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In-Home Smart Device Pilot – Evaluation Summary

March 31, 2014

The following report summarizes the results of Public Service Company of Colorado's (Public Service's) In-Home Smart Device (IHSD) Pilot. The report includes background on the pilot; energy and demand savings results; answers to the research questions posed by the pilot; and recommended next steps. The report draws upon the pilot evaluation provided by the Company's third-party evaluator, EnerNOC, and the results of the participant survey administered by Public Service. The objectives and findings, full evaluation report, and survey results are attached.

Summary

The evaluation of the IHSD Pilot yielded statistically significant demand reduction during control events and monthly energy savings over the duration of the pilot. During high temperature summer events approximately 0.52 kW in demand reduction per deployed system was observed. This increased to 0.99 kW per system if only active event responders were considered. Annual energy savings of 300 kWh per participant were also attributable to the devices. Overall, customer satisfaction was high with over 74% of participants being satisfied with the pilot and devices. Due to the high cost of the devices Public Service does not plan to convert the pilot directly into a new DSM product, but the pilot results have identified multiple pathways to cost-effective new product offerings that the Company is currently investigating.

Background

As part of the SmartGridCity project, Public Service began to investigate how IHSD systems could provide benefit to both residential customers and the electric grid. Through those efforts Public Service launched an IHSD Pilot, which was added to the Company's 2009/2010 Biennial DSM Plan via a 60-Day Notice, implemented in October 2009.

The IHSD Pilot was designed to test how residential customers respond to various demand control strategies and energy consumption information delivered to their homes through in-home energy management devices. Participants were expected to lower their energy consumption when provided with the tools to monitor and track their energy usage. The following devices were installed in the home of each participant at no cost to the participant:

- EnergyHub Home Base, a smart controller with in home display;

- Honeywell Wireless Thermostat, controllable by the Company;
- Two Sockets (15 amp smart plugs), controllable by the Company; and a
- Wireless CT Sensor, which sends whole home electricity use to Home Base.

Customers were also asked to participate in demand response control events. Those events were called from 2:00 to 8:00 p.m. primarily on hot summer days, no more than 15 times per year. During each event the customers' thermostats were set back by five degrees and their two appliance sockets were turned off. Customers could opt-out of the event at any time, and received no incentive for participation or penalty for non-participation.

To be eligible for the pilot, customers had to have a central air conditioning (A/C) system. Public Service recruited customers from two areas within the Colorado service territory: 1) Boulder and 2) Denver metro suburbs of Centennial and Westminster. Customer recruitment and participant device installation began in late 2011 and by the summer of 2012 when the first demand response events were initiated over 1,100 customers had been enrolled.

Evaluation Results

The evaluation of the IHSD Pilot delivered demand savings during high temperature summer events (2013) of 0.52 kW per participant for all IHSDs in the pilot, and 0.99 kW per participant for event responders. The difference between these two figures was event participation rates, which averaged 49% in 2012 and 42% in 2013. Table 1 shows the full set of demand response event results from the summer of 2012 and 2013.

Table 1. Comparison of Summer Event Demand Response Impacts

Event Type	Analysis Year	Group Type	Adjusted Control Group Average kW	Estimated Average kW Reduction	Percent Reduction	Average Event Day High Temp. (°F)
Summer – High Temp	2012	All Pilot Participants	2.65	0.71	27%	97
		Event Responders	2.80	1.29	46%	
	2013	All Pilot Participants	2.57	0.52	20%	96
		Event Responders	2.53	0.99	39%	
Summer – Medium Temp	2013	All Pilot Participants	2.28	0.47	21%	92
		Event Responders	2.22	0.82	37%	
Summer – Low Temp	2013	All Pilot Participants	2.07	0.44	21%	82
		Event Responders	1.94	0.76	39%	

The average annual billing energy (kWh) savings delivered by IHSDs was 3.0%. These savings ranged from 2.0% in winter to 4.6% in the summer, showing the influence of IHSD capabilities.

The evaluation was based on matched treatment and control group comparisons. For the demand response events, the total pilot participant pool was split into two equal groups that alternated as treatment and control for each event (interval billing data was not broadly available outside of the pilot participant pool). For calculating energy savings, all IHSD pilot participants were matched to a non-contact control group from the same geography with similar demographics as the pilot group.

Customer Survey Results

Customers were generally very satisfied with the IHSD pilot based on a survey of pilot participants conducted in 2013. Seventy-four percent of participants rated the pilot as an 8-10 (on a 1-10 scale), while 91% of survey respondents rated it between 6 and 10. This result aligned with the 2012 survey results. Participation rates in both surveys were high, at or above 50%. The survey also found that satisfaction with the pilot and the IHSDs correlated with the perception of value and savings. That is, if a participant thought the device and the pilot helped them save money, they were more satisfied. Most customers reported taking some action during control events to defer energy usage, and also took actions over time to reduce total energy usage based on the information provided by the device. Their motivation was typically to save energy, but also to support grid reliability and the environment. Finally, customers were more willing to participate in demand response events if we offered additional incentives, and either made the events shorter or offered the ability to pre-cool their home (a home being “too hot” was the most cited reason for opting out of events).

Next Steps

Offering an IHSD program is complicated by the fact that Public Service does not have advanced metering infrastructure (AMI) to provide real-time data feed to the devices. There are proven energy savings through the IHSD Pilot, but not enough to support the full cost of the metering solution needed. Public Service will revisit offering an IHSD program as future metering technology implementation decisions evolve, or explore different co-payment options for adding smart devices to the home absent of a large-scale AMI metering rollout.

The IHSD Pilot results will be used to inform the Company’s strategy around utilizing these types of devices to fulfill energy efficiency or demand response goals in the future; efforts will focus on program strategies to increase demand response event participation and determine energy saving solely due to the smart or communicating thermostat. A focus solely on the thermostat would likely result in significantly reduced product costs relative to the approach used in the Pilot, improving cost-effectiveness.

In-Home Smart Device Pilot: Objectives and Findings

The purpose of the IHSD Pilot was to determine whether providing customers with energy feedback and control devices resulted in energy savings and peak demand reduction. Ten key questions, designed to address this objective, were detailed in the initial IHSD 60-Day Notice posting. The findings from the evaluation are detailed below:

1. **How much will customers reduce their residential electricity use when provided with energy consumption feedback coupled with behavior change techniques?**

   Pilot participants received real time energy feedback as well as historical cost and consumption data via the Home Base display installed in their homes. Additional usage and cost information as well as energy savings techniques and comparison data were available through an online portal. The pilot evaluation confirmed that the IHSD systems provided to customers did result in energy savings. On average, participants reduced their energy consumption by 3.0% annually or 300 kWh/yr per participant. These savings were statistically significant, with an error band of 5.6% or ± 17 kWh of savings annually. Over the course of the entire measurement period (June 2012 – September 2013), the 1,100 participants reduced their energy usage by a total of 0.45 GWh.

2. **How much will customers reduce residential electricity demand and energy usage when Public Service is allowed to control the temperature setting on their thermostats?**

   During the course of the pilot Public Service initiated control events to determine how much peak demand reduction could be achieved from the devices. Control events were initiated to coincide with times of actual system peak as well as other candidate days selected to determine seasonal and temperature impacts. Events were always scheduled on weekdays between the hours of 2:00 p.m. and 8:00 p.m. Participants were notified one day in advance of the upcoming event. Over the two-year pilot 30 events were called. Participants' thermostats were automatically set back 5º F for the duration of the event unless the participant overrode the setback. Participants were not given a reward or penalty for their level of participation in any event.

   Results of the analysis indicate that during high temperature (≥93 degrees) control events, participating devices saw an average demand reduction of 0.99 kW (±0.11 kW). However, not every device participated in the events, either because customers chose to opt-out or because their devices were offline at the time of the event. This decreased the overall demand reduction to 0.52 kW (±0.03 kW) per deployed system. The demand reductions resulted in energy savings during the six-hour control events, which were partially offset by additional energy use, or "snap back," immediately after the events. Overall energy consumption on high temperature event days was reduced by 2.10 kWh per participating device or an average of 1.16 kWh per device deployed.

3. **What are the technical assumptions per participant (i.e., energy, demand, and savings per participant, number of hours controlled equipment is operated per year, equipment operation coincidence with peak, etc.)?**

   The technical assumptions per participant are dependent on future program design, as many of the pilot learnings point to methods of improving control event participation. Assuming a future program design identical to this pilot, the technical assumptions would be 0.52 kW and 300 kWh/yr per participant, with 24 hours of controlled equipment (10 events x 6 hrs/event x 40% participation rate), and a 100% coincidence factor. Alternate program designs could attempt to boost control event participation rates closer to the 0.99 kW/event participant.

4. **Does the program produce sufficient energy and demand savings to make it cost-effective?**

   The pilot itself was not cost-effective, with an MTRC of 0.3. One primary driver was its short duration, resulting in all upfront costs being incurred for only two years of benefits. If the equipment's useful life were assumed to be 10 years, the cost-effectiveness could be improved to an MTRC of 0.7. The design of a potential future IHSD product would need to focus on deploying a less expensive control device and/or increasing participation during control events to maximize potential demand reductions. The pilot also assumed all of the up-front equipment and installation costs, which would not necessarily be part of future program or pilot designs. Under these varying conditions it is plausible that a cost-effective product could be developed.

5. **What is the expected lifetime savings from smart device installations and behavioral changes?**

   A slight decline in demand and energy savings was seen from the first to the second year of the pilot. Assuming the values from the second year of the pilot hold through the remainder of a 10-year product lifetime, under a similar design to this pilot, the lifetime savings would be annual peak reduction of 0.52 kW and 3,000 kWh/year energy savings per deployed system.

6. **How do customers perceive the various types of feedback, and what actions account for their savings?**

Customers valued the whole house energy consumption information provided[1]. Over three-quarters of survey respondents found information on overall energy usage, energy cost, and usage over time to be valuable. Sixty-one percent of survey respondents found individual appliance energy consumption information to be helpful. During control events, in addition to thermostat control, the most common actions cited by survey participants were delaying activities (washing clothes, running the dishwasher, and, occasionally, cooking) and turning off plug loads (typically lights but sometimes electronics). In response to the energy usage information, customers most frequently turned off lights, created and followed a thermostat schedule, and ran the dishwasher and washing machine with full loads.

7. **Which is the preferred device manufacturer and what components are most appealing?**

   This question was no longer applicable after the scope of the pilot was revised per the 60-Day Notice (posted in May 2012). Originally, devices from multiple vendors were to be deployed, but based on the nascent market at the time, only one system, provided by Energy Hub, was found to meet all specified requirements.

8. **How do customers choose to manage home energy usage via in-home devices?**

   The primary method of managing home energy usage appeared to be using the real-time energy usage data to become more aware of energy consumption and as a motivating tool to take voluntary actions. Customers also anecdotally indicated that the appliance sockets helped them understand the relative consumption of different plug loads, and even identify large energy consuming appliances that could be retrofitted or simply retired.

9. **Are there comfort issues associated with various load management strategies?**

   Yes, the most common reason for opting out of a control event, cited by 54% of survey respondents, was because the house became too hot. A five degree thermostat setback over six hours was a noticeable change for many participants, particularly since the events lasted until 8:00 p.m.

10. **What level of energy and/or financial savings makes behavioral persistence worthwhile for the customer?**

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[1] Public Service currently provides this type of data to some residential customers through its Energy Feedback Pilot, in the form of bi-monthly reports that compare each participant's energy consumption to a peer group of neighbors. These reports do not provide real-time consumption like an IHSD but have been demonstrated to be cost-effective.

The answer to that question is unique to each customer and pilot participant. Every person has a different threshold of savings which motivate persistent behavioral action; and often the motivation can be tied to relative savings rather than absolute savings. For instance, the average control event savings of 3.84 kWh per event responder (or approximately $0.40-$0.50 at current residential rates) wouldn't seem to support a 40-50% event participation rate. Likewise a 3% average savings on each participant's electric bill may not be enough in absolute terms to motivate action. The gap between participation and absolute savings might be explained by relative savings, customers are motivated to save relative to their current usage, particularly through actions that have little or no impact on the energy services or perceived value they receive.

