolled population increased substantially between 2011 and 2012 from about 4,000 to 26,753. This increase came primarily through signing up existing SmartAC customers onto SmartRate. This means that by excluding these customers from the ex post impact estimates we are reducing the population included in the estimates as compared to the 2011 evaluation. The actual impact estimates are still fairly close to what was observed in 2012. However, for the sake of comparing the program across years and for ex ante forecasting, we include the dually-enrolled population, as discussed in Section 4 and Section 6.

There are greater than 14,500 SmartAC customers with more than 1 control device in their homes (just under 10% of the population). These houses were omitted from the primary analysis. Over 95% of customers with multiple CAC units had control devices in different randomized groups, meaning that one control device could be called for an event while another device in the house would not. In a situation like this, the whole-house load impact would not represent the true effect of a SmartAC event on that household. For this reason, all customers with two or more devices were not included in the primary ex post analysis. Instead, a secondary analysis of these premises was

[8] "2011 Load Impact Evaluation for Pacific Gas and Electric Company's SmartAC Program" prepared for PG&E by the FSC Group.

undertaken separately, as described in Section 4.3. This analysis showed that multi-device premises do not provide higher impacts than single-device premises. Therefore, the primary results, which are based only on single-device premises, can be applied to the entire population on a per customer basis. That is, we assume that premises with multiple devices provide the same average impacts as premises with multiple control devices. This assumption was also used in the 2011 evaluation. To estimate impacts for the entire SmartAC population, the impact estimates per customer are multiplied by the total number of customers in the population.

After excluding customers with multiple CAC units and dually-enrolled customers from the primary analysis, there were almost 111,000 residential SmartAC customers by the last event of the summer. For less than 5% of these customers, interval data was not available. However, the 95% of premises for which data is available provides a highly representative sample, as shown in Table 3-2.

Table 3-2: Comparison of Randomized Groups

Customers	Greater Bay Area	Greater Fresno	Kern	Northern Coast	Other	Sierra	Stockton	Total Customers
Interval Data Available	33%	19%	4%	6%	17%	11%	9%	106,216
Full Population	33%	19%	4%	7%	17%	11%	9%	110,898

On average, the interval data for approximately 104,000customers were used to calculate ex post impacts on each event day. In the case of all but the last event, one group of customers — based on device serial number — was called for the event and the remaining set of customers served as a control group. For the last event, multiple groups of customers were called for events for the sake of side-by-side testing of different control strategies and timing. Side-by-side testing is discussed in Appendix B.

Ex post event impacts for each LCA are estimated for each hour of each event by taking the average load in the group that received the event and subtracting it from the average load in the larger group that did not receive the event. Impact estimates for the entire SmartAC population for each hour of each event are calculated by taking a weighted average of the impact estimates for each LCA, with weights determined by the number of devices in each LCA.

4 Residential Ex Post Load Impact Estimates

This chapter presents the ex post SmartAC program load impacts for 2012 program year. The average ex post impact per customer for participants that are only enrolled in the SmartAC program (not dually enrolled in both SmartAC and SmartRate) equaled 0.57 kW during the hour from 4-5 PM.[9] This is quite similar to the program's performance in 2011.

This chapter is divided into three main sections. Section 4.1 describes the ex post impact results for all 10 of the 2012 events. Section 4.2 provides impact estimates for participants segmented by average usage decile, which provides an estimate of the distribution of impacts across the population. Section 4.3 provides impact estimates for participants with multiple control devices.

There are several technical appendices to this document that are relevant to the ex post evaluation. These are:

- Appendix B discusses the results of the side-by-side testing of different control strategies and event timing;
- Appendix C provides results from a post-event discomfort survey; and
- Appendix D discusses the change in temperature experienced by customers with PCTs during events.

4.1 SmartAC Primary Test Event Results

Table 4-1 shows the average impact per customer for each test event along with average temperature over the event period for the residential SmartAC population not enrolled in SmartRate. To make the results comparable, the table only includes the hour common to all events, 4-5 PM. The largest impact occurred on July 11, which had an estimated impact of 0.70 kW per customer. Not coincidentally, July 11 was the hottest event day. The average impact from 4-5 PM of 0.57 kW represents an average of 24% in whole house load reduction. The percent reduction across event days ranged from a low of 18% to a high of 29%. This table does not reflect the full operation of the program because it excludes SmartRate customers. Table 4-2b shows results including SmartRate customers. The reason for including Table 4-1 is that its results (aside from the system-wide event day) are derived only from an RCT and that it shows results for the same hour of each event. Therefore it is useful for understanding the basis of our ex post analysis and our ex ante modeling.

The overall average event effect of 0.57 kW from 4-5 PM, with an average temperature of 96 degrees, is similar to the average effect and temperature seen in 2011 (see discussion of Figure 4-1). For historical context, the average event temperature for 2008, 2009 and 2010 was 93 degrees. The average event impacts were 0.19 kW, 0.26 kW and 0.22 kW, respectively. The 2011 analysis was the first to show a much higher impact of 0.50 kW with an average temperature of 95 degrees. This increase was attributed to changes in the control device strategy that were implemented prior to summer 2011. Using the same control device strategy, those gains remained in place in 2012.

[9] This is the only hour covered by all events in 2012.

Table 4-1: Average Residential per customer Reference Loads,[10] Impacts and Temperatures from 4-5 PM on 2012 Event Days

Event Date	Event Hours	Average Whole-Building Reference Load (kW)	Average Event Impact (kW)	Percent Impact	Percent of Population Called	Average Temperature (°F)
7/9/12	4-5 pm	2.02	0.50	25%	10%	91
7/10/12	4-5 pm	2.41	0.70	29%	10%	97
7/11/12	4-5 pm	2.86	0.72	25%	10%	100
7/12/12	4-5 pm	2.83	0.69	24%	10%	97
8/2/12	4-5 pm	2.39	0.65	27%	10%	95
8/10/12	4-5 pm	2.88	0.53	19%	100%	99
8/13/12	4-5 pm	3.02	0.73	24%	10%	100
9/13/12	4-5 pm	1.93	0.47	24%	10%	92
9/14/12	4-5 pm	1.91	0.34	18%	10%	90
10/1/12	4-5 pm	2.07	0.38	19%	11%	97
10/1/12*	4-5 pm	2.07	0.52	25%	11%	97
Average	**4-5 pm**	**2.40**	**0.57**	**24%**	**10%**	**96**

*Two test events were called on 10/1/2012. One lasted from 2-5 PM; the other lasted from 4-6 PM.

†System-wide event day. The aggregate impact was reduced by a factor of 10 before being included in the average.

Figure 4-1a shows ex post impacts from 4-5 PM for 2011 and 2012 plotted against the average daily temperature from 12 AM–5 PM (*mean17* — a summary temperature variable used in the ex ante model). It also includes trend-lines for each year. The figure shows a clear difference between the two years due to the exclusion of dually-enrolled customers from the primary ex post analysis. As discussed in section 6, dually-enrolled customers tend to provide lower load impacts due to SmartAC alone than do SmartAC-only customers. This appears to be due to dually-enrolled customers generally having lower usage.

Figure 4-1b shows the same values, but with the 2012 results adjusted to include dually-enrolled customers, as has been done for ex ante modeling and as is described in section 6. As the figure makes clear, there is no major difference between the set of points for 2011 and for 2012, other than random variation. This indicates that the program provided very similar performance between 2011 and 2012. The trend-lines for each year are quite similar. The difference between them is small compared to the typical variance seen among different events under similar conditions, and indeed the difference is not statistically significant.

[10] Reference loads are whole-building loads.

Figure 4-1a: Average Residential Impacts and Temperatures from 4-5 PM on 2011 and 2012 Event Days

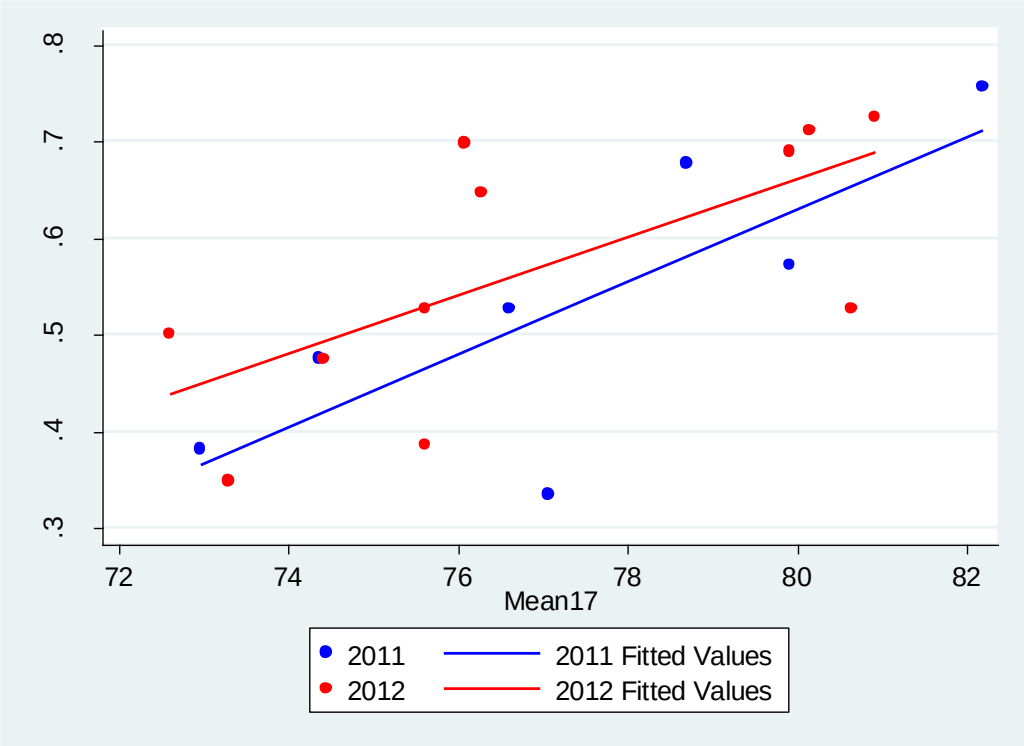


Figure 4-1b: Average Residential Impacts and Temperatures from 4-5 PM on 2011 and 2012 Event Days (2012 Adjusted)

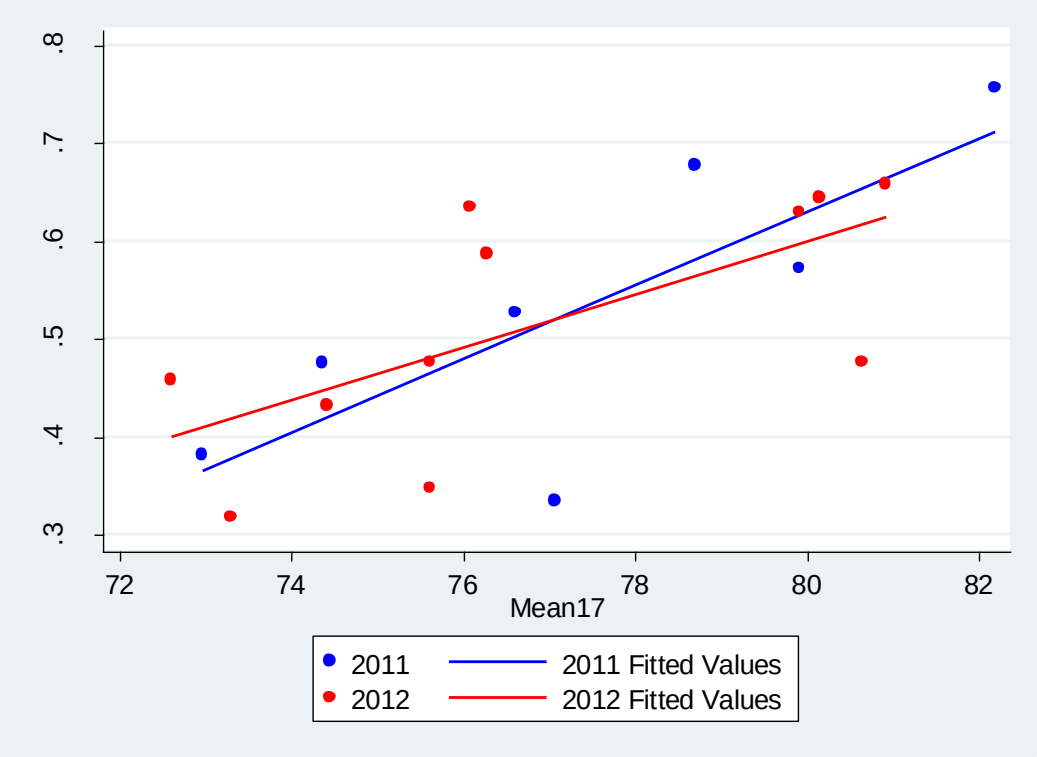


Table 4-2a shows the average event impact across the entire event window for each event in 2012. Average impacts over the full event may be higher or lower than the average impacts over the common 4-5 PM hour; residential loads tend to be lower in the early afternoon and peak later in the day, which has different implications for each of the different event period's impacts. For example, the average impact over the six events from 4-6 PM was 0.46 kW while the average impact from 4-5 PM on those same six days was 0.48 kW. These results again exclude dually-enrolled customers, the effects of which are included in Table 4-2b.

Table 4-2a: Average Residential per Customer Reference Loads, Impacts and Temperatures during Event Hours on 2012 Event Days

Event Date	Event Hours	Average Whole-Building Reference Load (kW)	Average Event Impact (kW)	Percent Impact	Average Aggregate Event Impact (MW)	Average Temperature (°F)
7/9/12	4-6 pm	2.11	0.46	22%	4.7	91
7/10/12	4-6 pm	2.53	0.65	26%	6.8	97
7/11/12	3-6 pm	2.83	0.75	27%	7.7	100
7/12/12	2-5 pm	2.59	0.63	24%	6.5	97
8/2/12	4-6 pm	247	0.58	24%	6.1	95
8/10/12	4-6 pm	2.95	0.63	22%	66.2	99
8/13/12	3-6 pm	2.99	0.76	25%	7.9	100
9/13/12	4-6 pm	1.99	0.41	20%	4.3	91
9/14/12	3-5 pm	1.81	0.37	21%	4.1	90
10/1/12	2-5 pm	1.80	0.33	18%	3.6	95
10/1/12*	4-6 pm	2.14	0.46	21%	4.9	97

*Two test events were called on 10/1/2012. One lasted from 2-5 PM; the other lasted from 4-6 PM.

Table 4-2b shows the aggregate event impacts on each event day, including the effect of SmartRate customers. Due to the overlap with SmartRate events, which precludes the use of a control group for SmartRate customers, these aggregate values are calculated under the assumption that SmartRate customers provide an impact equal to a particular fraction of the impact for SmartAC-only customers. This is the same assumption used to develop ex ante estimates and is discussed in Section 6.1. The table does not include the impact of SmartRate events that may overlap with SmartAC. It shows what the impacts would have been if a SmartAC event were called alone. Importantly, except for the system wide test event conducted on August 10th, the aggregate ex post impacts only represent about 10% of the SmartAC-only population. As such, the aggregate impact estimates in the table are not at all representative of the load reduction potential for the SmartAC program. Excluding August 10, aggregate impacts range from 3.9 MW to 8.6 MW.

Table 4-3b: Total Customers Called and Aggregate Event Impact Including Dually-Enrolled Customers

Event Date	Event Hours	Total Number of Customers Called	Average Aggregate Event Impact (MW)	Average Temperature (°F)
7/9/12	4-6 pm	12,074	5.1	91
7/10/12	4-6 pm	12,221	7.3	97
7/11/12	3-6 pm	12,117	8.3	100
7/12/12	2-5 pm	12,117	7.0	97
8/2/12	4-6 pm	12,273	6.6	95
8/10/12	4-6 pm	123,481	71.2	99
8/13/12	3-6 pm	12,304	8.6	100
9/13/12	4-6 pm	12,407	4.7	91
9/14/12	3-5 pm	12,565	4.4	90
10/1/12	2-5 pm	12,568	3.9	95
10/1/12*	4-6 pm	12,497	5.3	97

Impacts can be broken down by type of control device. Table 4-3 shows the per-premise impacts by device type for residential SmartAC customers. On average, customers with switches provide average impacts that are more than 50% greater than the average for PCT customers. Table 4-3 only shows impacts from 4-5 PM because all events covered those hours. In 2011, this result held when comparing two-hour and five-hour events as well. Additionally, this difference is not due to systematic temperature or building size differences between houses with different device types, as shown in Table 4-4. In fact, premises with PCTs tend to be in hotter areas and have somewhat higher reference loads than those with switches, indicating that the performance gap is even larger than Table 4-3 indicates. As is shown in Section 5, PCTs have worse signal reception than switches. This probably accounts for much of the performance gap.