In-Home Smart Devices Pilot Program

Impact Evaluation Results, 2012-2013

Final Report

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April 3, 2014

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Executive Summary

Results from the impact analysis of the In-Home Smart Device (IHSD) pilot show that there were clearly significant demand reductions during summer events, in addition to overall energy savings across the duration of the pilot period. The average short-term demand reduction during events for the population of notified participants was 20-27%. Additionally, the pilot realized average annual energy savings of 3%.

Pilot Background

As part of its SmartGridCity project, Public Service Company of Colorado (Public Service) began to investigate how IHSD systems could provide benefit to both residential customers and the electric grid. Through those efforts, Public Service launched an IHSD pilot. The objective of the pilot was to test participant willingness to reduce loads in response to utility load control events, as well as to assess participant behavioral changes (in the form of lower overall energy use) due to access to in-home energy consumption information and thermostat control. Customer recruitment and device installation began in 2011. To be eligible for the pilot, customers had to have central air conditioning (AC) systems. Public Service recruited customers from two areas within the Colorado service territory: 1) Boulder; and 2) Denver metro suburbs (collectively referred to as "Denver"). By the summer of 2012 over 1,100 customers had been recruited to participate.

Each pilot participant received an IHSD system consisting of a "Home Base" control module and energy display, a smart thermostat, two smart plugs capable of monitoring and controlling plug loads, and a wireless CT sensor for monitoring whole home energy usage. These devices communicated wirelessly within the home via Zigbee communications protocol. The Home Base then provided communications back to the service provider and Public Service over the participant's WiFi internet connection. Through this configuration, participants gained access to their data and greater control over their energy consumption both within their homes and remotely through a web-enabled portal. Systems were originally configured to respond to demand response events automatically; thermostats were preprogrammed to increase the cooling temperature set point by 5°F and smart plugs would turn off. Participants were able to adjust the thermostat temperature offset during events if they desired.

The first of 30 demand response event was in July 2012 and the last was in September 2013. Forecasted temperature was the criterion used for calling an event. For the analysis of impacts, the events were categorized into five types: 1) high temperature summer; 2) medium temperature summer; 3) low temperature summer; 4) high temperature non-summer; and 5) low temperature non-summer. The temperature levels chosen for events were seasonally relative (e.g., the low temperature non-summer days were cold and the one high temperature non-summer day was mild for the time of year).

Study Objectives

The EnerNOC project team supported Public Service in the design of the pilot and conducted a preliminary impact evaluation at the end of 2012. This report covers the complete impact evaluation for the analysis period spanning June 2012 to September 2013. There were five main objectives of our work:

- Support Public Service during design and initiation of the IHSD pilot, including defining control groups and developing protocols for recruiting customers and calling events
- Estimate impacts for each year of the pilot, including peak demand reductions on event days and monthly energy savings, during both non-summer and summer periods
- Develop a model to estimate actual energy savings impacts achieved during the pilot and to predict potential impacts under various scenarios
- Discuss findings from the pilot and provide comparisons to other similar programs
- Offer recommendations for program implementation considerations, including modifications to improve the likelihood of success for a wider scale deployment

Analysis Methods

Demand Response

We analyzed demand reductions using a difference of differences approach based on interval data collected from the devices. As there was not a non-participant control group with interval data available, it was necessary to use the pilot participants as both the treatment and control group. To accomplish this, we created a randomized split of the participants into two groups: Group A and Group B. Demand response events were called separately for the two groups on different but similar days. In this manner, Group B could act as the control population on event days for Group A and vice versa. We estimated hourly demand impacts for each event day using a difference of differences approach, with the “pretreatment period” being similar non-event days in the same year and season. This allowed us to correct the hourly impact estimates on the event days based on the pre-existing differences between the two groups on non-event days. We then averaged the event day impacts across events on days with similar temperatures to get stable hourly demand impacts. We analyzed the impacts for two sets of participants: 1) the population of all participants notified for the events, and 2) the subset of participants that responded to the events.

Energy Savings

We estimated energy impacts for the pilot program using two methods: difference of differences and regression modeling. These analyses were based on monthly billing data, which allowed us to create a matched control group of non-participants to capture variation in energy use not due to the pilot. The difference of differences method provided a preliminary estimate of monthly energy savings, with estimates in the range of 2-5% for the months with the majority of the pilot customers installed and active. However, the precision of the difference of differences estimates was low because the approach did not account for the variability in energy use between customers. In order to estimate the savings more precisely, we also analyzed the data using a fixed effects regression approach. This method looks at the energy use of each customer in each month as a function of a number of variables, including a customer-specific “base energy use” (referred to as the customer fixed effect), as well as variables related to participation and temperature (in the form of heating degree days (HDDs) and cooling degree days(CDDs)). Because the regression approach accounted for the variability between customers, it was able to estimate the savings more precisely, and showed statistically significant energy savings. Another benefit of the regression approach is that it can be used to estimate the actual savings from the pilot based on the weather that occurred while the devices were in the field, and can also be used to estimate what the savings would be during a normal weather year.

Results

The analysis of the IHSD pilot shows that there are clearly significant demand reductions during summer events, followed by increased usage, or snapback, after the events. Statistically significant energy savings were also measured throughout the pilot period.

Table ES1 below shows the average per-customer demand reductions on summer event days for all notified customers in the pilot, and for the subset of the pilot customers that actively responded to events.

Table ES1. Comparison of Summer Event Demand Response Impacts

Event Type	Analysis Year	Group Type	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Average Event Day High Temp. (°F)
Summer - High	2012	All [b]	2.65	0.71	±0.02	27%	97
		Responders [c]	2.80	1.29	±0.14	46%	
	2013	All	2.57	0.52	±0.03	20%	96
		Responders	2.53	0.99	±0.11	39%	
Summer - Medium	2013	All	2.28	0.47	±0.03	21%	92
		Responders	2.22	0.82	±0.10	37%	
Summer - Low	2013	All	2.07	0.44	±0.05	21%	82
		Responders	1.94	0.76	±0.07	39%	

[a] These include estimated confidence intervals based on averages of the confidence intervals for individual on-peak hours.
[b] Pilot participants as a whole. Load reduction impacts have been discounted to account for off-line participants.
[c] Event responders.

Figure ES1 shows these demand response results graphically.

Figure ES1. Comparison of Summer Event Average Load Reduction Impacts

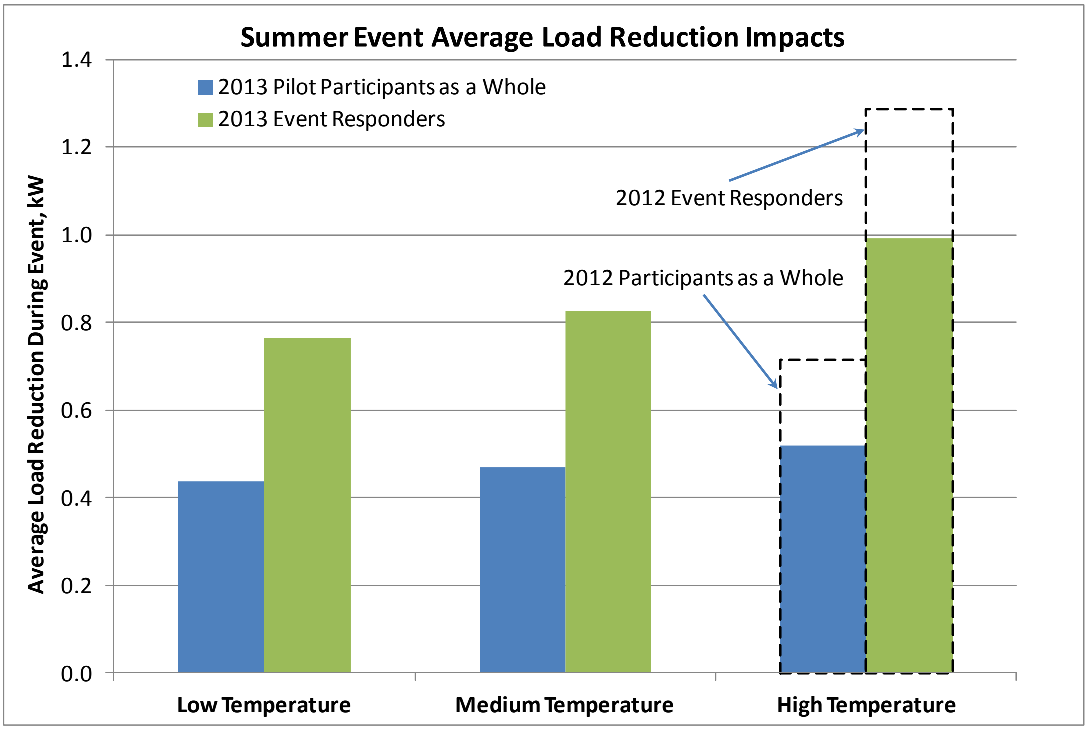


Table ES2 summarizes the average per-participant snapback results by year and summer event day type for pilot participants as a whole and for event responders. The snapback effects include maximum demand increase in kW, and overall energy use increase in kWh, between the hours of 8 PM and midnight. The table compares snapback with total energy savings achieved during the event and provides the kWh savings, net of the snapback increase.

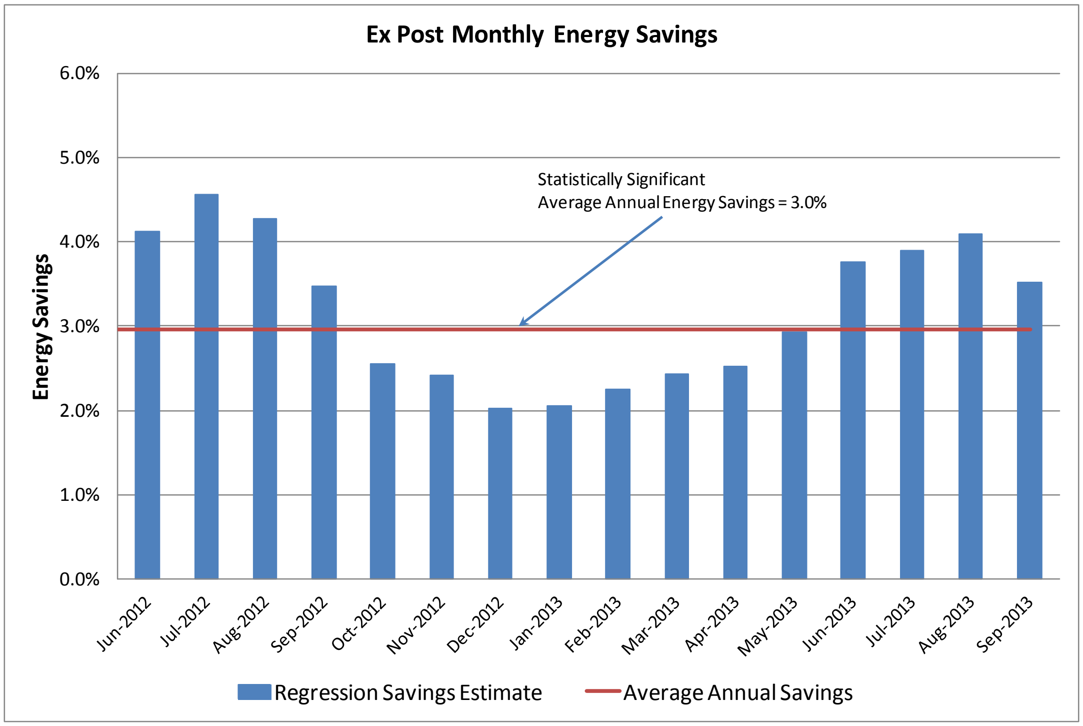
Table ES2. Energy Effects of Snapback

Event Type	Analysis Year	Group Type	Maximum Snapback kW Increase, 8 PM - 12 midnight	Total Snapback kWh Increase, 8 PM - 12 midnight	Total kWh Savings During Events, 2– 8 PM	Net kWh Savings	Average Event Day High Temp. (°F)
Summer - High	2012	All [a]	0.48	1.26	4.29	3.03	97
		Responders [b]	0.76	2.01	7.73	5.72	
	2013	All	0.42	1.16	3.11	1.95	96
		Responders	0.77	2.10	5.94	3.84	
Summer - Medium	2013	All	0.40	0.95	2.82	1.87	92
		Responders	0.73	1.77	4.95	3.18	
Summer - Low	2013	All	0.30	0.76	2.63	1.87	82
		Responders	0.49	1.17	4.58	3.41	

[a] Pilot participants as a whole.
[b] Event responders

Figure ES2 shows the average per-customer percentage energy savings by month across the pilot period, along with the average annual percent savings.

Figure ES2. Monthly Energy Savings Estimates: Percentage Savings



Key Findings

There are several key findings from the results presented above:

- **Summer Events had Significant Load Reductions:** There were statistically significant load reductions during summer demand response events. In 2013, the average per-participant load reduction across the six-hour event period was in the range of 0.44-0.52 kW (or 20-21%) for the total population of pilot participants, with slightly higher kW reductions for hotter event days. The total population of pilot participants was made up of all customers notified of an event, including those whose devices were off-line, and those who opted out of events. Thus, the reported load reduction reflects participants who contributed to load reduction averaged with those participants who did not contribute. Because of this, it is somewhat of a “worst case scenario” for per-participant savings.
- **Event Responders had Higher Demand Response Impacts:** The subset of event responders had higher load reductions relative to the pilot participants as a whole for each event day type. This effect was a little more pronounced for higher temperature events. For example, during the 2013 high temperature summer events, the average load reduction for event responders (0.99 kW) was 91% larger than that of pilot participants as a whole (0.52 kW); by comparison, for low temperature summer events in 2013, the event responders saved 74% more than the overall group of participants (0.76

kW vs. 0.44 kW). This per-customer load reduction is the best that can be expected from a broader roll-out under a similar pilot design, since it is what happens when all customers accept the event and have devices that are configured to respond.

- **Load Reductions Decreased between 2012 and 2013:** During 2012 high temperature summer events, the average per-participant load reduction for the group of pilot participants as a whole was 0.71 kW (or 27%) compared with 0.52 kW (20%) in 2013. This decrease could be due to a smaller percentage of pilot participants responding to events from one year to the next. It could also be due to participants changing thermostat settings over time from the default cooling offset of 5°F to a reduced offset. This could also be due to the cumulative effect over time of customer energy conservation efforts unrelated to events, which would tend to lower the baseline load and reduce demand savings by a small amount.
- **Non-Summer Events had Insignificant Load Reductions:** The impacts for the non-summer events were not statistically significant and appeared to be very small at best, ranging from 1% to 2% for pilot participants as a whole. These results are most likely due to the lack of any AC load to reduce during the non-summer events, implying that most of the event savings result from the thermostat cooling offset during hotter periods.
- **Customers Are Reducing Energy:** Using a regression analysis, we were able to estimate statistically significant energy savings across all months of the pilot period. The energy savings range from about 2% during non-summer months to over 4% during most summer months. This level of energy savings is consistent with savings observed in other behavioral programs.
- **Off-Line Participants Reduce Per-Participant Impacts:** The share of off-line participants in the notified group ranged from 5% to 19% across the events. These customers' devices did not receive the signal to reduce load, and so would not be expected to contribute any savings. Accordingly, the per-participant impacts were reduced relative to what would have been achieved had all participants been connected. This is an important consideration for future deployment of an IHSD program. An effort to reduce the number of off-line participants would increase the savings for the program, and would likely be warranted, since without it, similar off-line rates could also be expected in the future.
- **The Snapback Effect was Significant:** Snapback is when AC units work extra hard and consume additional energy after an event to make up for the thermostat offset in place during the event. (An analogous type of snapback can also occur with non-AC loads such as electric water heaters, washers and dryers, etc.) The results show a significant snapback effect for summer events. The effect was most pronounced for the subset of event responders, for whom the maximum demand increase in the four hours following the event ranged from an average of 0.49 to 0.77 kW across the different event day types. This increase offset about one third of the energy reduction realized during the event.

Recommendations

We have the following recommendations for any future pilots or full roll-outs of similar programs:

- **Increase Event Participation:** For any future pilot or roll-out, we recommend efforts to decrease the number of customers off-line. Begin by investigating the reasons customers were off-line during the pilot. Possible ways to reduce the number off-line could include providing alternative technologies that do not depend on the customer's WiFi and internet service, as well as continuing to offer technical support. We also recommend exploring ways to encourage more customers to configure their devices to respond to events, as well as to discourage customers from opting out of events. Offering a small monetary incentive to customers for responding to events could increase the percent responding, which would increase the per-participant savings and make the program more cost-effective. If Public Service launches another pilot, different incentives could be tested across customers to determine the most effective way to improve participation in events. Another possibility is to offer the option to configure the devices for pre-cooling homes ahead of events, which could help people be less uncomfortable during the events, and would probably make the savings last longer.
- **Call Events Only on Extreme Days:** For a pilot, it is important to call events across a variety of days to determine what the load reduction might be during different circumstances. However, if a program is rolled out to the general population, events should be called on the hottest days and other days when the electric grid is constrained. This will provide the greatest load reduction, and will provide that reduction on the days when it is needed most.
- **Consider Shortening the Event Duration:** Given the drop off in savings at the end of the event period, if Public Service would like to raise the average load reduction throughout the event, and perhaps improve customers satisfaction with the program, the event duration could be shortened somewhat. However, care must be taken to ensure that the event still covers the system peak hour and enough of the hours around it to avoid simply shifting the peak an hour later or earlier. We do not recommend changing the start and end times of the events during a single season, since that can cause customer confusion and reduce impacts.

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Chapter 1 – Introduction

Background

Public Service Company of Colorado (Public Service) carried out an In-Home Smart Device (IHSD) Pilot between 2009 and 2013. The purpose of the pilot was to test participant willingness to reduce loads in response to utility load control events, as well as to assess participant behavioral changes (in the form of lower overall energy use) due to access to in-home energy consumption information that is streamed in real time. Smart devices were installed in homes beginning in late 2011. The first of 30 demand response events was in July 2012 and the last was in September 2013. The EnerNOC project team supported Public Service in the design of the pilot and conducted a preliminary impact evaluation at the end of 2012. This report covers the complete impact evaluation for the analysis period spanning June 2012 to September 2013.

Scope

This report describes the pilot program, explains our analysis methods, presents detailed impact results for the two years of analysis, and discusses findings and recommendations from the pilot in comparison with best practices observed in similar programs nationwide. Our evaluation employs difference of differences analysis to estimate the demand response and energy savings impacts achieved during the pilot. It also utilizes regression modeling to study the impacts of weather on overall energy use and energy savings.

Report Organization

The report is organized as follows:

- Chapter 2 summarizes the key features of the pilot to provide context for the impact evaluation.
- Chapter 3 describes the analysis methods, including the approaches we followed for the difference of differences analysis and the regression modeling.
- Chapter 4 presents results from the impact analysis across the life of the pilot. The appendices include supplemental graphs and information.
- Chapter 5 discusses additional analysis we completed related to energy and demand effects after events and comparisons with other programs.
- Chapter 6 summarizes key findings from our analysis and provides recommendations for program modifications to improve the likelihood of success for a wider scale deployment.

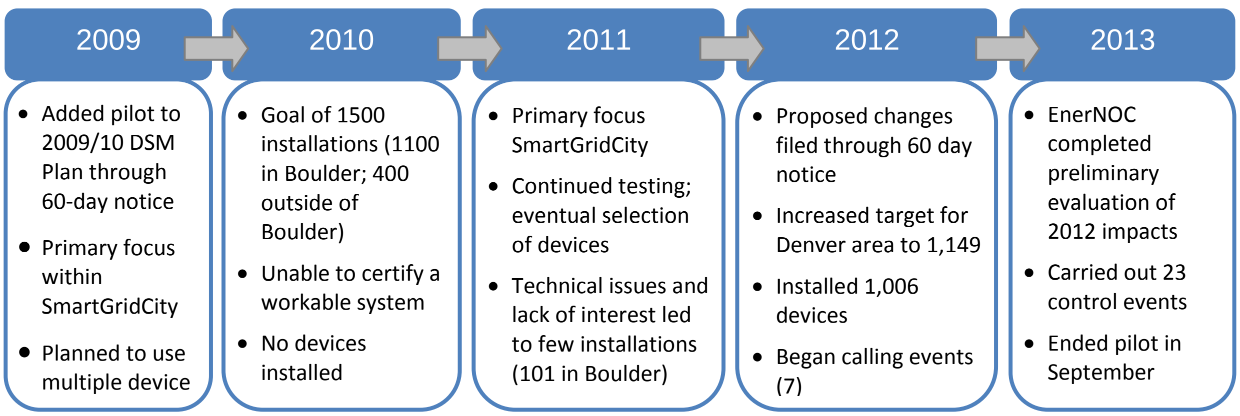
Chapter 2 – Overview of Pilot Program

IHSD Pilot Description

Evolution of Pilot

Public Service first initiated the pilot in 2009 with a 60-day notice that added it to the 2009/2010 DSM Plan. The pilot was originally focused on Boulder customers in the SmartGridCity™ footprint. In addition, the initial intent was to compare different devices from multiple vendors, with installations expected to start in 2010. Due to difficulties recruiting customers in Boulder and technical issues with some types of devices, the plan for the pilot evolved over time to comprise a greater share of customers outside of Boulder and to include only one type of device. The timeline in Figure 1 illustrates some of the main pilot activities between 2009 and 2013. For more information, refer to Xcel Energy's regulatory filings.

Figure 1. Timeline of IHSD Pilot Activities



Target Market

The target market for the IHSD pilot was Public Service's residential customers with electric service. To be eligible, customers had to have central air conditioning (AC) systems. If a customer was interested in participating in the pilot, but they were already enrolled in the Company's Saver's Switch program, the Saver's Switch was deactivated for the duration of the pilot to avoid any impact of the existing program on this pilot. [1] Public Service recruited customers from two areas within the Colorado service territory: 1) Boulder; and 2) Westminster and Centennial (collectively referred to as "Denver").

In-Home Smart Devices

Public Service provided pilot participants three types of products:

- **EnergyHub Home Base:** The Home Base was the key technology employed in the pilot. It provided participants with an interface to view energy use information and

[1] A few participants signed up for Saver's Switch and were inadvertently enrolled in that program after already being enrolled in the IHSD pilot. To make sure the Saver's Switch events were not included as part of the IHSD demand response event days, we removed all Saver's Switch event days from the analysis for those Saver's Switch participants.

manage thermostats, appliances, and other plug loads. Through a web-enabled account supported by EnergyHub, participants could also view and manage energy use remotely over the web. In this report, we refer to the Home Base as the “IHSD” or “device”.

- **Honeywell wireless thermostat:** This smart thermostat was controlled by the Home Base and was a major source of demand savings during the IHSD pilot’s summertime events. The participants’ devices were installed with a preprogrammed cooling offset of 5°F for summer events, but that offset was configurable so participants could adjust the setting during the pilot if they wished.
- **Two appliance sockets:** These special sockets allowed for a wireless connection to the Home Base, enabling participants to view their appliance or plug load’s energy consumption as well as to control the appliances and plug loads. Participants selected a wide variety of plug loads and appliances to be controlled by the devices. Examples include lamps, televisions, washing machines, power strips, fans, and coffee makers.

A small percentage of the Home Base units failed during the pilot. Some failures were caused by issues with the devices themselves, while other failures were due to customer mishandling of the units. Public Service estimated the annual failure rate to be about 4%. Participants were supplied with a new device upon failure.

Pilot Study Design

The pilot study design had two main features to enable estimation of demand response and overall energy savings impacts:

- **Demand Response:** We used a split design for the IHSD pilot with two separate, but similar, participant groups. In this design, one group of customers was notified of the event each time and the other group was not. The notified group alternated from one event to the next. As a result, the two groups could serve as a control group for each other by comparing the load shapes of the group receiving notice on that day with the load shape of the group that did not receive notice. This approach allowed us to estimate the demand response impacts during the events.
- **Energy Savings:** To estimate any changes in energy use resulting from participants having devices installed in their homes, we compared the energy use of participants to a matched control group of similar non-participants.