Table 4-3: Average Residential Impacts per Customer by Device Type

Date	Event Hours	PCT	Switch
9-Jul-12	4-5 pm	0.31	0.54
10-Jul-12	4-5 pm	0.52	0.74
11-Jul-12	4-5 pm	0.47	0.76
12-Jul-12	4-5 pm	0.45	0.73
2-Aug-12	4-5 pm	0.53	0.67
10-Aug-12	4-5 pm	0.36	0.57
13-Aug-12	4-5 pm	0.47	0.78
13-Sep-12	4-5 pm	0.29	0.51
14-Sep-12	4-5 pm	0.23	0.36
1-Oct-12	4-5 pm	0.23	0.41
1-Oct-12*	4-5 pm	0.42	0.54
Average	**4-5 pm**	**0.39**	**0.60**

Table 4-4: Comparison of Device Type Groups

Device Type	Greater Bay Area	Greater Fresno	Kern	Northern Coast	Other	Sierra	Stockton	Mean Daily Usage (kW)[11]
Switch	35%	17%	3%	7%	17%	12%	9%	32.0
PCT	28%	23%	9%	6%	17%	8%	9%	34.9

4.2 Distribution of Impacts Across Customers

We examine the distribution of impacts across two different dimensions: LCA and usage decile. Table 4-5 shows the average load impact from 4-5 PM across all 2012 events by LCA. As we discuss in Section 6.2, we have found that event response appears to follow essentially the same trend with respect to temperature, regardless of LCA. So it is not surprising that the average impacts in Table 4-5 are highly correlated with the average temperature at the same time period. Kern and Greater Fresno are the hottest LCAs and also provide the highest load impacts, while the Greater Bay Area and Northern Coast are the coolest and provide the smallest. Note that the this table is only calculated over the 2012 events, which is a relatively small sample and that the average temperature is only one particular measure of temperature, so it is probably not worth making too much of the exact ranking of LCAs in the table.

[11] Calculated over days when the customer was in the control condition.

Table 4-5: Average Event Impacts from 4-5 PM by LCA

Local Capacity Area	Impact (kW)	Average Temperature (°F)
Greater Bay Area	0.39	90
Greater Fresno	0.77	103
Kern	0.97	102
Northern Coast	0.26	90
Other	0.60	99
Sierra	0.66	98
Stockton	0.62	97

Table 4-5 shows the load impact from 4-5 PM averaged across all 10 event days by customer usage deciles. Customers were divided into deciles based on average monthly usage in June 2012. Customers in the lowest decile had an average monthly usage of 212 kW compared to 1,284 kW for customers in the highest decile of usage.[12] As would be expected, customers with higher average usage show greater absolute impacts. Customers in the greatest decile of usage provided impacts almost three times greater than customers in the lowest decile of usage.

Table 4-5: Average Event Impacts by Usage Decile

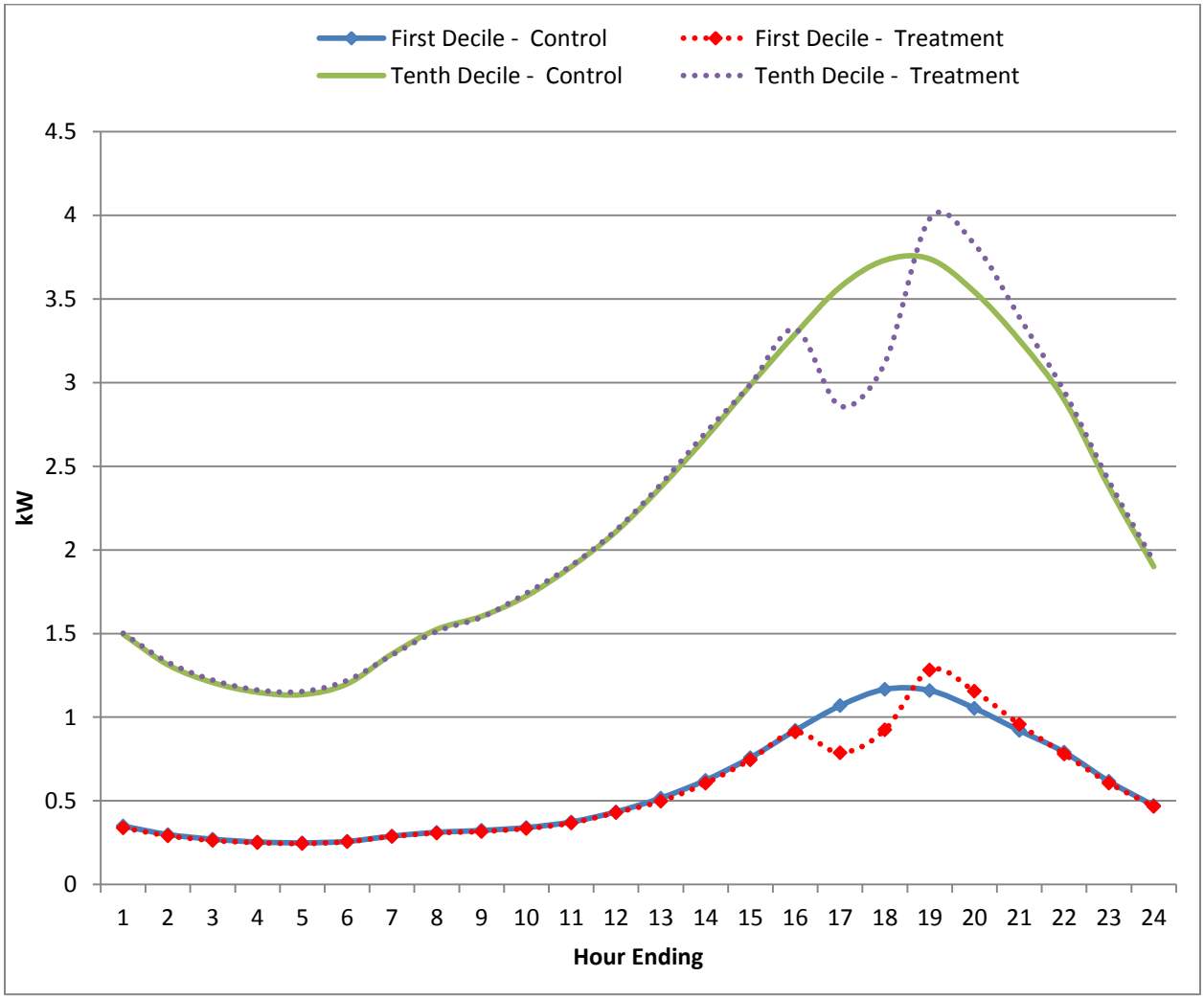
Monthly Usage Decile	Average Monthly Usage (kW)	Average Impact from 4-5 PM (kW)
1	212	0.28
2	329	0.43
3	399	0.48
4	459	0.53
5	518	0.57
6	581	0.62
7	654	0.67
8	745	0.69
9	881	0.71
10	1,284	0.78

Figure 4-2 further illustrates how different impacts and usage are from the first to the tenth decile. The dotted purple and solid green line represent the treatment and control loads across the six two-hour event days that ran from 4-6 PM for customers in the tenth percentile. The red dotted line with

[12] Usage deciles could also be calculated using daily SmartMeter data instead of monthly billing data.

diamond markers and the blue solid line with diamond markers show the treatment and control usages for customers in the first decile. These findings suggest that PG&E could increase program impacts by focusing marketing efforts on customers with higher-than-average monthly usage.

Figure 4-2: Event Impacts for Events from 4-6 PM – 1st and 10th Usage Deciles



4.3 Customers with Two SmartAC Devices

Although customers with two or more SmartAC devices were excluded from the main ex post analysis dataset, it is still possible to explore the impacts these customers provide and to include them in our final estimates. Of customers with more than 1 CAC unit, 89% (about 19,000 customers) have 2 CAC units. For customers with two CAC units, it is possible to calculate impacts for circumstances when both devices in a household are controlled and also when only one of two devices is controlled. Just fewer than 8% of customers with 2 CACs have devices that both fall in the same randomized group used for calling events.

To estimate ex post results for customers with both devices controlled, the treatment group for any given day is defined to be customers with both devices in the group called for an event that day.

Customers with two devices installed, but no devices being tested, serve as the control group; customers with only one of two devices tested are dropped from the analysis, as are customers with more than two devices. For example, on July 10, group 1 was called for an event. For the analysis of customers with 2 devices, the treatment group consisted of about 98 customers who had 2 devices that were both in group 1. Customers with two devices and exactly one device in group 1 were dropped from the analysis for that day. The remaining customers with two devices and no devices in group 1 served as the control group.

For any given 2012 event day, there were about 9,000 customers with 2 devices in the control group and around 90 customers with both devices called in the treatment group. Impacts were calculated by comparing treatment and control group usage during the event hours with a same-day adjustment. When analyzing the full residential SmartAC population, same-day adjustments are not needed between the treatment and control group due to the large number of customers. However, when looking only at customers with two devices, the adjustment increases the accuracy of impact estimates. The same-day adjustment is based on the ratio of usage between the treatment and control groups for the four hours prior to the event start. For example, for an event that runs from 4-6 PM, the average ratio of treatment usage to control usage over the hours of 12-4 PM is used to adjust the control usage for the entire day. In addition to the same-day adjustment, event days with the same event hours were analyzed together to compensate for small sample sizes. There were two sets of three-hour events that were analyzed together. The first set includes the events on July 12 and October 1 that lasted from 2-5 PM and the second consists of events on July 11 and August 13 that lasted from 3-6PM. There were also two sets of two-hour events that were analyzed together. The first set includes the events on July 9, July 10, August 2, September 13 and October 1 that lasted from 4-6PM. The second set only consisted of the September 14 event that lasted from 3-5PM. The August 10 system-wide event was not included in the analysis due to lack of a control group.

Table 4-6 shows the ex post event impacts for customers with two devices compared to the main results for customers with one device. The first two columns show the results for the three-hour event days and the last two columns have results for the two-hour event days. For three-hour events, customers with two devices showed lower impacts, with an average of 0.34 kW compared to 0.56 kW.[13] For two-hour events, however, customers with two devices had slightly higher impacts than customers with one device, with an average of 0.41 kW compared to 0.38 kW.[14] Although standard errors are not shown in Table 4-6, differences in load impacts between customers with one device and customers with two devices have quite high standard errors as compared to their magnitude, suggesting that the difference in the average impact between the two groups is not statistically significant.

[13] These values are averaged over the two sets of three-hour events in Table 4-6.

[14] These values are averaged over the two sets of two-hour events in Table 4-6.

Table 4-6: Ex Post Event Impacts for Customers with Two Devices Treated

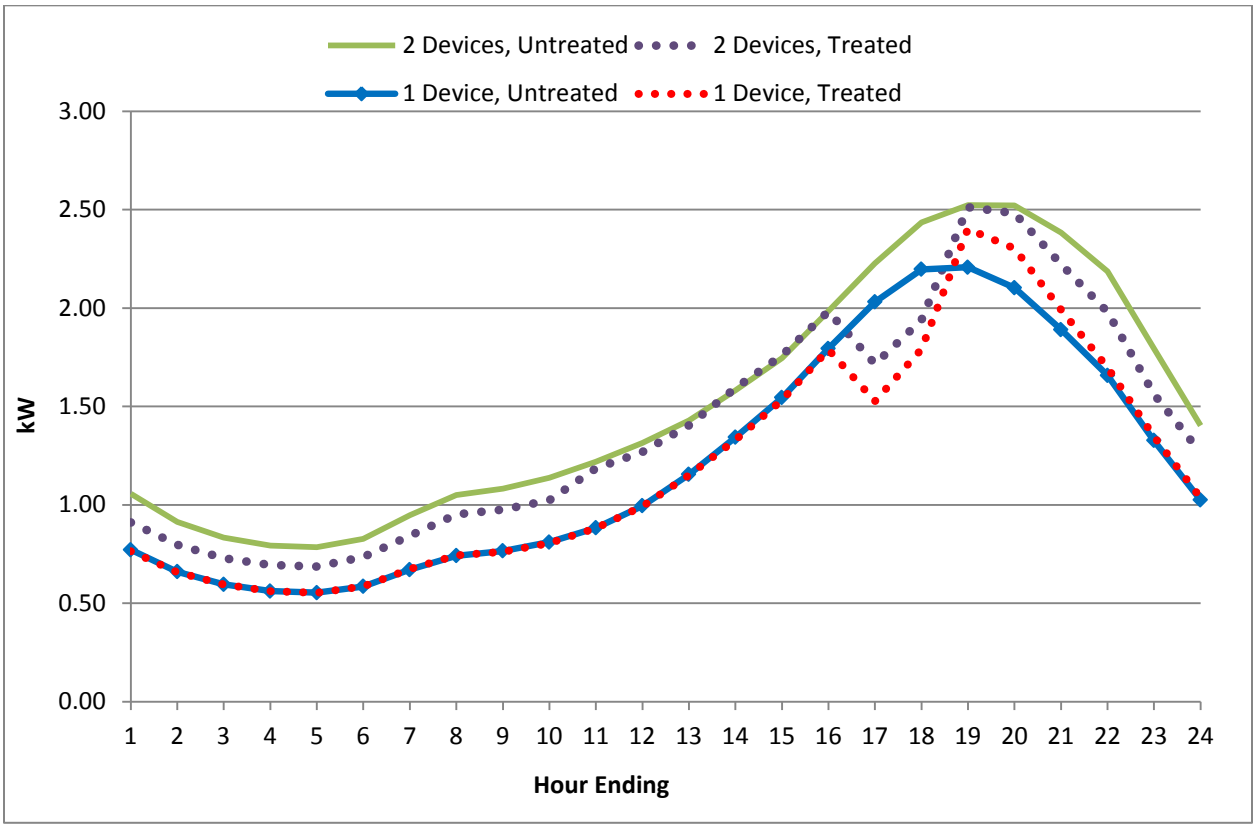
Hour	Three-Hour Events				Two-Hour Events			
	2 - 5 PM Event		3 - 6 PM Event		3 - 5 PM Event		4 - 6 PM Event	
	2 Devices	1 Device	2 Devices	1 Device	2 Devices	1 Device	2 Devices	1 Device
2-3 PM	0.24	0.44	N/A	N/A	N/A	N/A	N/A	N/A
3-4 PM	0.14	0.44	0.53	0.67	0.38	0.32	N/A	N/A
4-5 PM	0.18	0.52	0.46	0.63	0.27	0.27	0.51	0.50
5-6 PM	N/A	N/A	0.51	0.68	N/A	N/A	0.50	0.41
Average	**0.19**	**0.47**	**0.50**	**0.66**	**0.32**	**0.30**	**0.50**	**0.46**

Figure 4-3 depicts the load impacts on two-hour event days from 4-6 PM for customers with one device and customers with two devices. What is striking about the figure is that although the average customer with two devices has a higher average usage, the event impacts are very similar. To illustrate, the difference between the two groups in terms of average hourly usage is 0.31 kW, with customers with two devices having greater usage.[15] However, in terms of impacts, customers with two devices give average hourly impacts that are only 0.04 kW greater than customers with one device, and that difference is not statistically significant.

These results suggest that installing control devices on houses with more than one CAC may not be cost effective. Customers with two devices, regardless of whether one or both devices are called, show equal or lesser impacts than households with only one CAC. As hardware and installation costs are higher for two devices than for one device, households with one CAC provide much greater impact for the cost.

[12] This number is calculated by comparing average hourly control group usage for both sets of customers.

Figure 4-3: Event Impacts for Two-hour Events
Customers with Two Control Devices Treated vs. Customers with One Control Device



The 2011 evaluation contained an analysis of load impacts at premises where one of two devices was activated for an event. As would be expected, load impacts at these premises are lower than at single-device premises, suggesting that the uncontrolled CAC unit at least partially compensates for the controlled unit by running more. That analysis is not repeated here.

5 Control Device Success Rates

The load control switches and PCTs used to activate events have internal data loggers that keep track of when the device received an event signal; they also record how many minutes per hour the device operated to curtail load (referred to as shed minutes). As an additional part of this evaluation, technicians visited a sample of residential premises to download this internal data and to check on the status of the control device at each sample premise.

A random sample of SmartAC customers, all of whose control device serial numbers ended in 8 was drawn for recruitment by telephone. An additional random sample of customers on SmartRate and SmartAC was drawn for similar recruitment. The SmartRate program is a critical peak price program that subjects customers to up to 15, 5-hour events each summer during which the price of electricity increases by about $0.60/kWh. Dually-enrolled customers have their CAC units controlled during these events, just as SmartAC customers do under SmartAC events.

The group of SmartAC customers was chosen to include only customers with a serial device ending in 8 because in addition to that group's main test event on July 9 and the system-wide event on August 10, four additional notch tests were called on September 13 and 14. In these notch tests, customers were called for two 30-minute events each on each of the days, for a total of four extra events. The dually-enrolled SmartRate/SmartAC group of customers was included because those customers were subjected to 11 events in 2012, which provided a larger set of events for analysis than the SmartAC-only customers. We look at the two groups separately, comparing the success rates.

Customers were offered an incentive of $20 allow a technician to visit their home, note the condition of the control device and download its internal data log. Switches are located outdoors and PCTs are located indoors, which makes this procedure less convenient for customers with PCTs because they must be home to allow the technician access to the device. This means that there is a skew towards switches in both samples. This also reflects the smaller size of the PCT population among residential customers.

The sample of devices visited cannot be considered a completely representative sample because only about 1 in 10 customers phoned agreed to allow the technician access to their device. This implies a large degree of selection bias, although it's hard to know what effect, if any, that bias has on the results below. Additionally, customers with PCTs have a lower rate of acceptance than customers with switches, implying the potential bias may be worse for PCTs. One reasonable possibility is that customers with broken or missing devices would be less likely to allow a technician to have access, suggesting that this sample may over-represent working devices and under-represent broken devices.

A total of 685 home visits were scheduled; however 84 customers were unable to keep appointments, 14 devices were physically impeded, and two customers were no longer in the program. Of those devices successfully visited, 25 were broken, 16 were missing, and 53 had corrupted data or were unable to provide data. Finally, 28 devices did not have data for any dates in 2012; 45 devices had dates in 2012, but no data during event hours; and one additional device was not listed in the current population list so it was also dropped from the analysis. This left a total of 415 devices with usable internal data.

Ignoring the issue of customer self-selection, if we take the 585 devices that technicians accessed as representative of the device population, then this suggests a minimum of 7% broken and missing devices (41/585); and a maximum of 28% devices with operational problems or that are attached to AC units that are rarely or never on ((25+16+53+28+45)/585; including all broken and missing devices and devices with corrupt data or no event data in 2012). If self-selection is an issue here, it probably tends to make these numbers optimistic since customers who have removed or broken their devices are probably less likely to allow technicians to access the devices.

Table 5-1 shows the number of device loggers that were successfully downloaded and that had data for at least one event in the SmartAC-only group as well as the dually-enrolled group. The sample of control data on event days is smaller than the overall set of data downloaded because control data for PCTs does not appear if a customer does not have their thermostat in cool mode or if it was powered off entirely. Additionally, switch logs occasionally have days or hours where data is missing due to an issue with a time sync page getting through to the device —which accounts for the slightly different sample sizes on each SmartAC event day among SmartAC-only switches. Similar issues were also noted in the 2010 and 2011 evaluations.

Table 5-1: Number of Devices with Valid Internal Data during at Least One Event

Device Type	SmartAC-only		SmartRate/SmartAC Dually Enrolled	
	Total Downloaded	Total with Control Data	Total Downloaded	Total with Control Data
Switch	165	165	194	193
Utility Pro	17	8	27	20
Express Stat	6	4	7	5
Total	**188**	**177**	**228**	**218**

Ideally, each device would receive each event signal. For switches and PCTs operating under the TrueCycle2 algorithm, shed minutes should be greater than or equal to 30 minutes per hour for residential devices.

A variety of issues can lead to a device not receiving a control event signal, but the reasons can be divided into two main categories. Devices are sent over-the-air pages at the time of installation which designate the device's address and that page may not get through to the device due to paging system communication issues or because something blocked the signal from getting through such as a thick wall. The device's address tells the device which pages to respond to. Because addressing failure is an operational error which occurs prior to an actual control event, we have attempted to exclude those cases from our calculation of average success rates. Second, control event signals themselves may not get through to devices. This can occur for the same reasons as the address page failure. Both issues are thought to affect PCTs more frequently because they are located indoors while switches are located outdoors.

The remainder of the section is divided between switches and PCTs due to an important difference between the two: for switches, the data logs used to analyze the effectiveness of control signals record shed minutes whether the CAC unit is off or on, but for PCTs, this is not true.

If the PCT is not in cooling mode, then it will record no evidence of the event. However, there is a way to determine whether the PCT was in cooling mode during each event. The PCT records the temperature, the temperature set-point it is programmed to, and the number of minutes the CAC runs each hour. If the PCT shows that the temperature is above the set point but the CAC does not run during a given hour, then it can be inferred that the PCT is not in cooling mode. Therefore, for PCTs, a distinction is made between devices that are not in cooling mode and devices that are in cooling mode and fail to receive a control event signal. Both of these situations lead to zero load impact for the device, but for different reasons and only the second situation reflects a communication failure.

A PCT that is not in cooling mode even on hot days suggests that the CAC has little potential to provide load reduction in the program. On the other hand, a PCT in cooling mode that fails to respond to an event is only an operational problem that can be addressed. Understanding the number of customers, and what types of customers, that do not run CAC on hot days, can have an impact on program recruitment. These customers can be defined through understanding whole premise load profiles and recruitment activities can avoid load profiles incapable of delivering reduction during traditional program hours.

Table 5-2 shows the number of switches with data for each event and the percentage of switches successfully controlled for residential SmartAC-only and dually-enrolled SmartRate SmartAC devices. Among SmartAC-only customers, only devices with serial number ending in 8 were sampled. The Event Type column does not indicate overall whether it was a SmartAC, SmartRate or Both event day. It indicates whether we have recorded logger data from SmartAC customers, SmartRate customers or both types of customers who were supposed to have an event that day.

All events considered, residential switches among dually-enrolled customers successfully received event signals 62% of the time. However, the success rate for dually-enrolled customers for July 9, July 10, July 11 and July 23 was much lower due to a series of system operation issues with calling SmartRate events for customers new to SmartRate in 2012. The issues were resolved at some point in August as can be seen by the other SmartRate only event, September 4, 2012. Ignoring the days affected by that operational problem (which is not a signal reception issue), the average success rate among dually-enrolled customers was 90% and among SmartAC-only customers was 99%.

Table 5-2 presents a decreased number of dually-enrolled customers called for several event days: July 12, 2012, August 2, 2012 and August 13, 2012. These were SmartAC event days only with no corresponding SmartRate events called. For such days, only one tenth of the SmartAC residential population were called on each day as based on the serial number Therefore, a smaller number of dually-enrolled customers were called on those days because they were within those groups.

Table 5-2: Percentage of Switches Controlled and the Number of Devices with Data for Each Event

Event Date	Event Type with Recorded Data	SmartAC-only		SmartRate/SmartAC Dually Enrolled	
		Percentage Controlled	N	Percentage Controlled	N
9-Jul-12	Both	99%	161	32%*	190
10-Jul-12	SmartRate†	N/A	N/A	27%*	190
11-Jul-12	SmartRate†	N/A	N/A	27%*	187
12-Jul-12	SmartAC	N/A	N/A	71%	21
23-Jul-12	SmartRate	N/A	N/A	10%*	173
2-Aug-12	SmartAC	N/A	N/A	75%	12
10-Aug-12	SmartAC System-wide	97%	163	99%	191
13-Aug-12	SmartAC	N/A	N/A	33%	23
4-Sep-12	SmartRate	N/A	N/A	85%	189
13-Sep-12	SmartRate	N/A	N/A	91%	193
13-Sep-12 3 PM (notch)	SmartAC	99%	164	N/A	N/A
13-Sep-12 6PM (notch)	SmartAC	100%	162	N/A	N/A
14-Sep-12	SmartRate	N/A	N/A	91%	193
14-Sep-12 3 PM (notch)	SmartAC	99%	162	N/A	N/A
14-Sep-12 6 PM (notch)	SmartAC	99%	162	N/A	N/A
1-Oct-12	SmartRate†	N/A	N/A	89%	193
Average		**99%**	**162**	**90%**	**127**

***Customers who joined SmartRate in 2012 were not called for the first four SmartRate events due to operational issues. These values are not included in the average calculation because they don't reflect signal reception failure.**

†July 10, July 11, and October 1 were also SmartAC test event days, but the table only includes data for SmartAC-only customers in group 8, which is why those days are listed as SmartRate-only here.

Table 5-3 presents the percentage of PCTs that were in cooling mode during each event, as determined by the temperature, set-point and run time. It also shows the percentage of the PCTs in cooling mode that received a control event signal for each event. The table shows that 78% of residential CAC units enrolled in only SmartAC were cooling during the event, while 66% of dually-enrolled in SmartAC SmartRate CAC units were cooling. Of units that were cooling, 39% of SmartAC-only units received event signals, on average, while 77% of dually-enrolled units did. The sample sizes of PCTs that were in cooling mode are quite small, but the overall average success rate between the two groups of 61% is consistent with previous year's results for PCTs.

Table 5-3: Percentage of PCTs Cooling, Percentage Controlled and the Number of Devices with Data for Each Event

Event Date	Event Type with Recorded Data	SmartAC-only			SmartRate/SmartAC Dually Enrolled		
		N	Percentage Cooling	Percentage Controlled	N	Percentage Cooling	Percentage Controlled
9-Jul-12	Both	8	63%	80%	15	60%	44%*
10-Jul-12	SmartRate†	N/A	N/A	N/A	20	65%	39%*
11-Jul-12	SmartRate†	N/A	N/A	N/A	21	62%	70%*
12-Jul-12	SmartAC	N/A	N/A	N/A	1	100%	100%
23-Jul-12	SmartRate	N/A	N/A	N/A	16	63%	40%*
2-Aug-12	SmartAC	N/A	N/A	N/A	3	67%	50%
10-Aug-12	SmartAC System-wide	10	90%	67%	18	67%	75%
13-Aug-12	SmartAC	N/A	N/A	N/A	0	0%	0%
4-Sep-12	SmartRate	N/A	N/A	N/A	21	67%	79%
13-Sep-12	SmartRate	N/A	N/A	N/A	24	71%	82%
13-Sep-12 3 PM (notch)	SmartAC	13	77%	30%	N/A	N/A	N/A
13-Sep-12 6 PM (notch)	SmartAC	13	85%	36%	N/A	N/A	N/A
14-Sep-12	SmartRate	N/A	N/A	N/A	22	64%	71%
14-Sep-12 3 PM (notch)	SmartAC	14	86%	25%	N/A	N/A	N/A
14-Sep-12 6 PM (notch)	SmartAC	14	64%	22%	N/A	N/A	N/A
1-Oct-12	SmartRate†	N/A	N/A	N/A	23	61%	79%
Average		**12**	**78%**	**39%**	**16**	**66%**	**77%**

***Customers who joined SmartRate in 2012 were not called for the first four SmartRate due to an operational problem. These values are not included in the average calculation because they don't reflect signal reception failure.**

†July 10, July 11, and October 1 were also SmartAC test event days, but the table only includes data for SmartAC-only customers in group 8, which is why those days are listed as SmartRate-only here.

6 Residential SmartAC Ex Ante Methodology

This section explains the steps used to predict ex ante load impacts for residential SmartAC customers. There are two issues that must be dealt with in this modeling. First, the weather observed during events in 2012 and 2011 is different than the ex ante weather conditions of interest. Second, the hours over which test events occurred, for the most part, do not match the resource adequacy window of 1-6 PM, for which ex ante impacts must be estimated.

The ex ante weather conditions are the same that were used for the 2011 SmartAC evaluation and have been chosen to be representative of 1-in-2 and 1-in-10 monthly peak days and 1-in-2 and 1-in-10 typical event days

At a high level, the modeling steps consist of the following analysis:

- First, a regression model was developed to explain average ex post impacts from 4-5 PM as a function of recent temperatures. This model was estimated across all of the LCAs together — a change from 2011. The model was used to estimate average impacts from 4-5 PM for the set of ex ante weather conditions. The estimates of the average impact from 4-5 PM were then converted to hourly impacts from 1-6 PM using a scaling factor based on load impacts observed during longer events.
- Next, whole-house reference loads from 4-5 PM were predicted for each set of ex ante weather conditions based on the loads observed over the summers of 2012 and 2011. Load shapes were estimated by taking the average load for each hour of the day, by LCA. The same load shapes calculated based on the entire residential SmartAC population were used in the dually-enrolled analysis as well.
- Finally, a similar regression model was applied to snapback as was applied to event impacts.

The first step, which provides estimated load impacts, is described in detail below. The steps used to predict whole-house loads and snap-back are described in Appendix A.

6.1 Accounting for Dually-Enrolled Customers

Ex ante impact estimates for the SmartAC program were calculated by making predictions for ex ante weather conditions using a regression model of adjusted ex post impacts. Adjusting the ex post SmartAC program impacts was necessary as much more of the SmartAC population was also dually-enrolled in SmartRate in 2012 than in previous years. The adjustment wasn't necessary in 2011 because such a small fraction of SmartAC customers were on SmartRate as well (about 3%). The 2012 SmartAC program ex post load impact tables do not include dually-enrolled customers but those customers would provide load impacts if the program were called in an emergency where SmartRate is not already called, so it is necessary to include them in ex ante modeling. The reason for excluding them from the main ex post load impact tables is that for all but three events in 2012, there were SmartRate events on the same day which make SmartAC-specific impact estimation for these customers impossible to estimate accurately. In this section we do provide ex post impact estimates for dually-enrolled customers on the three SmartAC event days when no SmartRate event was called.

This is an important issue for ex ante estimation because these dually-enrolled customers do not show the same average impacts on SmartAC-only event days as SmartAC-only customers. In 2012, dually-enrolled customers show both decreased loads and impacts as compared to SmartAC-only customers. This appears to be completely due to differences in underlying characteristics SmartAC-

only and dually-enrolled customers. It does not reflect any failing on the part of either the SmartAC or SmartRate program. Lower usage customers within the SmartAC population appear to find SmartRate attractive. This makes sense since many of them may be structural winners (meaning they save money by being on SmartRate with no adjustment in usage).

Table 6-1 provides evidence that the dually-enrolled population is fundamentally different from the SmartAC-only population. The table shows two quantities for SmartAC-only and dually-enrolled customers: it shows average monthly usage from May-October 2012; and it shows average hourly usage for control group customers during for the three SmartAC events that did not overlap with SmartRate events. Dually-enrolled customers show less average monthly usage across all LCAs as well as smaller hourly loads.