Chapter 3 describes the rationale for this design in greater detail.

Events

Event days were the key aspect of the IHSD pilot. Table 1 summarizes the demand response events that were called throughout the pilot. The table includes the date and day of week of each event, the group and number of customers notified, the high and low temperatures on the event days, and the type of event. The first event was called on July 13, 2012 and was a Group A event. At that time, the majority of devices were installed, but since participants were still being assigned to groups, only about one-third were notified of the event. By late 2012 when everyone was settled into groups, the number of notified participants increased by a factor of more than three.

Forecasted temperature was the criterion used for calling an event. If the next day's forecasted temperature was above a certain threshold, it was considered a candidate event day. For the impact analysis, the events were categorized into five types: 1) high temperature summer; 2) medium temperature summer; 3) low temperature summer; 4) high temperature non-summer; and 5) low temperature non-summer. The purpose of non-summer and milder temperature summer events was to see what level of demand reduction could be obtained from customers' actions and devices other than thermostat control of AC loads. Across the first summer of the pilot, the candidate event days were called as actual event days two thirds of the time, following a "call-don't call-call" sequence that was repeated throughout the summer. This resulted in event days called on many but not all of the hot days. The non-summer event days were called based on how low the forecasted high temperatures were, with the goal of getting days with varying temperatures. In 2013, the requirement of "call-don't call-call" was lifted to get more events, and an attempt was made to call the two groups on consecutive days where possible, particularly early in the summer. In total, there were 30 events: six summer events in 2012, five non-summer events in late 2012 and early 2013, and 19 summer events in 2013.

Table 1. 2012 and 2013 IHSD Event Day Information

Date	Day of the Week	Group Notified	No. of Customers Notified	High Temp. (°F)	Low Temp. (°F)	Event Type
07/13/12	Friday	A	154	96	67	Summer - High
07/20/12	Friday	B	134	101	67	Summer - High
07/23/12	Monday	A	154	100	64	Summer - High
08/01/12	Wednesday	B	134	94	65	Summer - High
08/08/12	Wednesday	A	338	96	61	Summer - High
09/14/12	Friday	B	356	77	49	Summer - Low
11/02/12	Friday	A	512	56	35	Non-Summer - High
01/29/13	Tuesday	B	519	30	14	Non-Summer - Low
01/30/13	Wednesday	A	518	37	2	Non-Summer - Low
02/21/13	Thursday	B	517	23	7	Non-Summer - Low
02/22/13	Friday	A	508	32	5	Non-Summer - Low
06/10/13	Monday	B	498	99	68	Summer - High
06/11/13	Tuesday	A	492	100	57	Summer - High
06/12/13	Wednesday	B	499	93	59	Summer - Medium
06/13/13	Thursday	A	490	94	53	Summer - High
06/20/13	Thursday	A	489	91	56	Summer - Medium
06/21/13	Friday	B	496	96	55	Summer - High
06/24/13	Monday	A	489	91	56	Summer - Medium
06/27/13	Thursday	B	496	97	67	Summer - High
06/28/13	Friday	A	489	96	65	Summer - High
07/16/13	Tuesday	B	485	82	56	Summer - Low
07/19/13	Friday	A	479	81	61	Summer - Low
07/22/13	Monday	B	482	94	63	Summer - High

Date	Day of the Week	Group Notified	No. of Customers Notified	High Temp. (°F)	Low Temp. (°F)	Event Type
08/01/13	Thursday	A	478	95	62	Summer - High
08/19/13	Monday	B	477	95	61	Summer - High
08/21/13	Wednesday	A	474	92	66	Summer - Medium
08/28/13	Wednesday	B	477	93	64	Summer - Medium
08/29/13	Thursday	A	475	95	65	Summer - High
09/04/13	Wednesday	B	478	93	69	Summer - Medium
09/05/13	Thursday	A	474	97	62	Summer - High

Participation

Recruitment

Public Service used several different types of recruitment approaches to reach enrollment targets:

- Email
- Outbound calls
- Direct outreach (e.g., town hall presentations)
- Direct mail

Direct mail was the most effective approach. Figure 2 shows an example of a postcard used in direct mail outreach of the pilot.

Figure 2. Postcard used in Direct Mail Customer Outreach

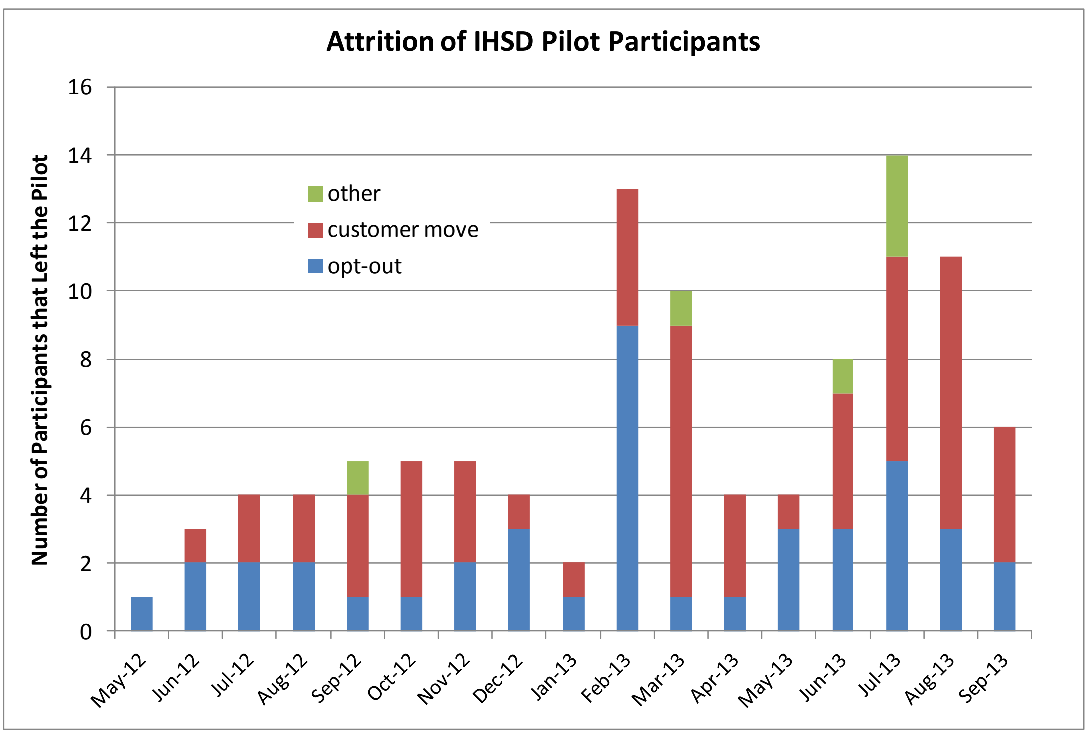
As noted previously, the IHSD pilot was originally designed to target customers within SmartGridCity. However, limited interest from eligible customers resulted in just 33 installations. This led to a focus on Denver metro suburbs where approximately 1,000 devices were installed.

Note that a total of approximately 100 devices were installed in Boulder, but about two thirds were installed at the homes of customers who were participating in a separate SmartGridCity Pricing Pilot. For the purposes of this report, we have only focused on the 33 devices in homes on the standard residential rate. We covered the Boulder IHSD customers on the Pricing Pilot in a separate impact evaluation. [2]

Attrition

Customer attrition occurred throughout the life of the IHSD pilot. There were two primary reasons for participants leaving the pilot: 1) the customer moved to a new residence; or 2) the customer decided to no longer participate ("opt-out"). Public Service tracked monthly attrition and estimated that, overall, about 9.4% of the total number of participants left during the pilot. Figure 3 plots participant attrition between May 2012 and September 2013. (Prior to May 2012, only one customer un-enrolled, and that was in September 2011, which is outside the scope of the evaluation period.) The figure shows that customer moves accounted for the majority of attrition (53%), followed by customer opt-out (40%), and then various other reasons including interaction with the pricing pilot (7%). In total, 104 participants un-enrolled from the pilot.

Figure 3. Attrition of IHSD Pilot Participants: May 2012 through Sep 2013



[2] *SmartGridCity™ Pricing Pilot: Impact Evaluation Results, 2011-2013*, prepared for Xcel Energy, prepared by EnerNOC Utility Solutions Consulting, Walnut Creek, CA: December 6, 2013.

Chapter 3 – Analysis Methods

Overall Analysis Approach

The analysis in this report covers the period beginning in June 2012, when most pilot participants had installed IHSDs, and ending in September 2013, at completion of the pilot. For simplicity, we refer to the June through September 2012 period as "Summer 2012," the October 2012 through May 2013 period as "Non-Summer," and the June through September 2013 period as "Summer 2013."

We estimated the impacts of the IHSD Pilot using two methods: 1) difference of differences, and 2) fixed effects regression modeling. We used the difference of differences approach to estimate the actual demand response and energy impacts for each period of the pilot; these are called "ex post" impacts. We used the regression modeling approach to develop more precise estimates of the ex post energy savings based on actual weather as well to predict what the savings would be during a normal weather year.

Difference of Differences

Approach

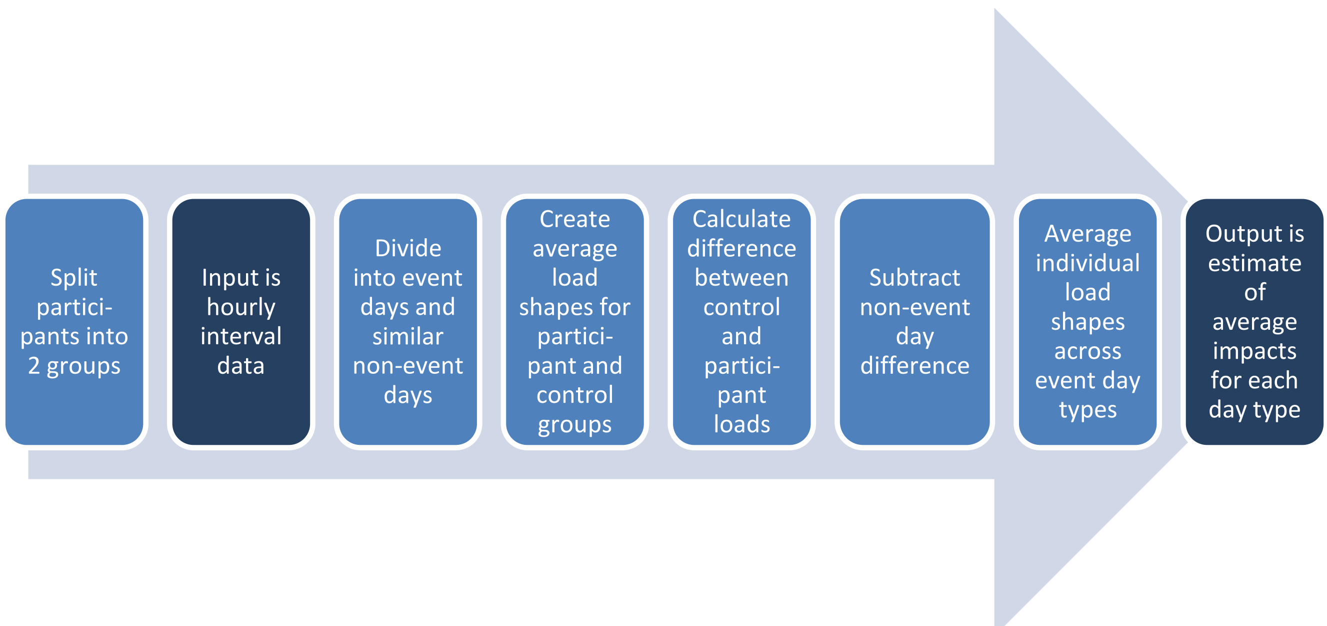
Demand Response

We used the difference of differences approach to estimate demand response impacts achieved for each event in the pilot. We also used the difference of differences approach to estimate monthly energy impacts across the duration of the pilot. The difference of differences method provides a savings estimation that is particularly useful for situations where there may be preexisting differences between the participants and the customers in the control group. This method compares participating customers with a control group of similar but non-participating customers, both during the participation period ("treatment period") and for a time before participation started ("pretreatment period"). Comparison during the treatment period gives an unadjusted estimate of the impacts. This estimate is then corrected using the difference during the pretreatment period to adjust for any preexisting differences between the participant and control groups. Therefore, the difference of differences method provides a robust savings estimation that is also intuitively easy to understand, since it involves a direct comparison of hourly demands or energy use. The difference of differences method for the demand response impacts consists of the following seven steps (Figure 4 illustrates the approach):

1. Randomly split the participants into two groups, referred to as Group A and Group B. For each event day, only one of the two groups will be called, and the other will serve as a control group for that event. The groups will be alternated, so there is approximately the same number of events called for each group.
2. Start with hourly interval energy usage data collected from the EnergyHub devices installed at customers' homes. For each event, use the hourly data for that event day and an average of several similar non-event days from the same year and season, and for all customers in both groups.