Table 6-1: 2012 Residential SmartAC and Dually-Enrolled Customer's Monthly and Peak Usages

Local Capacity Area	Monthly Usage (kWh)		Whole-Building Reference Load 1-6 PM (kW)	
	SmartAC-only	Dually-Enrolled	SmartAC-only	Dually-Enrolled
Greater Bay Area	605	541	1.85	1.34
Greater Fresno	623	547	3.16	2.74
Kern	556	525	3.20	2.82
Northern Coast	598	500	1.36	1.11
Other	607	524	2.53	2.09
Sierra	705	611	2.97	2.60
Stockton	640	569	2.80	2.39

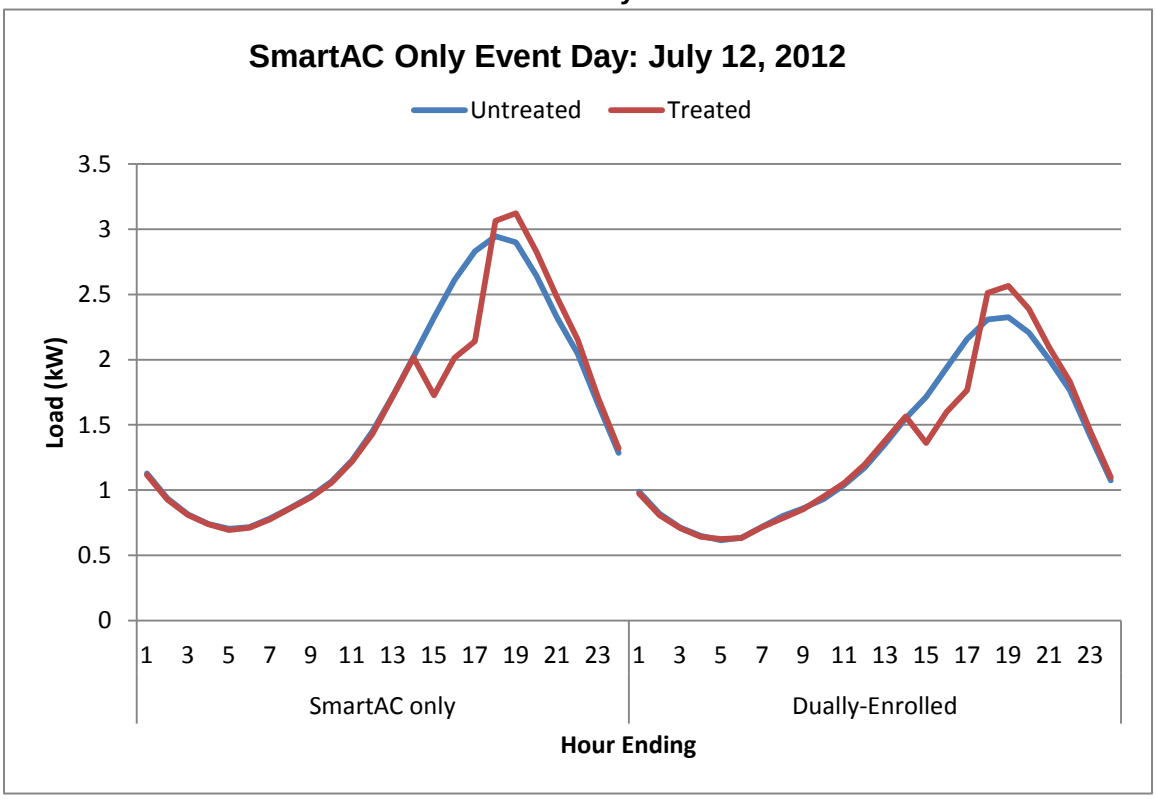
Table 6-2 shows impact estimates for the three days when a SmartAC event was called in absence of a SmartRate event. The table shows impact estimates for SmartAC-only customers and dually-enrolled customers. Impacts are estimated using the same treatment-control methodology that was used in the main ex post analysis. That is, 1/10 of each population was called for the event and the remaining 9/10 is used as a control group. For SmartAC-only customers, the control group is made up of SmartAC-only customers; and for dually-enrolled customers, the control group is made up of only dually-enrolled customers. As the table shows, the impacts for dually-enrolled customers when only a SmartAC event is called are significantly lower than for the SmartAC-only customers on the same days. Figure 6-1 highlights the differences between the SmartAC-only and dually-enrolled customers, in both control and treatment groups for the three days.[16]

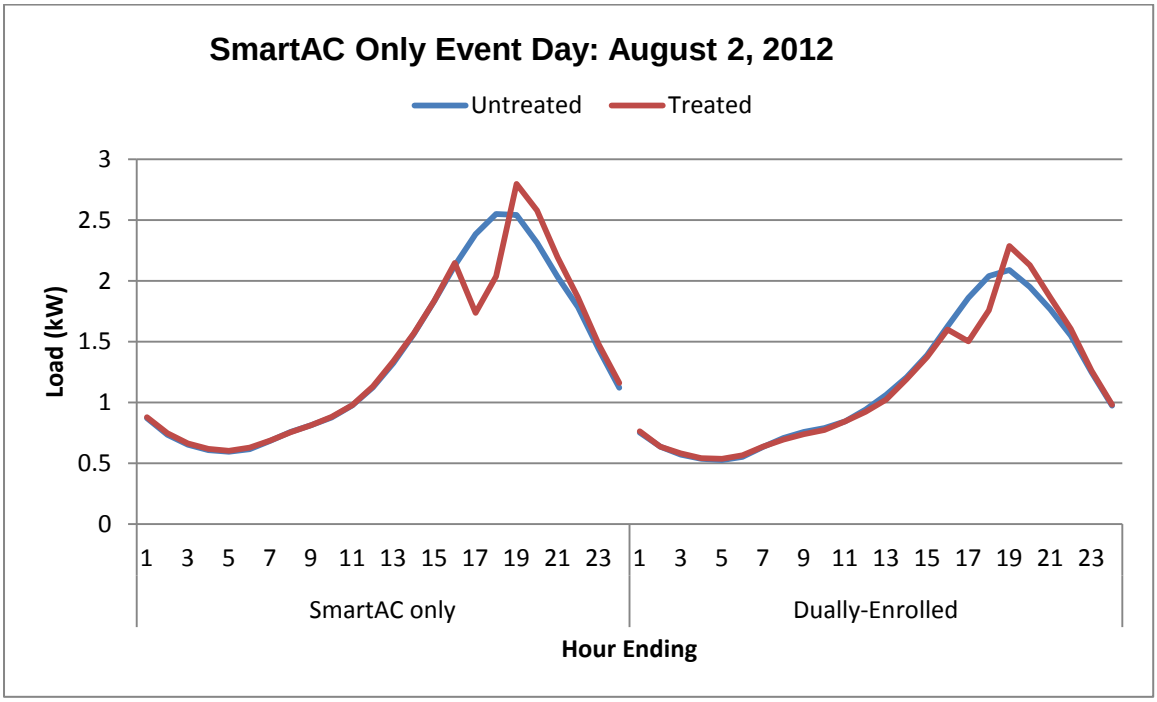
[16] To be clear: neither Table 6-2 nor Figure 6-1 tells us anything about the performance of the SmartRate program. Both the table and the figure focus on days when only SmartAC was called, and we then focus on the difference between SmartAC customers who are enrolled on SmartRate or not. For a comprehensive treatment of the load impacts for dually-enrolled customers when SmartRate is called (which automatically entails SmartAC load control for dually-enrolled customers) see "2012 Load Impact Evaluation of Pacific Gas and Electric Company's Residential Time-based Pricing Programs" prepared for PG&E by the FSC Group.

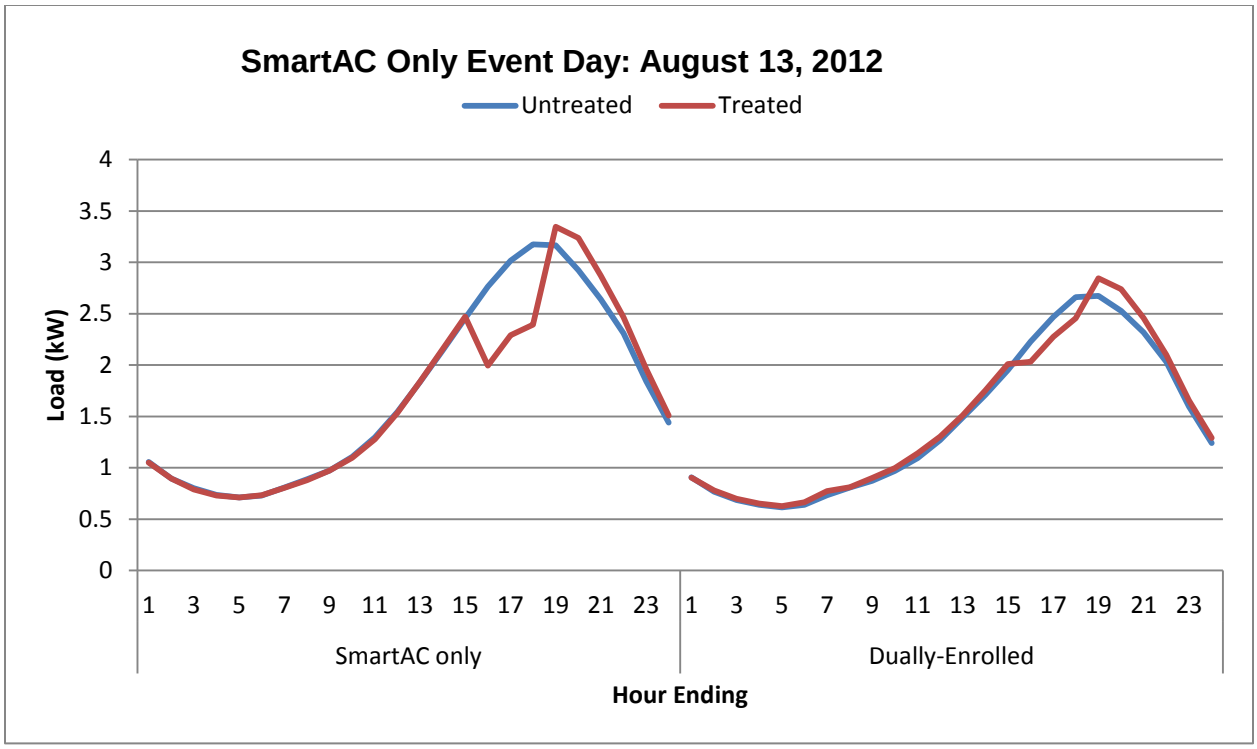
Table 6-2: 2012 Residential SmartAC and Dually-Enrolled Impacts

Date	Hour	Impact		Total Treated and Control	
		SmartAC-only	Dually-Enrolled	SmartAC-only	Dually-Enrolled
12-Jul-12	2 – 3 PM	0.59	0.35	104,058	17,876
	3 – 4 PM	0.60	0.34	104,058	17,876
	4 – 5 PM	0.69	0.39	104,058	17,876
2-Aug-12	4 – 5 PM	0.65	0.36	105,164	17,904
	5 – 6 PM	0.51	0.28	105,164	17,904
13-Aug-12	3 – 4 PM	0.77	0.20	105,575	17,911
	4 – 5 PM	0.73	0.19	105,575	17,911
	5 – 6 PM	0.78	0.21	105,575	17,911

Figure 6-1: Comparison of Residential SmartAC and Dually-Enrolled Loads on SmartAC-only Event Days







To include dually-enrolled customers in the ex post impacts for modeling, we calculated the average ratio between the impacts from 4-5 PM for the SmartAC-only customers and those who were dually-enrolled, at the LCA level. This calculation was only performed over July 12, 2012, August 2, 2012, and August 13, 2012 because those are the only days when SmartAC event impacts can be estimated for dually-enrolled customers in the absence of SmartRate. We multiplied the ex post impacts by this ratio at the LCA level to produce an estimated impact for from 4-5 PM for dually-enrolled customers for each LCA and each event. We then calculated whole program ex post impacts for modeling as a weighted average of the estimated impacts for SmartAC-only customers and the estimated impacts for dually-enrolled customers. Table 6-3 shows the ratios used to calculate the new impacts as well as the distribution of SmartAC-only and dually-enrolled customers. For example, on July 10, 2012 in the Stockton LCA, we observed an impact of 0.62 kW for the SmartAC-only customers. We then found the expected impact for dually-enrolled customers by multiplying this impact by 0.41, the ratio for Stockton in Table 6-3, giving an impact of 0.25 kW. We then weighted each impact by their respective percentages before adding them for the final adjusted impact of 0.55.

One implication of this strategy is that there are no explicit ex ante estimates separately for SmartAC-only customers and dually-enrolled customers. This is in contrast to the situation for SmartRate where there is a wholly-separate modeling exercise for SmartRate-only and dually-enrolled customers. This is because the data for modeling the SmartAC-specific (meaning load control without a change in price) impact for dually-enrolled customers is sparse (only three events), while there is a richer set of data for modeling the impacts of SmartRate plus load control for dually-enrolled customers. The model here implies SmartAC-specific ex ante impacts for dually-enrolled customers equal to the impacts for SmartAC-only customers, adjusted down by the ratios in Table 6-3. Colloquially, because there is very little data for modeling the SmartAC-specific impacts for dually-enrolled customers, we

have allowed those customers to piggyback on our SmartAC-only modeling effort, with a fairly rough adjustment, as per Table 6-3. In the future it may be worth deliberately calling SmartAC events on days when SmartRate is not called for the sake of better understanding the attribution issue for dually-enrolled customers.

These implicit ex ante values are used in the attribution of portfolio-adjusted impacts to the SmartRate program, as discussed in the SmartRate evaluation, referenced above. Portfolio-adjusted impacts for SmartAC are identical to program-specific impacts, so this issue is less important for this evaluation.

Table 6-3: 2012 Ratios Between Residential SmartAC and Dually-Enrolled Customer's Hour 4-5 PM Impacts

Local Capacity Area	Ratio	Percent Dually-Enrolled	Percent SmartRate Only
Greater Bay Area	0.44	21	79
Greater Fresno	0.60	12	88
Kern	0.10	24	76
Northern Coast	0.07	17	83
Other	0.57	17	83
Sierra	0.65	19	81
Stockton	0.41	18	82

Having adjusted the ex post impacts to reflect the contribution of dually-enrolled customers, the next step is to model ex post load impacts as a function of temperature.

6.2 Regression Modeling

For those familiar with the regression modeling approach used to estimate load impacts in other load impact evaluations such as the statewide Aggregator Program or statewide CPP, note that this methodology is quite different. Under the experimental design for test events in this evaluation, virtually no modeling is required to produce ex post impacts. In previous years, both ex post and ex ante impacts were an output of the same regression model. Here, ex post impact estimates are taken as the dependent variable in an ex ante regression model. This is a substantial step forward in modeling impacts because it has taken virtually all the uncertainty out of the ex post step of the process. Previously, to argue about ex ante impacts was equivalent to arguing about ex post impacts because the same model produced both sets of impacts. In this evaluation, there is very little to argue about regarding ex post impacts. The only serious uncertainty that remains is how to best use ex post impacts to predict ex ante impacts.

An important technical detail in the modeling is that Cooper's control algorithm begins each event by randomizing the start time of the control devices in the first half hour of the event. AS such, some AC units are not controlled until 30 minutes in to the event, and in our test events, on average, each

customer starts the event 15 minutes into the hour, meaning that load impacts are about 45/60=75% of their potential in the first hour. For our ex ante modeling, we assume PG&E anticipates this issue when calling the program and begins the event 30 minutes before the hour such that all devices will be controlled at the hour. Given this assumption, we scale up the ex post impact of the first hour of each event by 60/45=1.33 so that estimated ex ante load impacts represent the potential of the program once all AC units are controlled.

To determine the best regression to use for ex ante predictions, FSC tested 64 different models for predicting ex post impacts for 2011 and 2012 for the hour 4-5 PM based on different measures of recent temperature. The models include eight possible specifications of recent temperature using hourly cooling-degree hours (CDH) with a base temperature of 70°F, total CDH, average temperature and quadratic terms of some of these. The 8 specifications were then estimated using 8 different sets of hours of weather each, from the previous 3 hours to the previous 24 hours. As an example, one specification contained average CDH over the previous three hours and the same variable squared as its independent variables. Another contained similar variables, but calculated over the previous six hours. Yet another specification was similar, but used temperature instead of CDH. These 8 specifications by 8 sets of hours produced 64 different possible models.

The testing consisted of a technique known as cross-validation (which we also have sometimes referred to as out-of-sample testing). In this technique, the impact of each test event in each LCA is withheld from the regression model sequentially, one at a time, and the model is fit to the remaining test events each time and used to predict the load impact for the withheld event. This leads to a dataset of estimated load impacts for each test event, which can be compared to the actual ex post load impact for that event. Each model's performance is summarized using the mean absolute percent error across all test events. The same procedure was used for the 2011 evaluation. An important point is that the predictive abilities of several different models were virtually identical, and more sophisticated models (including polynomials in temperature or cooling degree hours, or more complicated weighted averages of temperature) did not perform better than simpler averages of temperature. Because several models were essentially tied at the top for best performance, including the 2011 model, the same model from 2011 was used again. Its specification is:

$$Impact_c = a + b \cdot mean17_c + \boldsymbol{\varepsilon}_c$$

Table 6-4: Description of CAC Load Regression Variables

Variable	Description
$Impact_c$	Average per customer ex post load impact for each event day from 4-5PM
a	Estimated constant
b	Estimated parameter coefficient
$mean17$	Average temperature over the 17 hours prior to the start of the event
$\boldsymbol{\varepsilon}_t$	The error term, assumed to be a mean zero and uncorrelated with any of the independent variables

The average temperature over the previous 17 hours was chosen as the weather variable for modeling based both on its predictive ability and on the fact that ex ante impact prediction is based on only one day's worth of temperature data for each set of conditions. Models using several other sets of hours

of average temperature performed similarly in prediction, but would require additional assumptions about weather in the day prior to each ex ante day. Using the previous 17 hours makes full use of the available ex ante weather information without requiring additional assumptions and without sacrificing model accuracy. Models using temperature as far back as 48 hours prior to the event were tested, but were not found to perform better than the model using 17 hours.

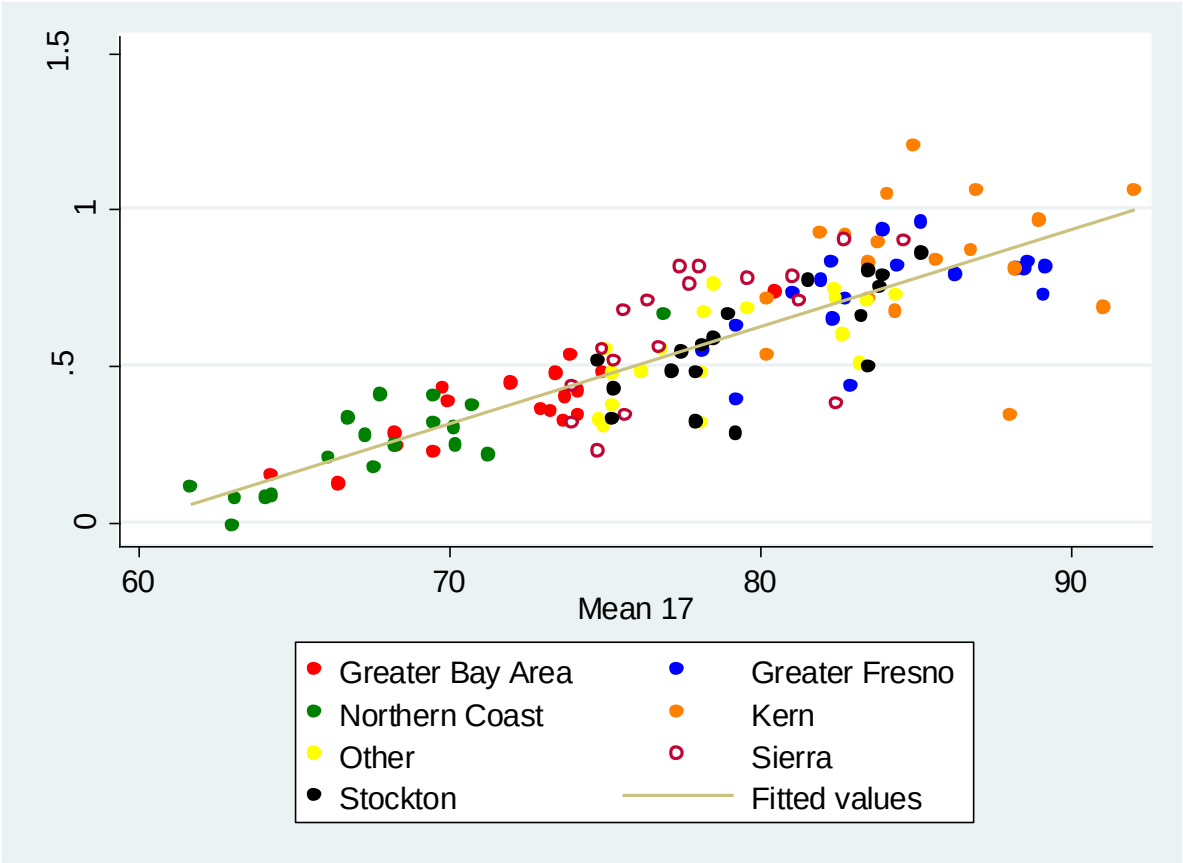
It is quite likely that event impacts depend on variables other than this average of recent temperatures, but after two seasons of test events and no large improvement in predictive accuracy based on using more complicated models, it is becoming dubious how much more variation in load impact will ever be predictable using currently available observable variables. FSC is currently performing an exercise using three years of ex post load impacts on PG&E's SmartRate population to estimate the lowest variance we might ever expect to see in load impact prediction for that program. After one or two more seasons of test events, a similar exercise would probably be useful here.

The choice of using load impact measured for the window 4-5 PM for the dependent variable was made because all test events covered the hours 4-5 PM. Side-by-side testing done in 2011 and 2012 has produced mixed results as to whether load impacts at a given hour of the day vary systematically depending on the length of the event up until that time. Currently, there is no strong evidence of such systematic variation. Additionally, given the control strategies currently in use, there is no strong technical reason to expect impacts to vary according to the length of the event prior to measurement. Therefore, for the sake of modeling simplicity and making the most of available data, we treat all impacts observed at the same hour of the day as comparable from a modeling standpoint.

In 2011, modeling was done for each LCA, mainly independently.[17] In this year's modeling, it was found that the ex post impacts across each LCA appeared to follow essentially the same trend with respect to *mean17*. This is shown in Figure 6-2. This implies that whether impacts are modeled separately for each LCA or using one model will have little impact on the ultimate results — a fact verified by FSC. For simplicity, one common model is used for all LCAs.

[17] Results across different LCAs were used in cases where ex ante temperatures exceeded temperatures observed in a particular LCA, as described in that report.

Figure 6-2: Average Event Impacts From 4-5 PM Versus Mean17 Across All LCAs

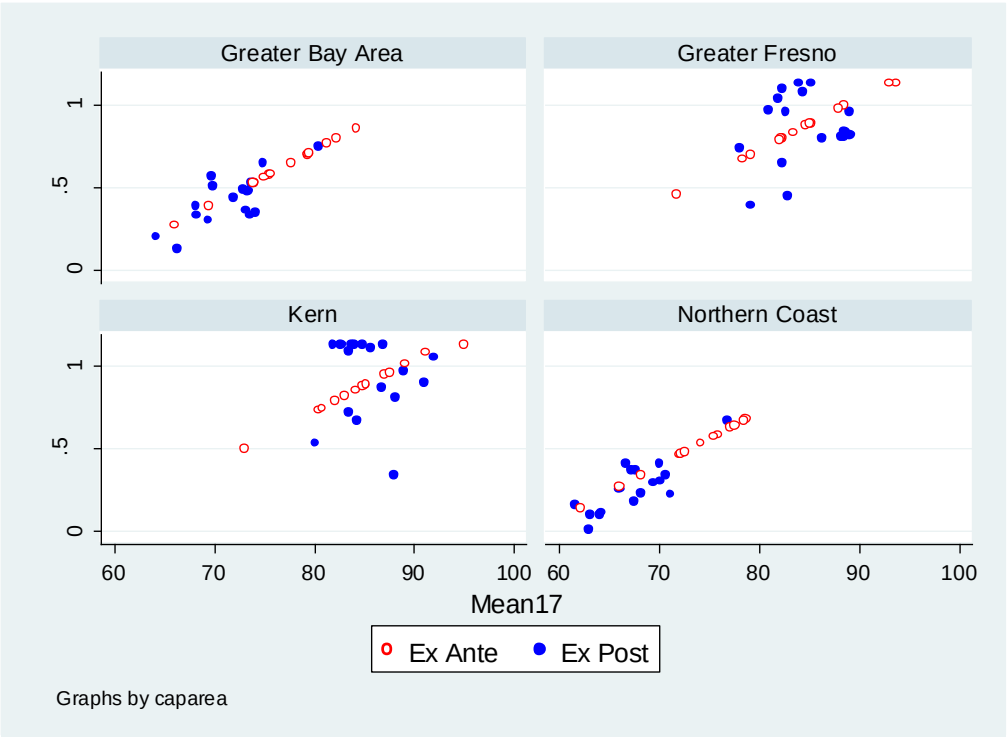


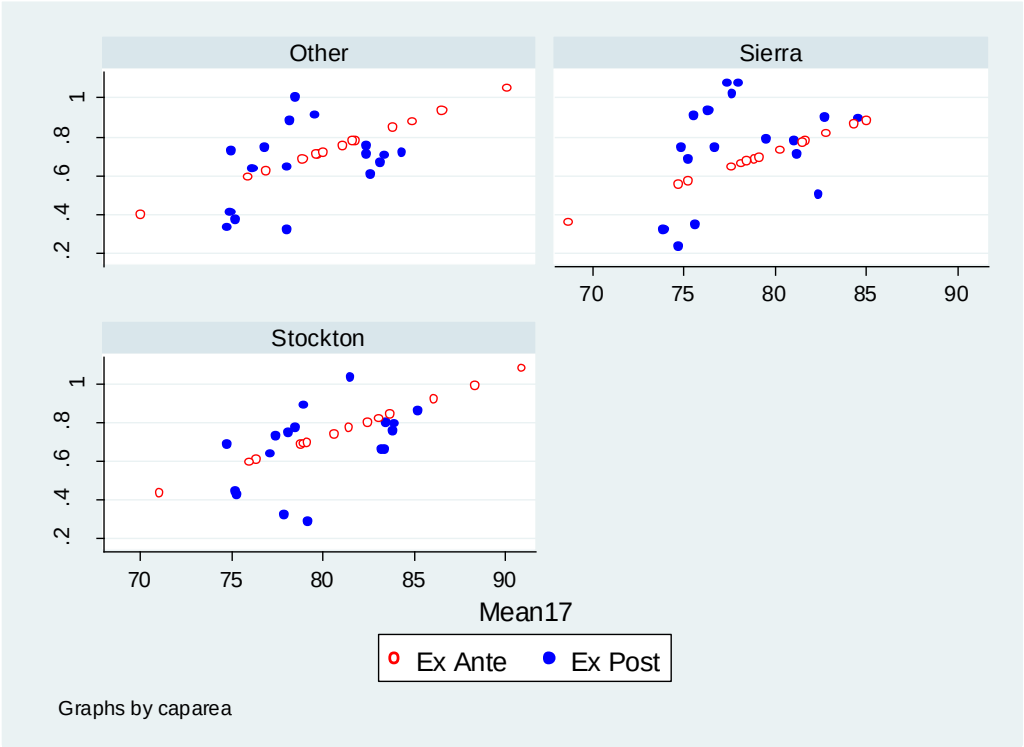
After using the trend line from Figure 6-2 to predict impacts from 4-5 PM, all impacts were capped at 1.125 kW per customer. This is 45% of the maximum average CAC load seen for any well-represented LCA in the CAC logger data collected during summer 2009 for the SmartAC evaluation. This dataset is appropriate to use here because there were no test events in 2009 and because there were several days for which temperatures in particular LCAs significantly exceeded 105°F — reaching 112°F at one point in one LCA. This cap is based on the assumption that under real world conditions, the greatest load reduction likely to be achieved through 50% cycling is 45%. The basis for this assumption is that communication with control devices will never be perfect and the TrueCycle2 algorithm will never perform perfectly. This cap affected 3 out of 98 LCA-level ex ante predictions. For example, the LCA-level regression predicted an average hourly impact from 4-5 PM of 1.19 for the August system peak day in a 1-in-10 weather year for Greater Fresno. The average of *mean17* for that day was 94°F – which is more than 4 degrees greater than the maximum *mean17* seen for the Greater Fresno LCA during 2011 or 2012. In cases like this, capping keeps the impacts within a realistic range.

Figure 6-3 displays the final ex ante and ex post estimates graphed against *mean17* by LCA. The solid blue circles represent ex post results and the hollow red circles are ex ante results. By graphing both ex ante and ex post results on the same plot, the figure shows that the ex ante results follow the same trend as the ex post results for each LCA, even though the model is based on ex post results

across all LCAs. There is a small amount of variation between the ex post and the ex ante results due to the decision to perform the regression not at the LCA-level. FSC also produced alternative ex ante impact estimates using LCA-specific models and the results were similar to these results. The effect of the cap on impacts is visible for the highest impacts for Greater Fresno, Kern and Sierra.

Figure 6-3: Ex Post and Ex Ante Impacts Versus Mean17 by LCA





The last step in estimating load impacts was to translate average impacts from 4-5 PM to hourly impacts over the entire range of time required for prediction, 1-6 PM. Using ex post impact estimates

from all of the events, which fell between the hours of 1-6 PM, the average impact for each hour from 1-6 PM was expressed as a fraction of the average impact from 4-5 PM. Then, for each hour, separate models were developed of this fraction as a function of *mean17*, using the same specification as was used to model impact magnitudes from 4-5 PM above. The results of this modeling are shown in Figures 6-4 and 6-5. Figure 6-4 shows how this modeling works for each hour (hour 14 indicates the hour ending at 14:00 or 1-2 PM, and so forth). Each graph within the figure shows a scatter plot of the ratios between the ex post impact estimates for that hour and the ex post impact estimates for 4-5 PM against mean17. The graphs include all such ratios calculated for each LCA over all events from 2011 and 2012. The graphs also show the trend line for each hour, which is used to provide estimates of each hour's respective ratio under each set of ex ante conditions. Figure 6-5 shows the trend lines together on one graph.

Figure 6-4: Impact Ratios for Each Hour to Hour 17 (4-5 PM) as a Function of *Mean17*

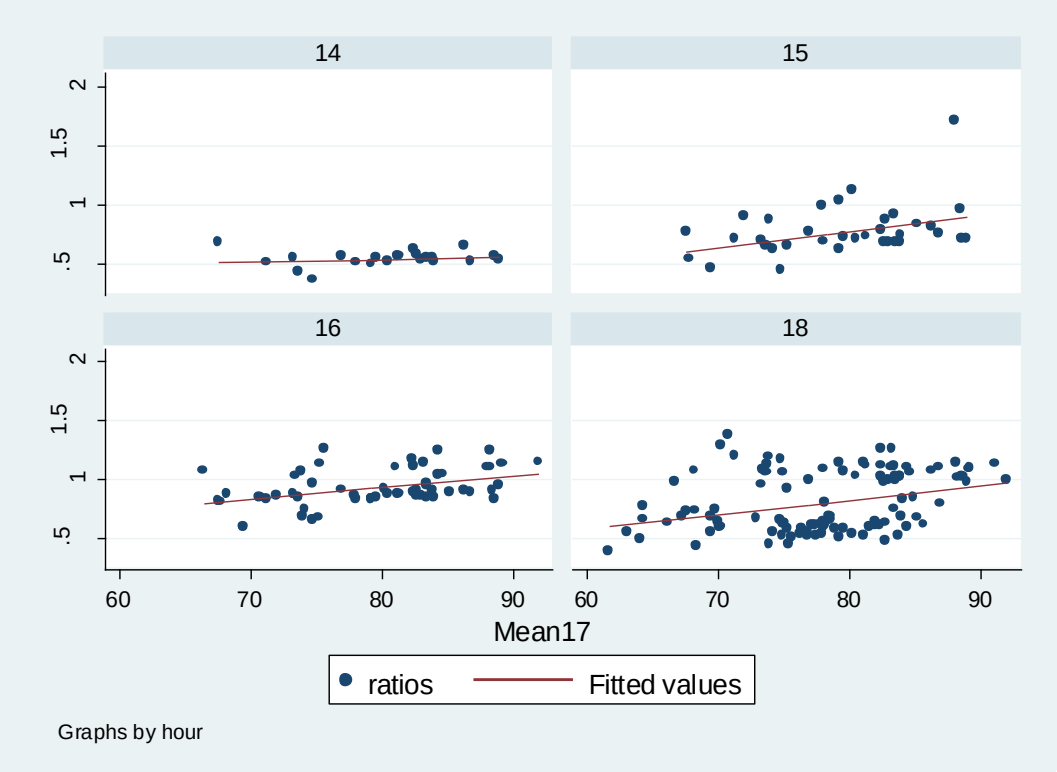
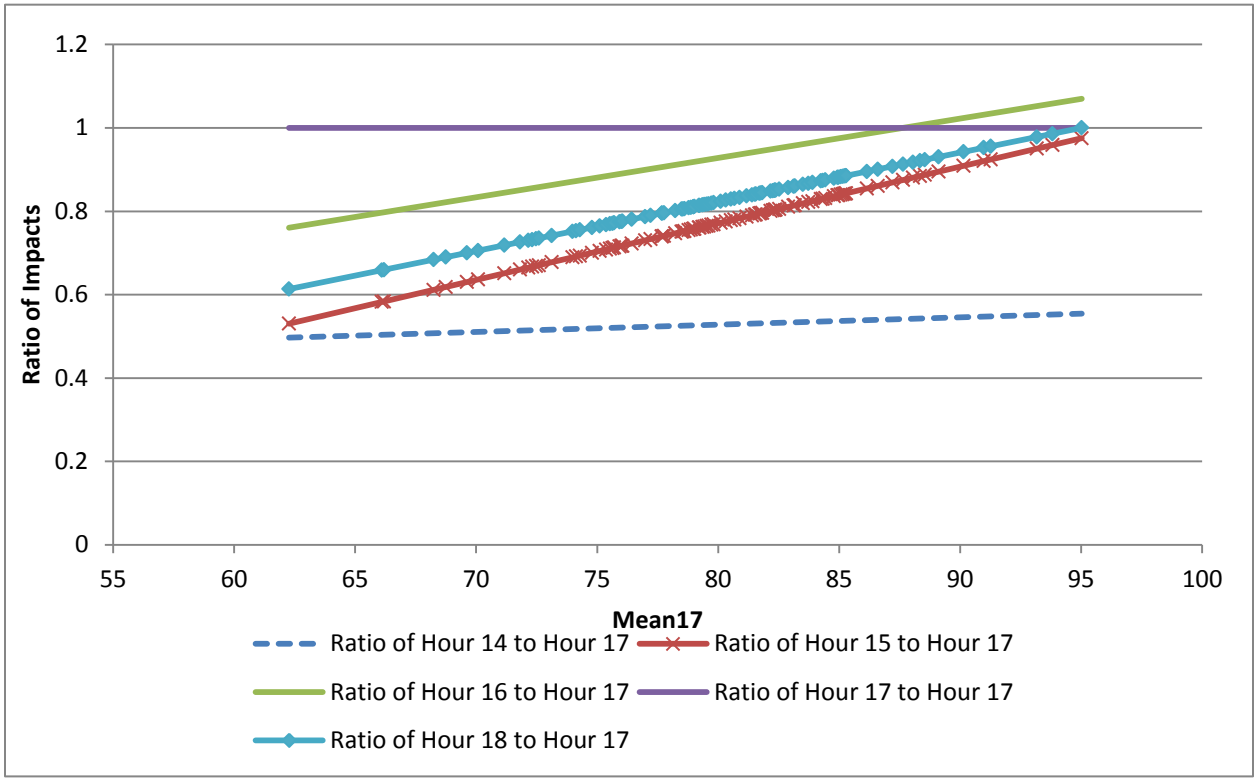