3. Divide the analysis into individual events and five event day types: a) high temperature summer, b) medium temperature summer, c) low temperature summer, d) high temperature non-summer, and e) low temperature non-summer.
4. Calculate the average load shape for the participant group (the group called on that day) and the control group (the group not called on that day) for each event.
5. Calculate the difference between the control group average load and the participant group average load for each event and the corresponding similar non-event day average. The result of the difference on the event day is the first difference, which represents the unadjusted impact.
6. Subtract the pretreatment difference (the difference between the groups on similar non-event days) for each event from the unadjusted impact to get the adjusted impact, which represents the estimated demand response impacts for each individual event corrected for the pre-existing differences between the two groups.
7. Average the individual event day participant and control group load shapes across the 5 different event day types, and calculate the average impacts for each event day type.

Figure 4. Difference of Differences Approach for Demand Response Impacts



Equation 1 shows a simplified form of the mathematical calculations used in the difference of differences analysis to estimate energy savings for each day type. In this case, the “before” refers to the similar non-event days, and the control group is the group that was not notified.

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

Where

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

Tx_{after} is the average participant group (also referred to as the treatment group) customer energy use in the treatment (after) period

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

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

This formula can easily be rewritten as shown in Equation 2, which allows for comparison of the actual participant group load in the analysis period with an adjusted treatment period control group. This is the way data is displayed on the load profile graphs in the report body and appendices. Visually, this depicts the savings as the difference between the two lines.

$$Savings = [Cntl_{after} - (Cntl_{before} - Tx_{before})] - Tx_{after} \quad (2)$$

The term in the square brackets is the adjusted control group load and the final term is the actual participant group load during the analysis period.

Energy Savings

For monthly energy savings, we used a similar approach to the difference of differences method described above for the demand response impacts. However, in this case, we had a separate matched control group, and we had pretreatment data for the year before the devices were installed. For the difference of differences, we used monthly energy data for the pretreatment and treatment periods and we calculated the impacts for each month in the analysis period. We had monthly energy data from January 2011 through September 2013. The pretreatment period for each customer was determined by their IHSD install date.

Control Groups

Because of the need for participants and to avoid customer dissatisfaction, we did not use a classic randomized experimental design. That type of design would have necessitated recruiting twice the number of customers to participate, and then telling half of them that they could not participate and would not receive a device so we could use them as the control group. In addition, for those IHSD customers outside of Boulder, the only interval data available for the analysis was the interval data collected and stored by the devices. As a result, there was no pretreatment interval data for the majority of participants. In addition, there was no interval data at all for the majority of representative control group customers. We dealt with this situation in two ways, using one control group approach for the demand response analysis and a different control group approach for the energy analysis. The following subsections describe the two approaches.

Note that there is potential for confusion with terminology. During events, devices are notified of the event and controls are put in place, including changing the thermostat set points and disconnecting loads on remote plugs. These actions can be referred to as a customer being “controlled” during an event. Because of the possible confusion with the idea of a statistical control group, we refer to customers being “notified” of an event instead of being “controlled” in the event. This terminology convention also reflects the fact that not all who are notified of an event will participate; those who opt out of an event do not have their energy use controlled in any way. When we discuss control group customers, we are referring to customers not notified of the event.

Demand Response

The lack of interval data for non-participants, as well as for the participants before the devices were installed, meant that selecting a matched control group would not provide the data granularity required to estimate the demand impacts. For this reason, we used a split design where we divided the participants into two groups: Group A and Group B. When an event was called, only one of the two groups was notified and the other group was treated as if the day was a non-event day. Key elements of our split design include the following:

- **Creation of Similar Groups:** We divided the participants in a manner that created two groups that were as similar as possible, so that each could function as a control group for the other. The goal was to split the participants randomly to ensure an unbiased comparison, but to do so in such a way that the two groups had about the same number of participants in each city and were similar demographically. First, we grouped the participants into cells based on the city in which they were located and their PRIZM Lifestage code, which is a demographics indicator. Then within each cell, we split the participants randomly into the two groups. This process resulted in two groups that were similar, with no systematic bias inherent in the assignments. Therefore, on non-event days, the two groups have similar (but not identical) load shapes.
- **Assignment of Treatment and Control Groups:** Only one of the groups was notified for each event, on an alternating basis. Group A was notified for the first event, but Group B was not; then Group B was notified for the second event, but Group A was not, and so on. In this way, for a given event, the treatment group was the group that received notification and the control group was the group that did not receive notification. Then the two groups were switched for the next event day.
- **Designation of Pretreatment and Treatment Periods:** For each event day, we defined the event day as the treatment period and we considered the average of several non-event days with about the same temperatures as the pretreatment period.

Energy Savings

For the energy savings analysis, we created a matched control group for the participants to estimate any overall change in energy use (generally referred to as a conservation effect). Our approach was as follows:

- **Control Group Pool:** We used a pool of potential control group candidates that was much larger than the number of participant customers (approximately 10 times the number) for each city and PRIZM Lifestage code.
- **Matching Process:** For each participant, we selected the customer from the pool of candidates in the same city with the same PRIZM code that had monthly energy use that was most similar to the participant's energy use during the pretreatment period.
- **Saver's Switch:** We also included Saver's Switch participation in the match. IHSD customers that were Saver's Switch participants were matched to control group customers who were also Saver's Switch participants, and non-Saver's Switch IHSD customers were matched with Non-Saver's Switch control group customers.

- **Resulting Match:** This matching resulted in a control group of non-participants that was the same size as the participant group and was very similar based on geography, demographics, and energy use.

Accounting for Off-Line Customers

During each event, a percentage of participants were off-line (i.e., not connected to the Internet). Therefore, these participants did not receive notification of the event and, as a result, their devices did not automatically respond to the event. Since we would expect a similar percentage of participants to be disconnected for events if this program is rolled out to a larger group in the future, it is important to estimate the effects off-line participants have on overall per-participant demand response impacts.

Because we did not have interval data for off-line participants during the events, we were unable to include them directly in the difference of differences analysis since that approach requires complete interval data. So we carried out the traditional difference of differences analysis for the set of on-line participants for whom we had complete interval data, with the results representing the demand savings for participants who are on-line during the event. To adjust this estimate to reflect the average across all participants, we then discounted the savings estimate to account for off-line participants. In essence, this makes the logical assumption that those that were off-line had no demand reduction, and so averages the zero savings with the estimated savings using the appropriate weight. To do the discounting, we first calculated a “Discount Ratio” of the number of on-line to total participants in the notified group for the given event. Then, we multiplied the estimated savings values from the difference of differences analysis by that ratio. The resulting impacts represent the appropriate per-participant savings based on all participants – on-line participants who responded to the event, on-line participants who did not respond, and off-line participants.

Accounting for Event Responders

For each event, some IHSD pilot participants opted out of the event, while others did not. We expected that demand reductions for the subset of event responders would be higher than for pilot participants as a whole. To quantify the impacts for this subset of participants, we first came up with a definition of an “event responder” for a given event and then defined what a “frequent event responder” would be. We then carried out the difference of differences analysis using only the subset of event responders from both Group A and Group B.

Definition of Event Responder

The participants notified for a given event were classified in one of six categories:

- **Accepted:** Accepted participation in event
- **Declined:** Declined participation in the event
- **Acknowledged but not Configured to Respond:** Acknowledged receipt of the notification, but the customer’s device was not configured to respond
- **No Response Yet but Configured to Respond:** Did not acknowledge receipt of the notification, but the customer’s device was configured to respond

- **No Response Yet and Not Configured to Respond:** Did not acknowledge receipt of the notification and the customer's device was not configured to respond
- **Not Delivered:** The customer's device was off-line (disconnected from the Internet)

We defined **event responders** for each individual event as those either accepting the event in response to the notice ("Accepted" category), or those who did not respond to the notice by the midpoint of the event (5:00 pm), but whose devices were configured to respond ("No Response Yet but Configured to Respond" category).

Definition of Frequent Event Responder

To carry out the difference of differences analysis for event responders, we needed to compare the average loads of the actual event responders in the group called during a given event with the average loads for the customers in the other group who would have been event responders on that day if they had been called. Of course, because those in the other group were not called, we had no way of knowing who would have been an event responder. Therefore, we developed a definition of a frequent event responder by looking at the distribution of responding customers across the events. Table 2 shows the number of Group A and Group B participants that responded to at least "k" events in the given period (Summer 2012, Non-Summer, and Summer 2013), where k is the number in the header. For the Summer 2012 and the Non-Summer periods, each individual participant was only called during three events; for Summer 2013, each group was called 10 times. Based on the results in the table, we defined **frequent responders** for each of the three periods as follows (also see green cells in the table):

- **Summer 2012:** Responded to at least 2 events
- **Non-Summer 2012-2013:** Responded to at least 2 events
- **Summer 2013:** Responded to at least 8 events

Table 2. Distribution of Event Responders

	Number of Events "k"										
Period/ Group	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Summer 2012											
Group A	335	234	**83**	50							
Group B	350	245	**79**	45							
Non-Summer											
Group A	509	264	**220**	167							
Group B	513	231	**178**								
Summer 2013											
Group A	490	402	375	342	296	271	237	201	**161**	126	74
Group B	495	397	371	341	307	272	241	204	**174**	122	65

The frequent event responders from each group for each season and year were used as the control group for the events that they were not called. For instance, the Group B frequent responders for Summer 2013 were used as the control group for the event responders for the 10 Group A Summer 2013 events. This ensured that the control group for each event was made up of similar customers.

Regression Modeling

In the regression analysis for estimating energy savings, we used a statistical model to estimate how different factors (independent variables) influence energy use (dependent variable). The independent variables investigated are as follows:

- Temperature (cooling degree days and heating degree days)
- Pilot program year and month – to account for any changes in customer response and in general energy use not related to the pilot
- Season (summer and non-summer)
- Participation

The model looks at the dependent variable as a function of the other independent variables and estimates the coefficients of the variables in that function.

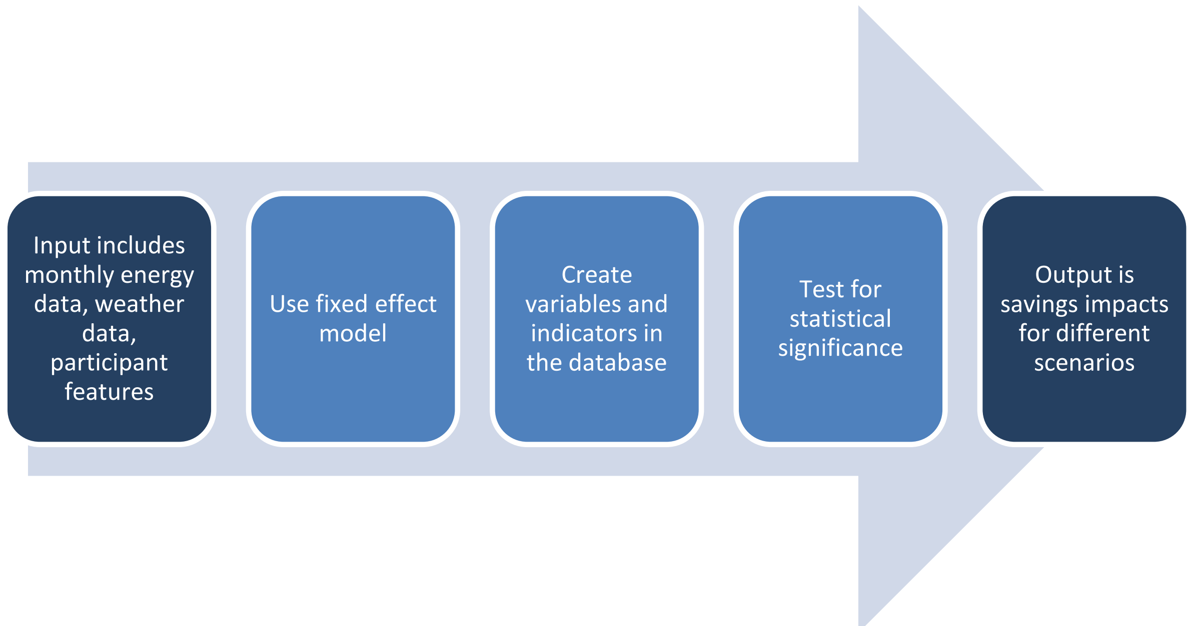
Specifically, we used a two-way fixed effect regression approach for the energy analysis. The regression analysis allows us to estimate how the different independent variables influence energy use. In addition, the fixed effect model introduces unique intercept variables for each customer, which we can use to capture and control for unobservable customer-specific differences and to reduce the variance of estimates due to those differences. We also included a fixed effect for each month of the analysis period, which accounted for any non-weather-related changes in energy use that were not related to the pilot, such as changes in the economy or rates. The regression approach estimates coefficients for each variable, which quantify the relationship between that variable and energy use. Some of the variables are set only for participants, and so can be used to estimate the impacts of the pilot.

Our regression analysis included the following general steps and assumptions (Figure 5 illustrates the approach):

- Use all participant and control customers in a two-way fixed effect model.
- Create variables and indicators in the database. Note: The independent variables investigated include some that are related to participation, and others that are not. Conceptually, information not related to participation goes into the model to estimate the baseline energy use based on all customers (including participants and control group customers), while the participation variables (in some cases interacted with weather data) estimate the program impacts. We used the number of degree days for each month in the model, both with and without participation, so that the model quantifies the relationship between energy use and temperature as well as the relationship between savings and temperature.

- Test all the coefficients of the individual variables for statistical significance, and include only variables that actually influence energy use significantly.
- Run the model to estimate the baseline energy use and the savings for the actual analysis period and for different scenarios (including normal weather) using the model coefficients.

Figure 5. Simplified Regression Modeling Approach



Equation 3 is the model specification we used. We tested other variables, but this was the final model that included only statistically significant coefficients.

$$kWh_{ij} = \beta_0 + \beta_{1i}Cust_i + \beta_{2j}Month_j + \beta_3 CDD_{ij} + \beta_4 HDD_{ij} + \beta_5 Tx_{ij} + \beta_6 Tx_{ij}CDD_{ij} + \varepsilon_{ij} \quad (3)$$

Where the variables and their coefficients are defined as:

$i = 1,2, \ldots ,1886$	Customer indicator; customer 1886 is the reference customer (includes treatment and control customers)
$j = 1,2, \ldots ,33$	Month indicator (January 2011 through September 2013); September 2013 is the reference month
kWh_{ij}	Consumption of customer *i* in month *j*, normalized to a 30-day month
β_0	Intercept term; represents the reference month of the reference customer
$\beta_{1i}Cust_i$	Fixed effect for each customer *i*
$\beta_{2j}Month_j$	Fixed effect for each month *j*

$\beta_3 CDD_{ij}$	Cooling degree days using base 68°F; determined by billing read dates; normalized to a 30-day month
$\beta_4 HDD_{ij}$	Heating degree days using base 55°F; determined by billing read dates; normalized to a 30-day month
$\beta_5 Tx_{ij}$	An indicator variable that takes on the value of one after the IHSD is installed for customer *i*
$\beta_6 Tx_{ij} CDD_{ij}$	An interaction term between the indicator variable Tx and CDD
ε_{ij}	The error for customer *i* in month *j*

Appendix C contains the SAS output of the regression model.

Data Used in Analysis

Demand Response

We conducted the demand response analysis using the hourly interval energy usage data collected from the devices installed at customers' homes. Table 3 shows the breakdown by group assignment of pilot participants with and without at least partial data available. Only six Group A and four Group B participants had absolutely no interval data available.

Table 3. High Level Count of Customers

	Group A	Group B
At least some data available	507	510
No data available	6	4
Total	**513**	**514**

Table 4 shows how many customers assigned to a given group had complete data for each event. It also shows the Discount Ratio used in the discounted savings analysis carried out to account for the effects of off-line participants on the per-participant impacts. The table includes customer counts for the set of "pilot participants as a whole" and for the subset of "event responders." The count of event responders is specific to each event for the group called during that event, but it represents the "frequent event responders" for the group used as a control group for each event. As the table shows, the customer counts vary over time and by event. Early in the pilot, the customer counts are lower because a smaller number of participants had signed up and been assigned to groups. The counts then reach a maximum over time and begin to drop off toward the end of the pilot as a result of participants un-enrolling and moving out of their homes. Another reason for customer count variability is that some customers were missing data for some of the events, while they had complete data for other events.

Table 4. Customer Counts and Discount Ratio for Each Event in Demand Response Analysis

Date	Pilot Participants as a Whole		Discount Ratio (Fraction of Participants On-Line)	Event Responders	
	Group A	Group B		Group A	Group B
07/13/12	132	125	0.89	76	77
07/20/12	129	128	0.95	75	87
07/23/12	130	127	0.89	87	78
08/01/12	128	124	0.93	76	84
08/08/12	290	307	0.89	190	77
09/14/12	286	304	0.87	74	194
11/02/12	443	443	0.89	219	169
01/29/13	444	436	0.86	216	198
01/30/13	445	434	0.88	215	174
02/21/13	434	427	0.86	209	197
02/22/13	434	429	0.89	205	171
06/10/13	413	400	0.85	156	213
06/11/13	416	402	0.88	243	165
06/12/13	412	402	0.84	156	242
06/13/13	412	404	0.88	243	168
06/20/13	412	395	0.87	248	167
06/21/13	411	393	0.83	156	241
06/24/13	404	400	0.87	257	170
06/27/13	400	399	0.84	155	226
06/28/13	403	402	0.86	221	169
07/16/13	395	398	0.85	154	260
07/19/13	396	395	0.87	248	169
07/22/13	394	394	0.86	153	234
08/01/13	392	390	0.86	251	167
08/19/13	386	374	0.83	151	228
08/21/13	387	362	0.85	229	162
08/28/13	383	363	0.81	152	215
08/29/13	379	361	0.85	214	161
09/04/13	378	367	0.82	151	214
09/05/13	376	363	0.85	228	159

Note: the cells shaded blue indicate the notified group for that event day.

Energy Savings

We conducted the energy analysis using monthly energy data for the pretreatment and treatment periods. For Denver participants, we used monthly billing data for the period of January 2011 to September 2013. For Boulder participants, we had access to interval data; therefore, to maximize data quality, we used the interval data to emulate the billing data for the Boulder customers. For participants who left the pilot, we only included energy data up until the time they left.

Chapter 4 – Impact Results

Organization of Results

We estimated two types of impacts for the IHSD pilot: 1) temporary load reductions due to participant response during demand response events; and 2) overall reductions in monthly energy use due to behavioral changes. As described in Chapter 3, we used a difference of differences analysis approach with a split design for estimating the ex post demand response impacts. We used a separate difference of differences approach with a match control group for the ex post energy savings estimates. The difference of differences was unable to detect statistically significant energy savings, so we also created a regression model to estimate ex post impacts and to enable estimation of weather-normalized energy savings impacts. The following subsections summarize the key demand response and energy savings results. The appendices contain complete demand response impacts for each individual event as well as the output from the regression model.

Demand Response Impacts

Pilot Participants as a Whole: Summer and Non-Summer Events

Table 5 summarizes the demand response impacts for the IHSD pilot for pilot participants as a whole. The table categorizes the per-participant results by event type and analysis year. It includes the average demand (in kW) for the adjusted control group, the discounted average load reduction (in kW) across the six-hour event period for the treatment group, the percent load reduction, and the average event day high temperature. It also designates the savings as statistically significant or not.

Table 5. Demand Response Impacts: Pilot Participants as a Whole

Event Type	Analysis Year	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Average Event Day High Temp. (°F)	Significant Savings?
Summer – High	2012	2.65	0.71	±0.02	27%	97	Yes
	2013	2.57	0.52	±0.03	20%	96	Yes
Summer – Medium	2013	2.28	0.47	±0.03	21%	92	Yes
Summer – Low	2012	0.99	0.06	±0.05	6%	77	No
	2013	2.07	0.44	±0.05	21%	82	Yes
Non-Summer – High	2013	1.09	0.02	±0.04	1%	56	No
Non-Summer – Low	2013	1.25	0.02	±0.01	2%	31	No

Note: Cells shaded in light blue represent statistically significant savings.
[a] Load reduction impacts have been discounted to account for off-line participants. These include estimated confidence intervals based on averages of the discounted confidence intervals for individual on-peak hours.

The results show that summer events yielded the largest load reductions, ranging from 0.44 kW to 0.52 kW in analysis year 2013. Note that the average kW reduction for high temperature summer events was 0.52 kW for 2013 compared with 0.71 kW for 2012. This decrease in response corresponds to a decrease in percent demand reduction from 27% in 2012 to 20% in 2013. Medium temperature and low temperature summer events in 2013 yielded similar impacts, with estimated average kW reductions of 0.47 kW (21%) and 0.44 kW (21%), respectively. Demand reductions were not statistically significant for the non-summer events when AC units were not in operation, indicating that appliances and plug loads contributed little to the demand savings. In addition, demand reductions were not statistically significant for the one low temperature summer event in 2012. However, that event was in mid-September, when people had probably shut off their AC units. In comparison, the 2013 low temperature summer events were during mid-July, in the midst of other warmer days. In addition, the temperature difference between the 2012 and 2013 events is notable. The 2012 high temperature of 77 °F is very close to the range of AC set points, so even if the participants' AC systems were cycling on, they probably were not on for long durations. With the 2013 high temperature of 82 °F, it is much more likely that the AC units were operating more continuously to bring the temperatures down.

Below we include the average load shapes and savings graphs for the high temperature summer event days in each year. The graphs reflect averages across the customers and across the individual high temperature summer events. Figure 6 shows the 2012 graphs and Figure 7 shows the 2013 graphs. Both figures contains three graphs for the given event day type.

- The first graph for each event day type is a comparison of the average load shapes for the control and treatment groups.
- The second graph is the average estimated savings for the given event day type based on the difference of differences analysis approach. The savings graph includes the associated 90% confidence intervals as dotted lines on either side of the estimate.
- The third graph for each event type represents the average discounted savings for the group of notified participants as a whole, including both on-line and off-line customers. Because the discount adjustment is treated as a constant, we applied that constant to the upper and lower bounds shown in the second graph to determine the estimated confidence intervals for the discounted savings. The savings reflected in the third graph are the values included in Table 5.

When the confidence intervals includes zero, the savings are not statistically significant. But, where the confidence intervals do not include zero, we can say that there are statistically significant savings during those hours. Because the values on the graph represent savings, a negative value means that the participating customer used more energy.