Figure 6-5: Impact Ratios for Each Hour to Hour 17 as a Function of *Mean17*



The regression functions underlying the trend lines were then used to estimate impacts as fractions of the impact from 4-5 PM for each set of ex ante weather conditions for each LCA. These fractions were multiplied by the already-predicted impacts from 4-5 PM to produce impact estimates for each set of ex ante weather conditions over the period 1-6 PM.

The advantage of this strategy for estimating impacts across all hours is that it forces load impacts across all hours to make sense with respect to each other. A common alternative in load impact evaluations is to model each hour completely independently. In cases with modest amounts of data or modest variation in observed conditions and impacts (as is frequently the case) this can lead to unreasonable results where, for example, the function that determines impacts from 4-5 PM is quite different from the function that determines impacts from 5-6 PM. This can lead to implausible impact estimates for particular hours. In our strategy, the fundamental relationship between event impact and temperature is allowed to be determined completely by the data, but we enforce a certain amount of uniformity on the relative load impacts across hours, recognizing that we lack the data to model each hour completely independently.

7 SmartAC Ex Ante Load Impact Results

The SmartAC program is intended to alleviate system stress during times of very high demand. The primary purpose of this evaluation is to predict load impacts during such conditions. These ex ante predictions cover a pre-chosen set of temperature profiles meant to mimic what could be expected for monthly system peak days that might occur every other year and every tenth year. Aggregate estimates of load impacts combine estimates of per customer load impacts developed in this report with estimates of program enrollment, developed in a separate effort by PG&E.

As mentioned previously, the ex ante weather conditions are sometimes outside of the range of weather that was observed in 2012 in some LCAs. This means that the model's predictions are extrapolations outside of the range of available data, which adds uncertainty. However, since we use one model across all LCAs, we were able to use data from LCAs that experienced higher temperatures to help predict for generally cooler LCAs.

Enrollment projections for residential customers by local capacity area as of August of each year are presented in Table 7-1. The source for these projections is PG&E's enrollment projections for 2013-2023.

Table 7-1: Projected Residential Enrollment for August of Each Year (1000s of Customers)

LCA	2013	2014- 2023
Greater Bay Area	54.5	55.1
Greater Fresno	26.4	26.4
Kern	6.5	6.5
Northern Coast	9.5	9.6
Other	28.3	28.4
Sierra	18.1	18.2
Stockton	13.5	13.6
Total	157.0	158.0

Ex ante load impact estimates are shown for residential customers in Table 7-2, including dually-enrolled customers. The first column shows the average hourly per customer ex ante load impact estimate over the event period from 1-6 PM and the second column shows the maximum per customer hourly impact estimate during the event. The third column shows the estimated aggregate load impact over the period 1-6 PM. The first set of rows corresponds to 1-in-2 weather conditions while the second set covers 1-in-10 weather conditions. For the 1-in-2 weather year, the highest estimated impact is on the July peak day, with an average impact of 104 MW and a peak hourly impact of 125 MW. The July peak day also shows the highest impacts for the 1-in-10 weather year. The mean impact over the five-hour event is 129 MW and the peak hourly impact is 149 MW.

Table 7-2: 2013 Residential SmartAC Ex Ante Load Impact Estimates By Weather Year and Day Type (Event Period 1-6 PM)

Weather Year	Day Type	Mean Hourly Per customer Impact (kW)	Max. Hourly Per customer Impact (kW)	Aggregate Mean Hourly Impact (MW)	Aggregate Max Hourly Impact (MW)
1-in-2	Typical Event Day	0.54	0.67	84	105
	May Peak Day	0.38	0.48	59	76
	June Peak Day	0.45	0.58	70	90
	July Peak Day	0.66	0.80	104	125
	August Peak Day	0.52	0.65	81	102
	September Peak Day	0.53	0.66	83	103
	October Peak Day	0.29	0.39	45	61
1-in-10	Typical Event Day	0.70	0.83	110	131
	May Peak Day	0.59	0.73	92	113
	June Peak Day	0.65	0.78	101	123
	July Peak Day	0.82	0.95	129	149
	August Peak Day	0.74	0.86	115	135
	September Peak Day	0.59	0.72	92	113
	October Peak Day	0.51	0.64	80	101

Residential ex ante impacts have changed modestly since the previous evaluation for three reasons (all of which are discussed in section 6):

- We have used a unified model across all LCAs, rather than LCA-specific models;
- We have modeled the hourly impact ratios as a function of temperature rather than using a single value per LCA;
- The fraction of dually-enrolled customers increased substantially, requiring additional modeling; and
- We have scaled up first hour ex post impacts to use for modeling.

The overall result is that ex ante estimates are quite similar on average, with small differences for each set of conditions from what was reported last year.

The Typical Event Day estimates in Table 7-2 are based on projected August 2013 enrollment. The Excel-based load impact tables that accompany this report provide substantially more information about the ex ante conditions, load shapes and impact estimates than is practical to include here. In interpreting those results, it is important to keep in mind that loads and load impacts depend not only on the temperature during the event, but also on the temperature before the event. Two days with the same high temperature can provide very different load impacts if one of them has a much higher overnight low due to heat retention in buildings.

The SMB segment of the SmartAC program is currently not recruiting new customers. No EM&V test events were called for this group during summer 2012 and no ex post impacts were estimated. Therefore, no new load impact information is available to use to alter the per device ex ante estimates from 2011. The operations of the SMB segment have not changed since 2011, and so the per device ex ante values for this segment are the same as in the 2011 evaluation. The only source of change in ex ante load impact estimates for SMB customers is a new set of enrollment projections.

Enrollment projections for SMB customers by local capacity area as of August of each year are presented in Table 7-4. The source for these projections is PG&E's enrollment projections for 2013-2022.

Table 7-4: Projected SMB Enrollment for August of Each Year

LCA	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Greater Bay Area	1,791	1,650	1,520	1,401	1,290	1,189	1,096	1,009	930	857	790
Greater Fresno	744	686	632	582	536	494	455	420	387	356	328
Kern	223	205	189	174	160	148	136	125	116	106	98
Northern Coast	584	538	496	457	421	388	357	329	303	280	258
Other	1060	976	900	829	764	704	648	597	550	507	467
Sierra	405	373	344	317	292	269	248	228	211	194	179
Stockton	376	346	319	294	271	250	230	212	195	180	166
Total	5,182	4,775	4,399	4,054	3,735	3,441	3,171	2,921	2,692	2,480	2,285

Table 7-4 shows the per-customer and aggregate ex ante impact estimates. For the 1-in-2 weather year, the highest aggregate mean hourly impact occurs on the July peak day, with an impact of 3.6 MW. The highest individual hourly impact during a 1-in-2 year is also the July value – 4.3 MW. The July peak day also shows the highest impacts for the 1-in-10 weather year. The largest aggregate impact over the five-hour event is 4.1 MW and highest individual hour provides an estimated impact of 4.8 MW.

Table 7-5: 2012 SMB SmartAC Load Impact Estimates By Weather Year and Day Type (Event Period 1 to 6 PM)

Weather Year	Day Type	Mean Hourly Per Customer Impact (kW)	Max. Hourly Per Customer Impact (kW)	Aggregate Mean Hourly Impact (MW)	Aggregate Max Hourly Impact (MW)
1-in-2	Typical Event Day	0.55	0.65	2.9	3.4
	May Peak Day	0.37	0.45	2.0	2.4
	June Peak Day	0.47	0.56	2.4	2.9
	July Peak Day	0.69	0.81	3.6	4.3
	August Peak Day	0.55	0.65	2.8	3.4
	September Peak Day	0.51	0.61	2.6	3.1
	October Peak Day	0.32	0.39	1.7	2.0
1-in-10	Typical Event Day	0.72	0.85	3.7	4.4
	May Peak Day	0.63	0.74	3.3	3.9
	June Peak Day	0.66	0.78	3.5	4.1
	July Peak Day	0.79	0.93	4.1	4.8
	August Peak Day	0.76	0.88	3.9	4.6
	September Peak Day	0.61	0.72	3.1	3.7
	October Peak Day	0.50	0.59	2.5	3.0

The Typical Event Day estimates are based on projected August 2013 enrollment. The Excel-based load impact tables that accompany this report provide substantially more information about the ex ante conditions, load shapes and impact estimates than is practical to include here. In interpreting those results it is important to keep in mind that loads and load impacts depend not only on the temperature during the event, but also on the temperature before the event. Two days with the same high temperature can provide very different load impacts if one of them has much higher overnight low due to heat retention in buildings.

8 Conclusions

The SmartAC program has shown quite consistent operations for the past two seasons. Because PG&E currently offers only the switch to its residential recruits, the primary operational deficiency — poor communication for PCTs — has already been addressed. As discussed in the recommendations section, the next steps for the EM&V effort of the program should focus on impact estimation to more directly aid the use of the program as a resource for Transmission & Distribution and to understand load impacts outside the resource adequacy window.

Additionally, continued side-by-side testing of events starting at different times will enable more accurate modeling in the future.

Appendix A Residential Ex Ante Load Impact Tables Methodology

A.1 Estimating Ex Ante Load Without DR

Although estimating impacts is the most important part of the ex ante analysis, whole-building reference load data is needed to illustrate the magnitude of impacts. This estimation took place in three steps:

1. The average hourly usage for each LCA was calculated based on control group load for all 16 event days from 2011-2012. This provides an average hot-day load shape, but does not account for temperature variation;
2. Next, a regression model, which was similar to the one used to predict load impacts, was also used to model average whole-building loads from 4-5 PM. The regression had the same form and the same independent variable as the load impact regression. Only the dependent variable was different. Also, each regression was estimated only at the LCA level — no pooled estimates were used — and the values for whole-building load were not capped. This model was used to predict average loads without demand response from 4-5 PM for each set of ex ante weather conditions; and
3. Finally, each LCA's control load during each hour for each set of ex ante conditions was adjusted up or down by the ratio of the load predictions from step 2 by the average building load from 4-5 PM in step 1.

Figure A-1 depicts the process used to calculate the load shapes for ex ante results. As an illustrative example, the figure shows the ex ante scenario for the typical event day for the Greater Bay Area during a 1-in-2 weather year. The solid purple line shows the average load shape for all Greater Bay Area control group customers over the 16 events during the summers of 2011 and 2012. The purple circle shows the average usage from 4-5 PM over all 2011 and 2012 event days while the green square shows the predicted average usage from 4-5 PM for the typical event day in a 1-in-2 weather year for the Greater Bay Area. Finally, the dotted green line shows the average control usage adjusted upwards using the ratio between the green square and the purple circle (represented by the black bracket). The values represented by the dotted green line are the load without demand response.

Figure A-1: Graphic Depiction of Control Load Calculations
Greater Bay Area, 1-in-2 Weather Year, Typical Event Day

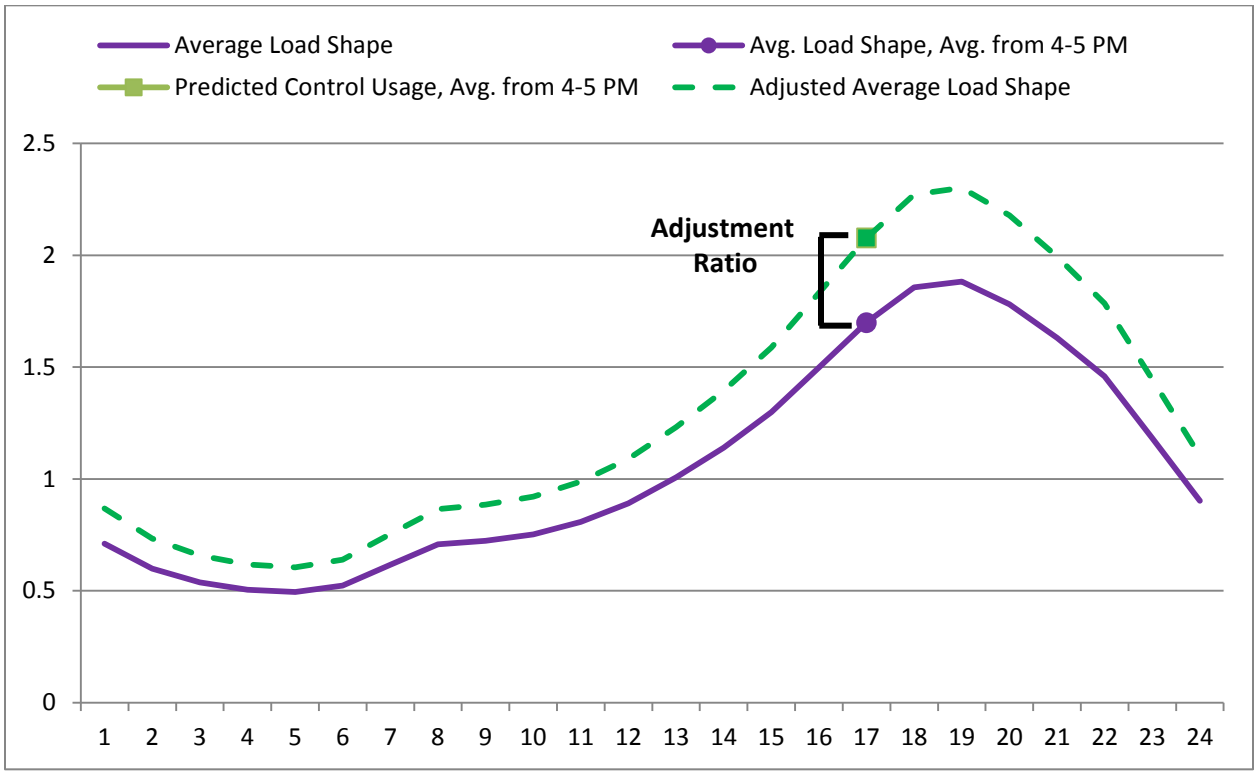
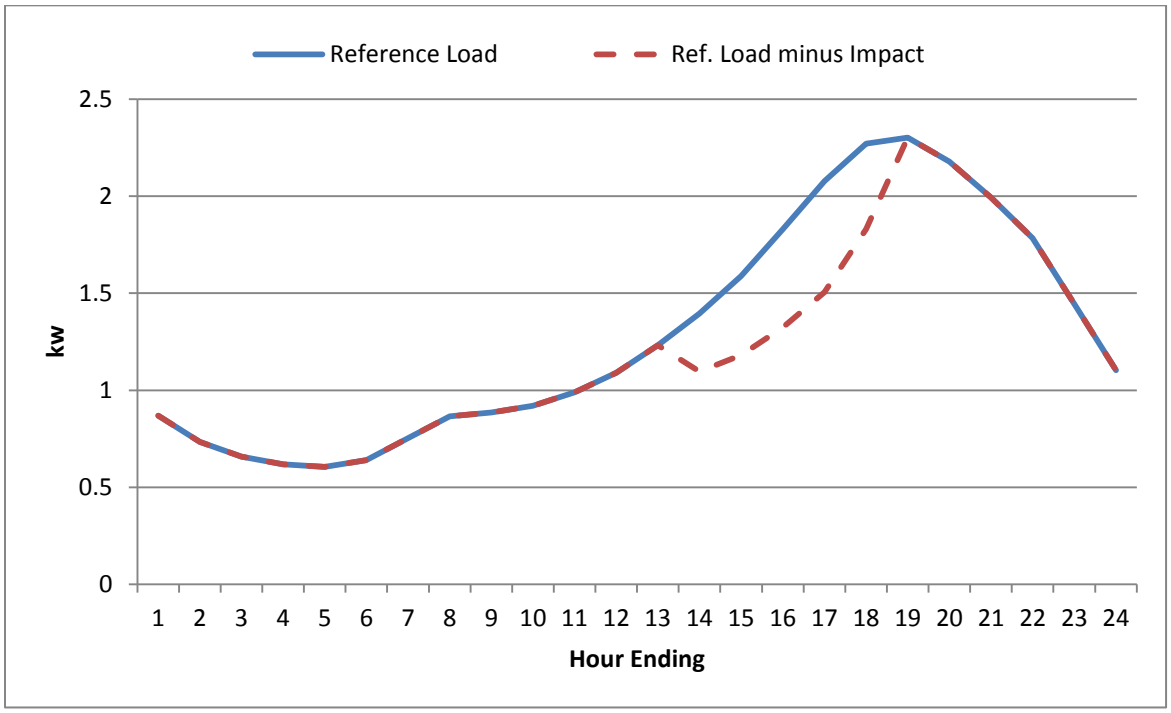


Figure A-2 shows the next step in creating the ex ante tables. As an example, it shows the Greater Bay Area under 1-in-2 weather conditions for the typical event day. The figure shows the loads as exactly the same for all hours except during the event, where the magnitude of the impact has been subtracted from the reference load to create the event load.

Figure A-2: Graphic Depiction of Ex Ante Impact Calculations
Greater Bay Area, 1-in-2 Weather Year, Typical Event Day



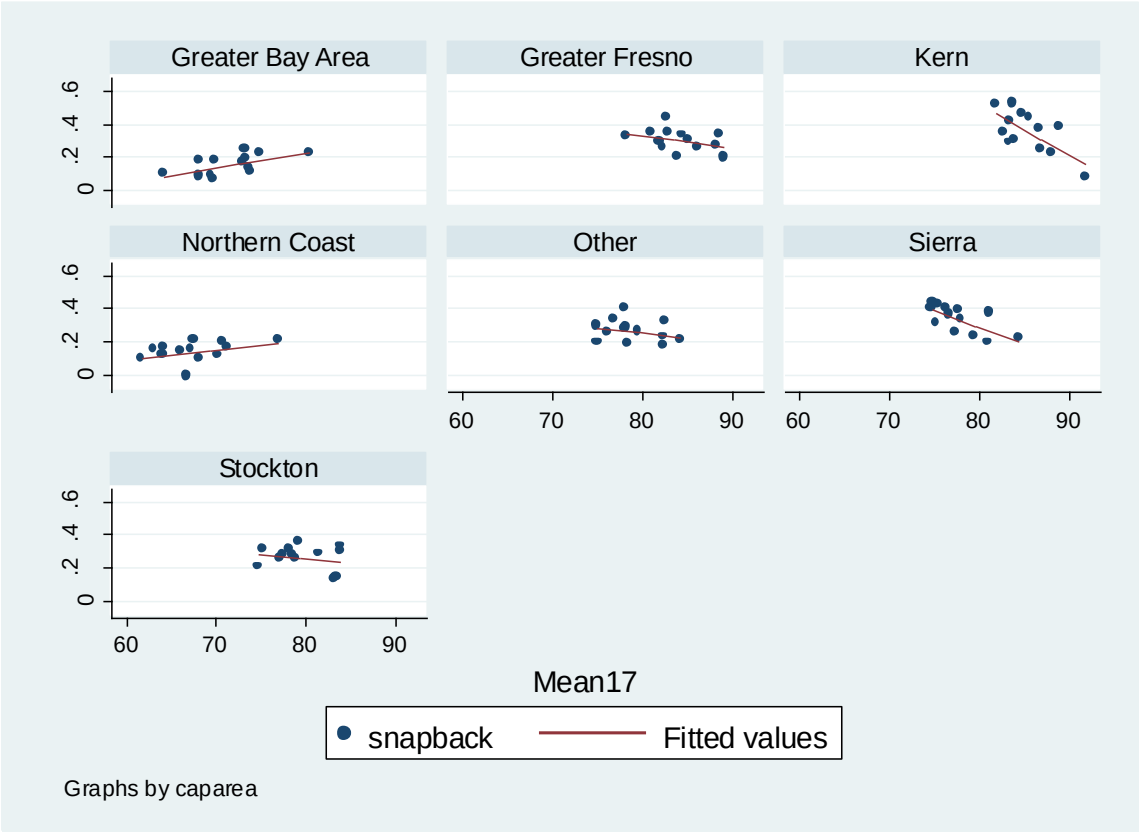
A.2 Estimating Ex Ante Snapback

As the final step in the ex ante analysis, snapback loads are predicted for all hours after the event ends. In addition to the 6 events in 2011, only the 5 events that ended at 6 PM of the 10 total events (excluding the system-wide event day) in 2012 were included in the analysis of snapback. The reasoning behind this is that as all ex ante events end at 6 PM, running from 1-6 PM. Snapback was not found to be a consistent function of temperature.

Figure A-3 shows the scatter plot of snapback — measured as the average difference between reference load and event-day load during the first post-event hour — versus *mean17* for each LCA. The figure shows that the relationship varies across LCAs. For example, in the cooler LCAs (Greater Bay Area and Northern Coast) higher temperatures over the 17 hours before the event are associated with larger snapback. For the other five LCAs, where temperatures were warmer, snapback is fairly consistent across temperatures or even tends to be lower at higher temperatures. It is likely that when a CAC is controlled for an event, the building becomes hot enough that the CAC turns on full blast during the hour after the event is over. Regardless of whether it is 95°F or 105°F, the CAC will work at its maximum capacity for the hour after the event.[18]

[18] This statement is a hypothesis based on the data currently available. In future evaluations, more data will be available to better test this idea.

Figure A-3: Scatter Plots of Snapback Versus *Mean17* by LCA



Perhaps with more data in future years, a regression would be able to accurately model snapback over the full spectrum of temperatures for each LCA. However, for this year's analysis, the average snapback across all event days ending at 6 PM for each LCA was used for ex ante prediction.[19] Table A-1 shows the average snapback in the first hour after the event for each LCA.

Table A-1: Average Snapback From 6 to 7 PM by LCA

LCA	Average Snapback From 6-7 PM (kW)
Greater Bay Area	0.15
Greater Fresno	0.30
Kern	0.35
Northern Coast	0.14
Other	0.26
Sierra	0.33
Stockton	0.26

[19] Although the length of the events varies from 2-5 hours, a side-by-side test was conducted in last year's analysis on June 21, 2011 that showed the snapback for five-hour and two-hour events was nearly identical. Thus, we believe it safe to assume the same applies for two and three hour events.

Just as with event load impacts, the average snapback for 6-7 PM was translated to hourly snapback using the ratio of average snapback in each hour to average snapback from 6-7 PM. Table A-2 shows these ratios for each LCA. For the Greater Bay Area, for example, the table shows that the snapback from 7-8 PM is 102% of the snapback from 6-7 PM.[20] Multiplying this ratio by the value in Table A-1, the snapback from 7-8 PM is 0.153 kW.

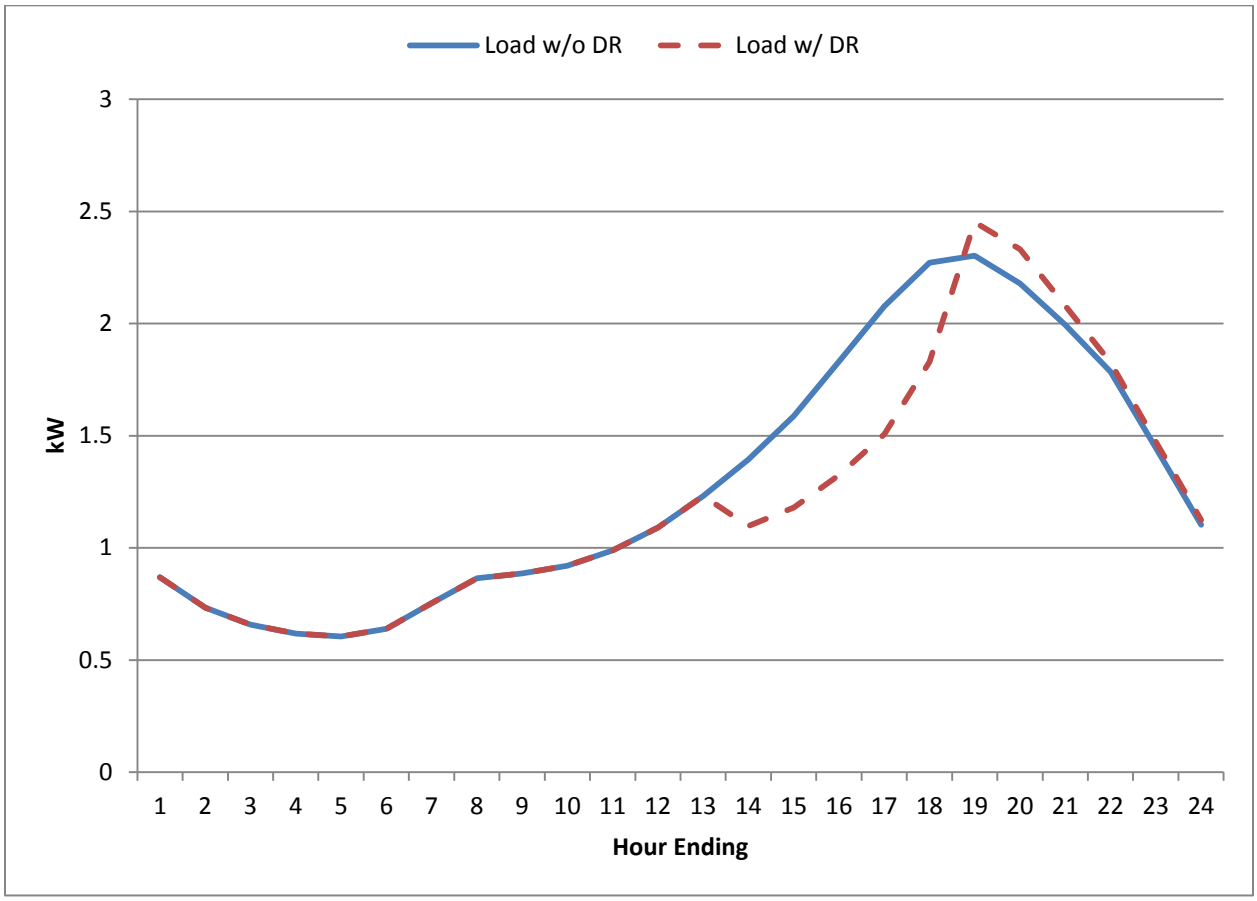
Table A-2: Hourly Snapback Compared to Average Snapback from 6-7 PM

Hour	Greater Bay Area	Greater Fresno	Kern	Northern Coast	Other	Sierra	Stockton
6- 7 PM	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7- 8 PM	1.03	1.08	1.18	0.83	1.01	0.98	1.04
8- 9 PM	0.60	0.70	0.77	0.50	0.57	0.62	0.69
9- 10 PM	0.29	0.41	0.52	0.31	0.32	0.32	0.43
10- 11 PM	0.19	0.21	0.37	0.21	0.18	0.21	0.26
11 PM- 12 AM	0.14	0.17	0.24	0.15	0.12	0.11	0.21

Figure A-4 shows the final ex ante results for the Greater Bay Area typical event day during a 1-in-2 weather year. All hours leading up to the event have exactly the same load with and without demand response. For the event hours, impacts are subtracted from the reference load as described above. For hours after the event, the snapback is added to the reference load based on the calculations also described above. This produces the estimates of load with DR for the post-event hours.

[20] Second hour snap-backs are generally larger than first hour snap-backs because events actually end sometime between 0 and 30 minutes after the official event end time, with the actual time determined randomly for each customer. This is similar to how events begin randomly as discussed in section 6.

Figure A-4: Ex Ante Results Example
Greater Bay Area, 1-in-2 Weather Year, Typical Event Day

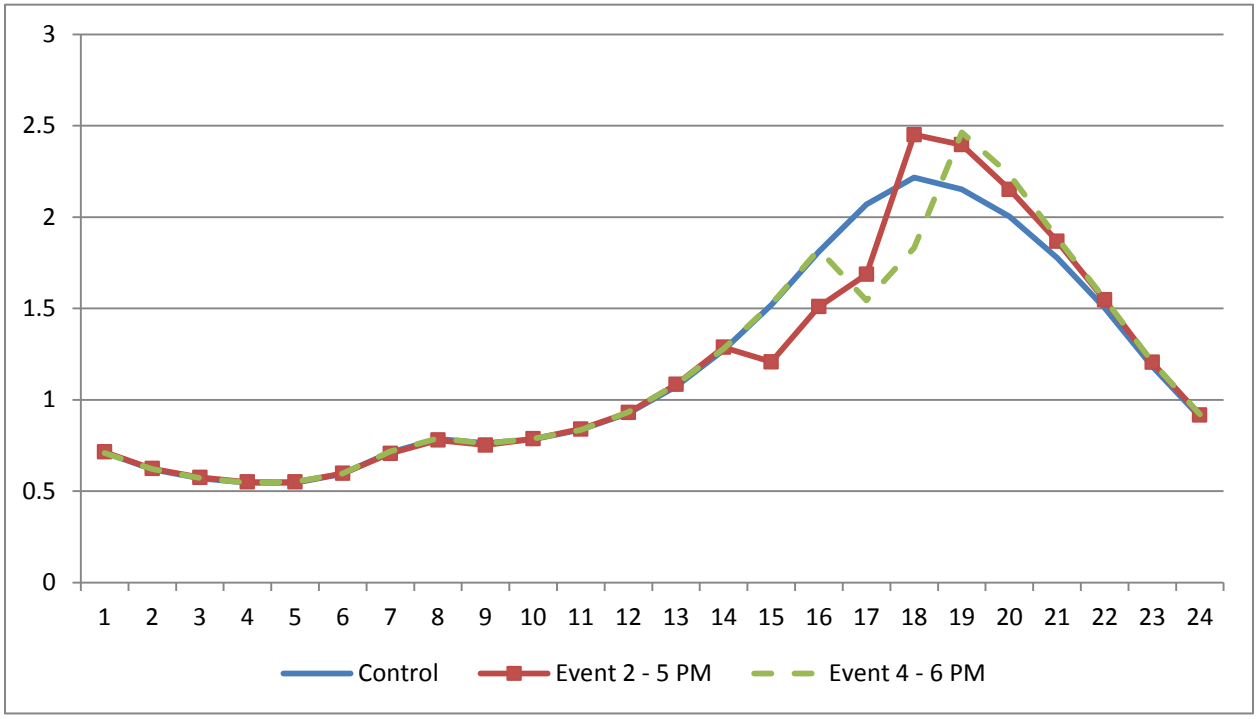


Appendix B SmartAC Side-by-side Testing Results

This section presents the ex post load impacts of the side-by-side test event for residential customers during summer 2012. During this test, two random groups of customers, based on the serial number of the control device as described earlier in this report, were called for events with different timing between the groups. The average loads for the customers in each group during and after the event can be directly compared to each other and to the control group loads to measure the effect of the different event timing. The virtue of this approach is that the only difference between the groups is the event timing. There are no confounding effects, such as differing populations or weather, which could confound the interpretation of differences between the groups' load impacts. The procedure constitutes a true, randomized experiment on the timing of the event. Similar tests were performed in 2011 both on different event timing and on different control strategies, as discussed in that report.