Figure 6. 2012 Average Summer High Event Day Graphs: Pilot Participants as a Whole

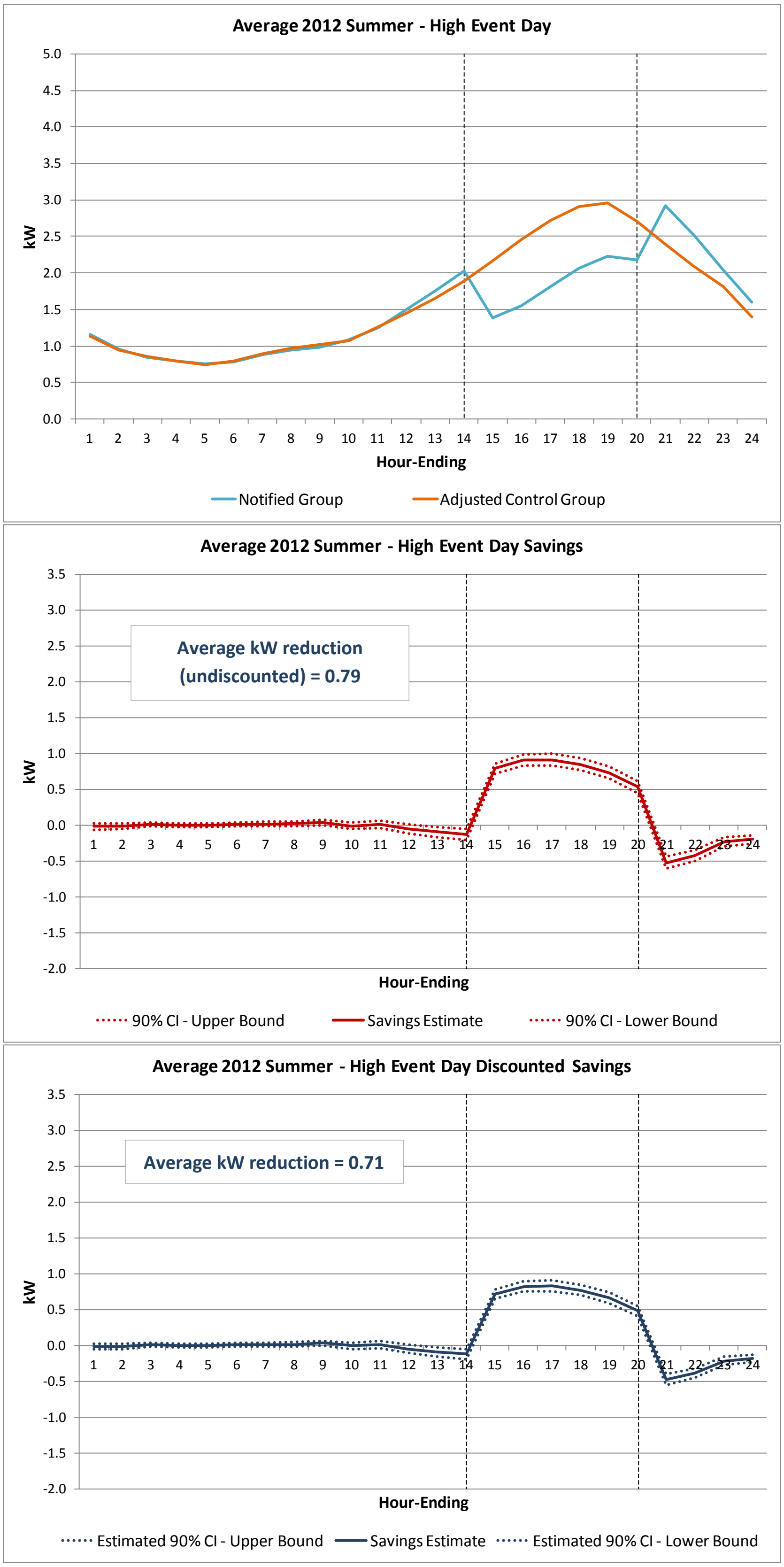
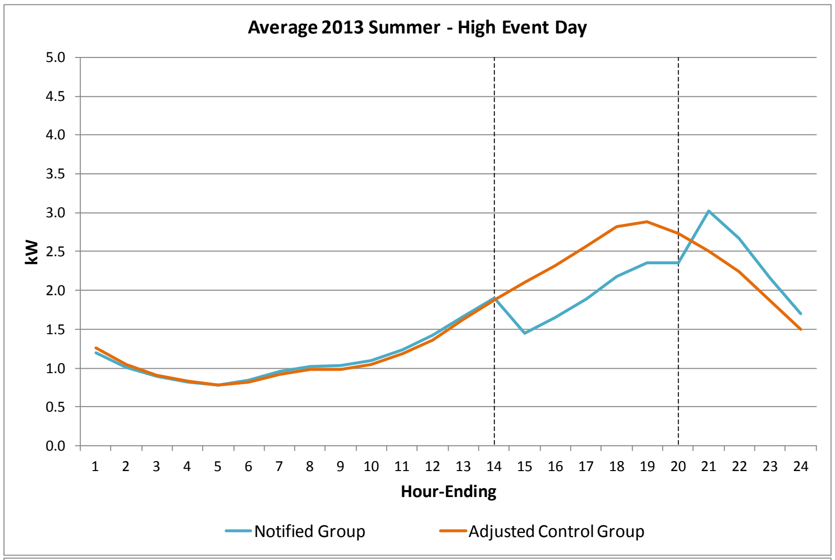
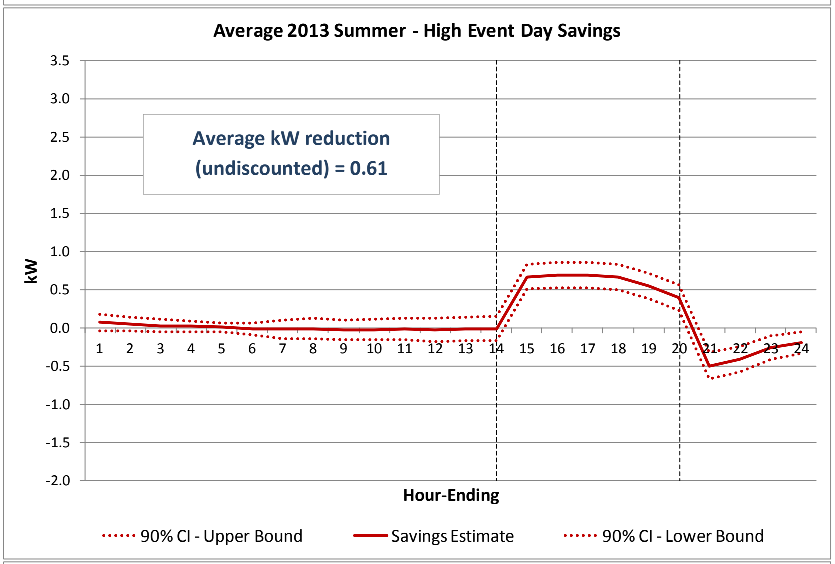
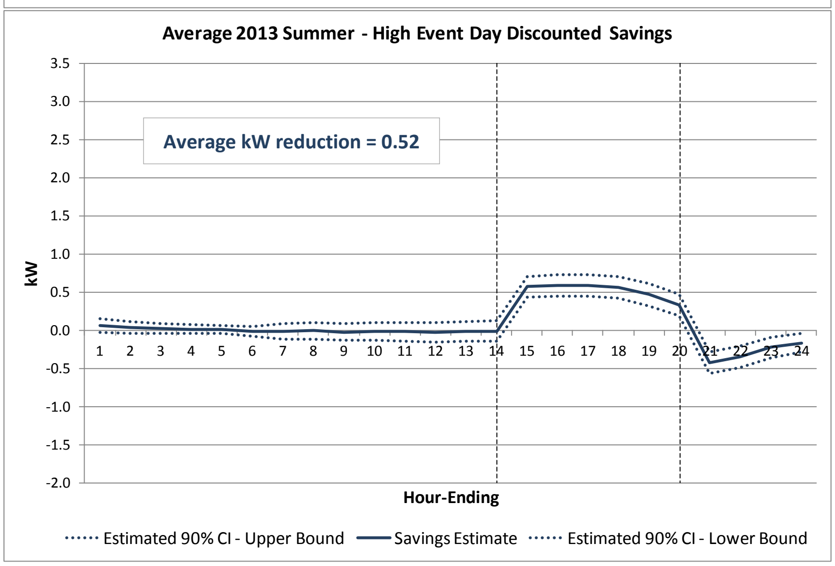


Figure 7. 2013 Average Summer High Event Day Graphs: Pilot Participants as a Whole





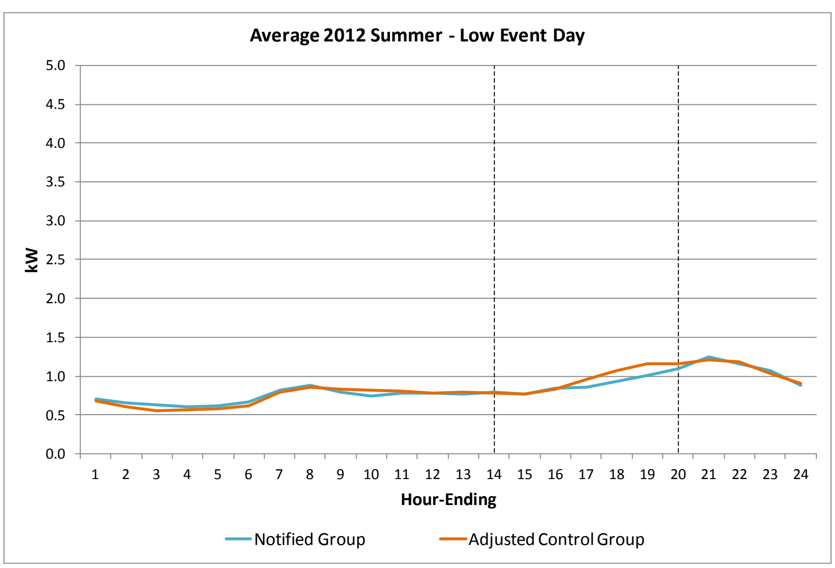


For the load shape graphs in Figure 6 and Figure 7, the treatment and control group loads are nearly identical overnight and in the hours leading up to the event. Then during the event there is a clear reduction in load that lasts throughout the event, peaking near the middle, and dropping off somewhat in the last three hours of the event. This drop off in the second half may be due to some AC units coming back on as the temperature reaches the new set points in some houses. These event savings are all highly significant, with little doubt that the savings are different from zero. After the event, there is a period of higher usage, which shows up as negative savings. This post-event higher usage represents the “snapback” effect when the customers’ AC units use more energy to “catch up” after the event. The snapback is statistically significant as well. Chapter 5 describes the snapback effect in more detail. There also appears to be a slight increase across the first three hours of the event. There are several factors that could be contributing to this. The AC load in the control group would continue to increase, with higher energy use as the day gets hotter, while the participant loads would stay flatter until the internal home temperature rose to the new set point. This could also be due to manual actions taken by customers as they think of things that they can turn off, or as they don’t add load that they would have if it were not an event day. If this latter effect continues throughout the event, it could be mitigating the drop-off in savings due to the AC units coming back on later in the event.

For the most part, the general form of each type of high temperature summer event day graph in Figure 6 and Figure 7 is representative of the results observed for low and medium temperature summer events days. (Refer to Appendix A and Appendix B for the complete set of graphs for each individual event.) The one exception is the 2012 low temperature summer event day.

Figure 8 shows the load shapes for the low temperature summer event in 2012, which was on September 14. It appears that there might be savings during the event, particularly later in the event, but it is hard to say if that is meaningful or just random variation since the savings are not statistically significant. As noted previously, since the event occurred on a mild day in mid-September, the demand for air conditioning was probably low.

Figure 8. 2012 Average Summer Low Event Day Load Shapes: Pilot Participants as a Whole



We have not included the average event day load shapes and savings graphs for the non-summer events here since the results were not statistically significant, but the graphs are in the Appendix A and Appendix B.

Event Responders: Summer Events

Table 6 summarizes the demand response impacts for the IHSD pilot for the subset of participants who responded to the events. Event responders were defined for each individual event as those either accepting the event in response to the notice, or those who did not respond to the notice by the midpoint of the event (5:00 pm), but whose devices were configured to respond. The table categorizes the per-participant results by event type and analysis year. It includes the average demand (in kW) for the adjusted control group, the estimated average load reduction (in kW) across the six-hour event period for the treatment group, the percent load reduction, and the average event day high temperature. It also designates the savings as statistically significant or not. The analysis of the subset of event responders only includes summer events when AC units would be in use since thermostat control for space cooling delivered the majority of the savings.