On October 1, a three-hour event from 2-5 PM was tested alongside a two-hour event from 4-6 PM. The purpose of this test was to find out whether load impacts during the residential peak hours from 4-5 PM varied substantially based on whether the event had already been ongoing for two hours prior to that time. This is an important question because the time at which the program is most likely to be needed is in the late afternoon or early evening, but it could also be important for the program to be able to supply load reductions earlier in the day as well.

Figure B-1: Load During the Side-by-side Testing on October 1



As can be seen in Table B-1, the common hour, 4-5 PM, showed a greater impact of 0.52 kW for the two-hour event compared to 0.38 kW for the three-hour event, a 27% increase. The average impact for the entire event was also lesser for the earlier three-hour event, showing impacts of 0.33 kW and 0.46 kW, respectively.

Table B-1: Hourly Impact During Side-by-side Testing on October 1

Hour	Event 2 – 5 PM	Event 4 – 6 PM
11 AM – 12 PM	0.00	-0.01
12 – 1 PM	-0.01	-0.01
1 – 2 PM	-0.01	-0.01
2 – 3 PM	0.31	0.00
3 – 4 PM	0.30	-0.01
4 – 5 PM	0.38	0.52
5 – 6 PM	-0.23	0.39
6 – 7 PM	-0.24	-0.31
7 – 8 PM	-0.15	-0.23
8 – 9 PM	-0.09	-0.11
9 – 10 PM	-0.04	-0.05
10 - 11 PM	-0.02	-0.02
11 PM – 12 AM	-0.01	-0.01

The results of the test are somewhat surprising. First, as discussed earlier, we expect the first hour of an event to have a smaller impact than later hours, all else being equal. That is not true here and it was also not true in the 2011 side-by-side testing. Second, the 2011 side-by-side testing showed that event impacts were approximately equal at the same hour of the day, regardless of how many hours had passed in the event up to that point, i.e., it does not matter whether it is the first hours of the event or the third hour of the event. Here we find that a longer event has a weaker impact for the same event hour.

This issue is important for ex ante modeling. In our current model, we use all ex post impacts from 4-5 PM for modeling on the same basis, regardless of which hour of the event they were (with the exception of the scaling up of the first hour). This year's testing result calls that assumption into question. For now we continue to use that assumption and we recommend further side-by-side testing to continue to test that assumption.

Appendix C Event Discomfort Results for Residential Customers

Following the test event on Thursday, September 13, 2012, the Population Research Systems (PRS) arm of The FSC Group conducted a post-event survey by phone on a random sample of residential SmartAC customers. High temperatures for the day were 101°F in Fresno, 96°F in Sacramento and 89°F in Concord.

The residential survey sample consisted of 1,000 customers who received the event (referred to as the treatment group or the treated) and 1,000 customers who did not. The survey is given to both treatment and control customers in order to distinguish between event-induced discomfort and discomfort that customers would report anyway.

The survey of treatment and control groups started immediately after the event. In total, 428 surveys were completed. There were 213 surveys completed by customers who had the event and 215 surveys by control customers.

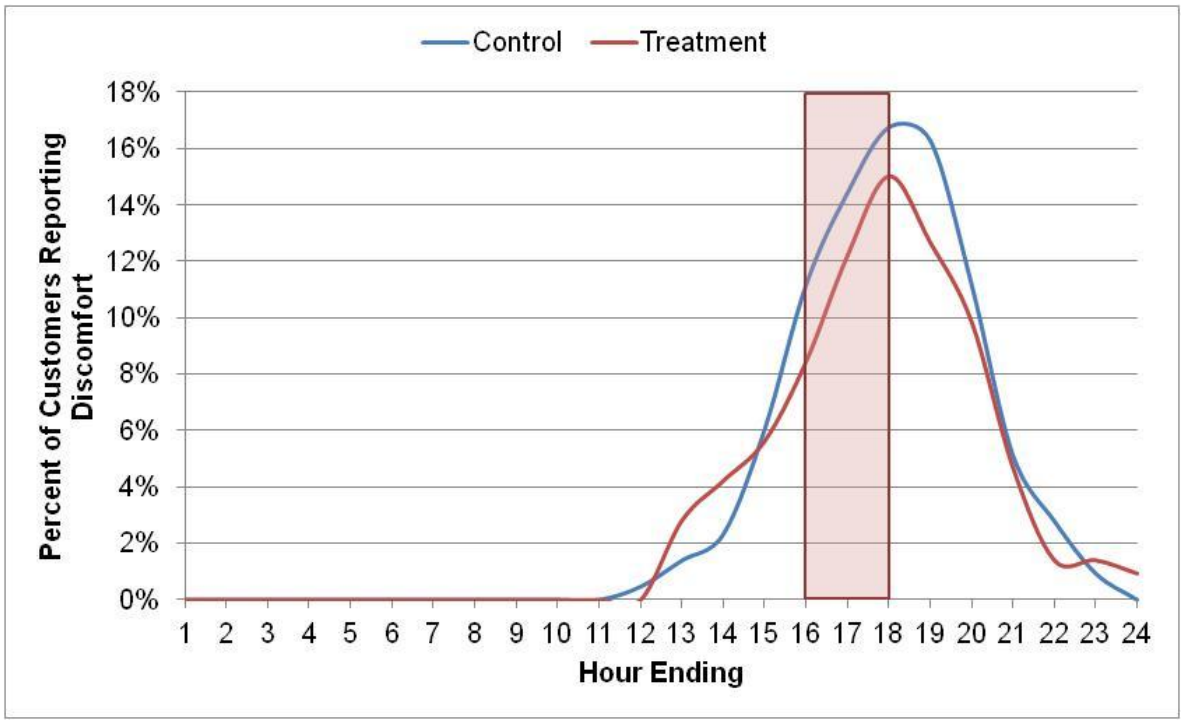
The key discomfort questions were:

- Was there any time on Thursday when the temperature in your home was uncomfortable; and
- If so, during which hours were you uncomfortable?

The key finding was that residential customers in the treatment group show similar levels of discomfort as customers in the control group. This suggests that customers who had their CAC controlled for two hours were unable to detect the event.

For residential customers, an average of 17% of treatment customers reported being uncomfortable during event hours compared to 18% of the control customers. This difference is not statistically significant. Over the entire event day, an average of 3.3% of treated customers was uncomfortable in each hour. For the control group, the average was 3.7%. Figure C-1 shows the levels of discomfort for each hour of the day for both groups. The peak values in Figure C-1 are below the percentages of people who reported discomfort at any point because people could report discomfort at different times of day. Reported discomfort in the treatment and controls groups peaked at 6 PM, the end of the event.

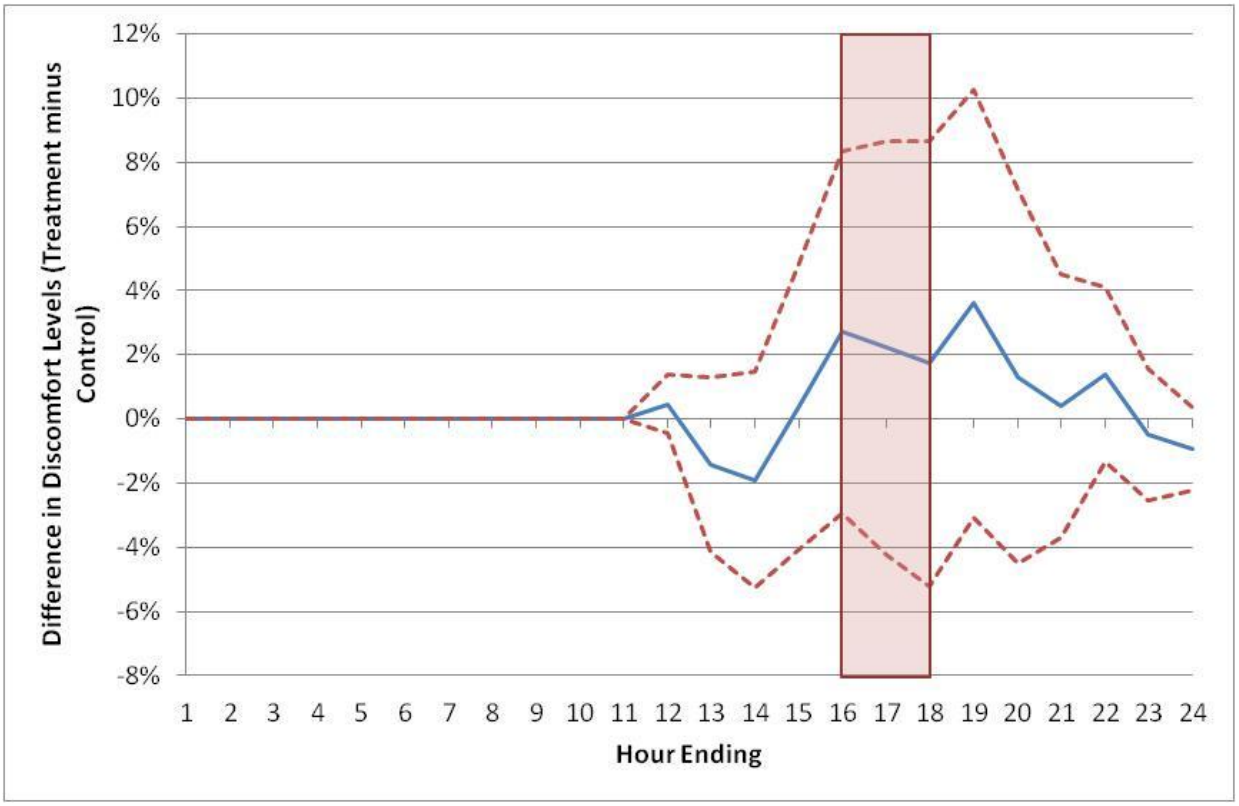
Figure C-1: Reported Discomfort Levels in the Residential Treatment and Control Groups



Treated and control customers show similar levels of discomfort throughout the day. The largest difference between the two groups occurred from 6-7 PM when 16% of control customers reported being uncomfortable compared to 13% of the treated population. To test whether the difference in discomfort between groups is statistically significant or simply random variation, a difference-in-means test for statistical significance was used. A difference-in-means test determines whether or not there is a statistically-significant difference in discomfort levels between the treatment and control groups. If the 95% confidence interval around the difference does not include zero, the difference is not likely due to random variation in response.

Figure C-2 shows the difference in means plotted for each hour of the day, along with the lower and upper bounds of the 95% confidence interval for that difference during each hour. As seen, the confidence interval always includes zero. This means that the difference in reported discomfort levels could well be due to random variation in responses rather than due to an actual difference in discomfort.

Figure C-2: Difference in Means Between Treatment and Control Groups for Residential Respondents with Confidence Interval Bounds



In addition to the questions about discomfort level, the survey contained several questions about the respondents' homes and the demographics of the respondents. The responses to these questions are summarized in Tables C-1 through C-6. The primary conclusion to draw from these tables is that the treatment group and control group have similar distributions for all these variables. This provides confidence that conclusions about discomfort and customer satisfaction that we draw from survey responses are not likely to be due to underlying differences between the control group and treatment group. Also note that survey respondents tend to be older compared to the population — the average age is above 60 for both the treatment and control groups. This response bias is typical of telephone surveys.

Table C-1: "Please tell me which of the following types of buildings best describes your home?"

Type of Home	Control Group	Treatment Group	Total
Single family detached house	88%	88%	88%
Townhouse	5%	3%	4%
Duplex	4%	4%	4%
Apartment	2%	5%	4%
Mobile home	1%	0%	0%
Don't know/Not sure	88%	88%	88%

Table C-2: "Do you own or rent your home?"

Rent/Own	Control Group	Treatment Group	Total
Own	91%	94%	93%
Rent or Lease	7%	5%	6%
Other	0%	0%	0%
Don't know/Not sure	1%	1%	1%

Table C-3: "What is your household's total annual income before taxes?"

Income Level	Control Group	Treatment Group	Total
<$15,000	5%	3%	4%
$15k - 20k	3%	5%	4%
$20k - $30k	6%	8%	7%
$30k - $40k	6%	11%	9%
$40k - $50k	4%	11%	7%
$50k - $75k	10%	8%	9%
$75k - $100k	9%	10%	10%
$100k - $125k	4%	3%	4%
$125k - $175k	5%	8%	6%
> $175k	11%	5%	8%
Don't know/Not sure	37%	28%	33%

Table F-4: "Which of the following is the highest level of education you have completed?"

Education Level	Control Group	Treatment Group	Total
8th grade or lower	1%	1%	1%
High school	17%	25%	21%
Associates degree, vocational degree	33%	25%	29%
Four year college degree	17%	21%	19%
Graduate or professional	27%	24%	25%
Don't know/Not sure	5%	3%	4%

Table C-5: "Including yourself and children, how many people live in your home at least six months of the year?"

Number of People	Control Group	Treatment Group	Total
1	23%	27%	25%
2	41%	41%	41%
3	14%	9%	12%
4	12%	9%	11%
5	4%	8%	6%
6 or more	4%	5%	4%
Average number of people*	2.4	2.4	2.4

*Assumes six people in households of six or more

Table C-6: "What is your age?"

Age Group	Control Group	Treatment Group	Total
< 25 years old	0%	1%	0%
25 - 34 years old	5%	5%	5%
35 - 44 years old	11%	9%	10%
45 - 54 years old	15%	9%	12%
55 - 64 years old	17%	14%	15%
65 - 74 years old	21%	21%	21%
> 75 years old	26%	35%	30%
Prefer not to answer	5%	5%	5%

Finally, the survey asked about satisfaction with SmartAC. After they were asked about discomfort, customers were asked, "Based on all of your experiences with the SmartAC program so far, how satisfied have you been with the program overall?" and given a range from 1 being "Very Dissatisfied" to 10 being "Very Satisfied." These answers are shown in Table C-7. Customers who were treated on September 13 had an average satisfaction rating of 8.0 and customers who were not treated that day had an average rating of 7.8. The difference is not statistically significant.

Table C-7: Satisfaction Levels with SmartAC

Group	Mean	Median	Std. Dev
Treatment	8.0	9.0	2.3
Control	7.8	9.0	2.5
Total	7.9	9.0	2.4

Appendix D Temperature Changes During Events

The internal data logs used to assess control device communication success also contain indoor temperature data; this is only true for PCT internal device logs.

Table D-1 below shows the average temperature increase during events for PCTs in the samples used to assess control device communication success. Only devices that were in cooling mode and received an event signal were included in the analysis. The number of devices with data varied for each event, but there were roughly 10 devices underlying each average. This is a smaller number than seen in previous years due to a decrease in the number of PCT devices successfully recruited for data downloads. The Event Type column does not indicate overall whether it was a SmartAC, SmartRate or Both event day. It indicates whether we have recorded logger data from SmartAC customers, SmartRate customers or both types of customers who were supposed to have an event that day.

In both groups, average temperature increases are about half a degree in the first hour and rise to about 2.5 degrees in the fifth hour. There is a fairly large amount of variation on a day-to-day basis though. These results are similar to those seen in 2011.

Table D-1: Average Temperature Increases During Residential SmartAC or SmartRate Events

Event Date	Event Type	2-3 PM	3-4 PM	4-5 PM	5-6 PM	6-7 PM
9-Jul-12	Both	0.6	1.0	1.6	2.3	1.8
10-Jul-12	Both	0.4	0.6	1.4	2.4	3.8
11-Jul-12	Both	0.5	1.3	1.8	3.0	3.6
12-Jul-12	SmartAC	3.0	5.0	6.0	N/A	N/A
23-Jul-12	SmartRate	-0.5	0.8	1.8	2.5	3.0
2-Aug-12	SmartAC	N/A	N/A	4.0	6.0	N/A
10-Aug-12	SmartAC	N/A	N/A	-0.1	1.0	N/A
4-Sep-12	SmartRate	0.3	0.9	1.7	2.2	2.2
13-Sep-12	Both	0.6	1.1	1.6	1.9	2.3
14-Sep-12	Both	0.6	0.9	1.7	2.1	2.3
01-Oct-12	Both	0.5	1.5	2.6	3.1	2.9
Total		0.5	1.1	1.5	2.1	2.5