Table 6. Demand Response Impacts: Event Responders

Event Type	Analysis Year	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Average Event Day High Temp. (°F)	Significant Savings?
Summer - High	2012	2.80	1.29	±0.14	46%	97	Yes
	2013	2.53	0.99	±0.11	39%	96	Yes
Summer - Medium	2013	2.22	0.82	±0.10	37%	92	Yes
Summer - Low	2012	1.03	0.14	±0.07	14%	77	No
	2013	1.94	0.76	±0.07	39%	82	Yes

Note: Cells shaded in light blue represent statistically significant savings.
[a] These include estimated confidence intervals based on averages of the actual confidence intervals for individual on-peak hours.

The results show that the statistically significant load reductions range from 0.76 kW to 1.29 kW. Summer high temperature events during 2012 yielded the highest impacts, with an average load reduction of 1.29 kW (or 46%). The single low temperature event during the 2012 analysis year did not result in significant savings. The load reductions for the average summer medium and low temperature event days in 2013 were 0.82 kW and 0.76 kW, respectively, showing that load reductions decreased with a decrease in event day temperature. However, on a percentage basis, the load reductions were very similar across the three different event day types in 2013, ranging from 37-39%, but were all less than the summer high reduction in 2012 (46%). As expected, the load reductions for the event responders were higher in all cases than the reductions for the total group.

Below we include the load shapes and savings graphs for the high temperature summer event days in each year. All graphs reflect results for the subset of participants who responded to the events. Figure 9 shows the 2012 graphs and Figure 10 shows the 2013 graphs. For each event day type, the graphs represent averages of the individual event day impacts for the subset of event responders on that event day. Because different customers are event responders on different days, this represents the average loads and impacts of slightly different groups of customers across the event days.

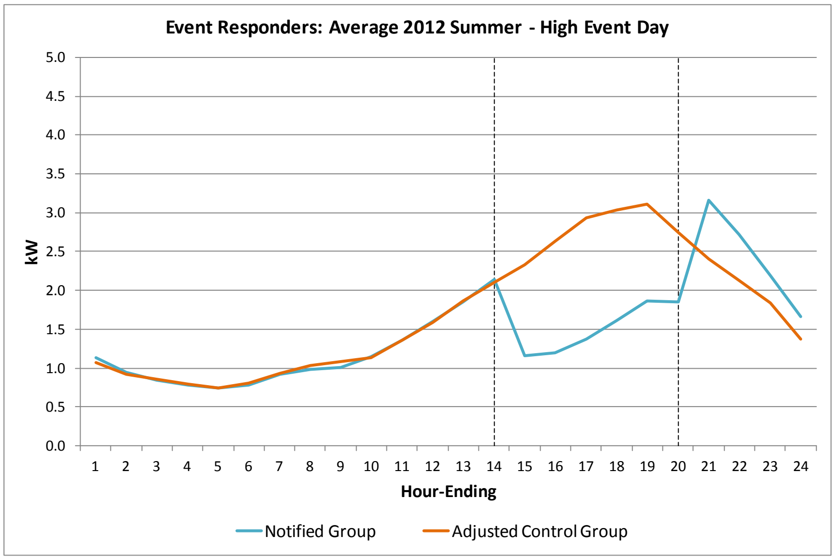
Both figures contains two graphs for the given event day type. The first graph for each event day is a comparison of the load shape of the event responders in the group that was notified with the adjusted load shape for the subset of frequent event responders from the group that was not notified. As described in the Analysis Methods chapter, this subset was used to ensure that it represented customers similar to those in the participant group for each event. The second graph is the estimated savings based on the difference of differences analysis.

The savings graphs shown here include estimated 90% confidence intervals on the savings for each hour. The confidence intervals for each individual event day were calculated directly using standard statistical methods. However, since customers were not consistently “responders” across all events, we could not calculate the confidence intervals directly for the average event day types, as we had done for the entire pilot event day type load savings. Instead, we estimated the confidence intervals by averaging the confidence intervals across the events for each day type. It is likely that that this is a conservative estimate of the interval, since averages tend to be less variable than individual values, so the “true” confidence intervals are probably slightly smaller than these.

The results here are similar to the results for the entire pilot; however, the savings are consistently higher, as expected, since this group includes only those customers whose thermostat set points were adjusted. There does also appear to be more of an increase in demand savings through the event, suggesting that these customers, who are more engaged, may also be taking more manual actions in response to the events. They may also be more likely to be using the plug devices to limit other loads.

Again, the general form of each type of high temperature summer event day graph in Figure 9 and Figure 10 is representative of the results observed for low and medium temperature summer events days, with the exception of the 2012 low temperature summer event day.

Figure 9. 2012 Average Summer High Event Day Graphs: Event Responders



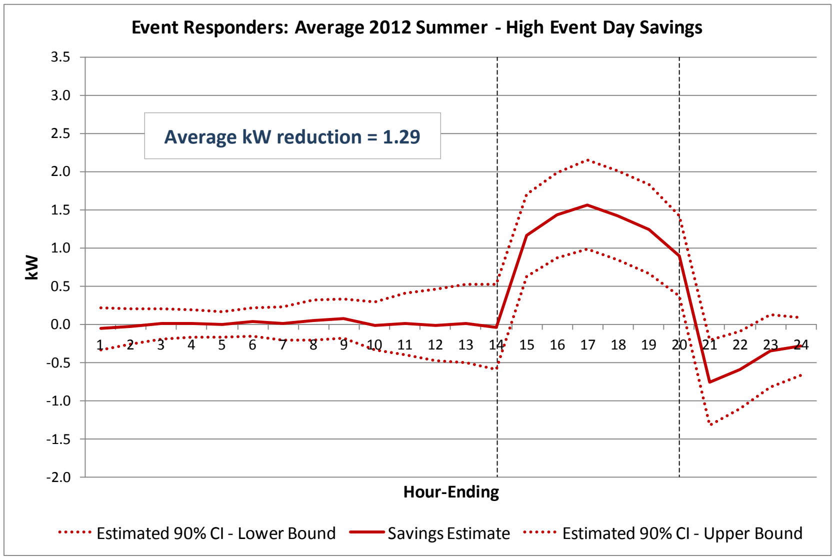
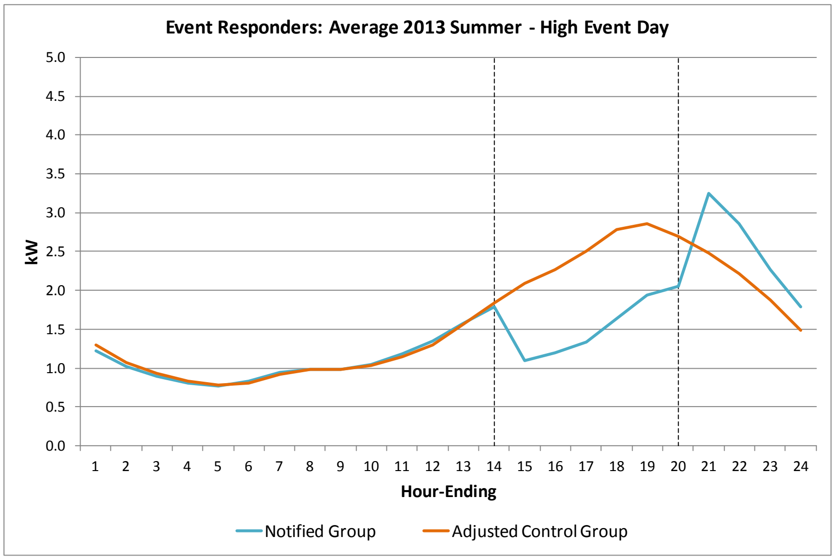
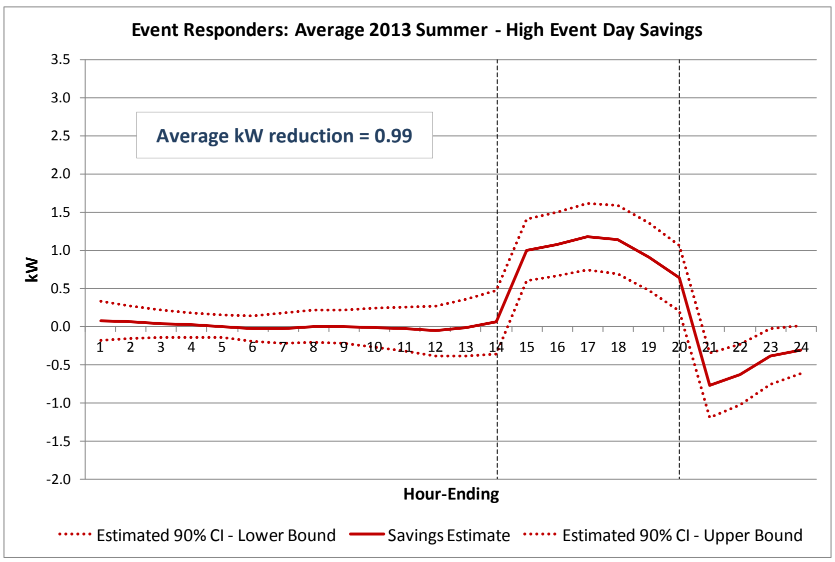


Figure 10. 2013 Average Summer High Event Day Graphs: Event Responders





Comparison of Demand Response Results

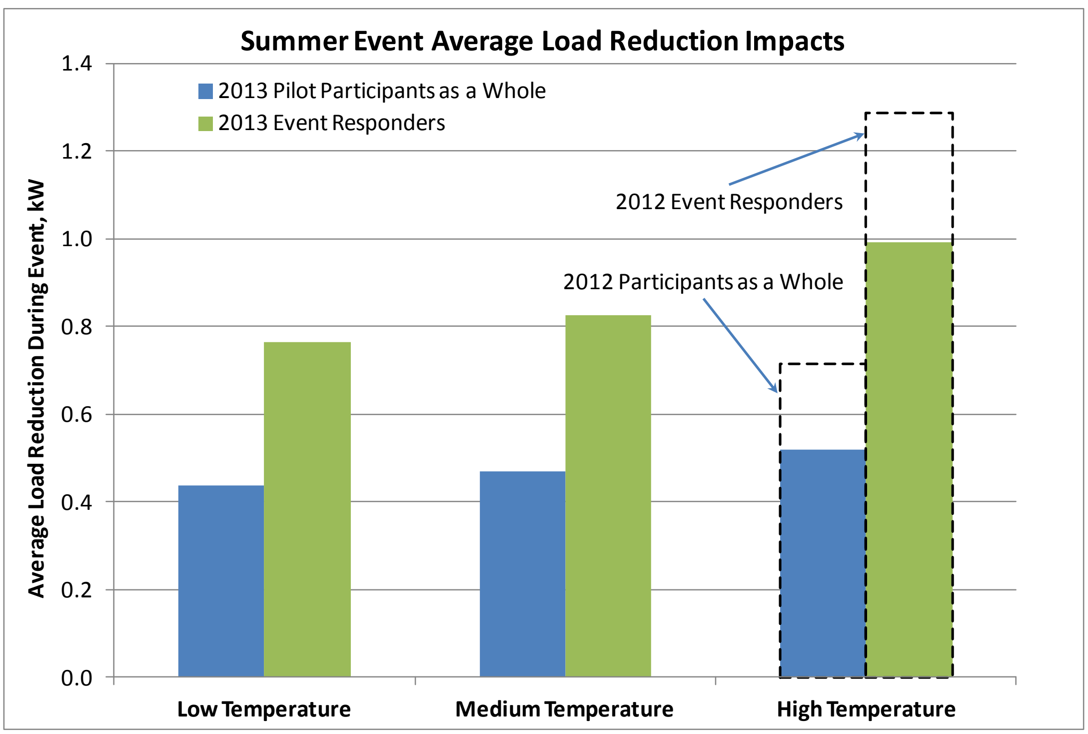
Table 7 and Figure 11 compare the statistically significant summer event load reduction impacts across the three different day types and two analysis years. All values represent per-participant averages for the given sets of participants. The subset of event responders had higher load reductions relative to the pilot participants as a whole. This effect was a little more pronounced for higher temperature events when AC units are using more energy. For example, during the 2013 high temperature summer events, the average load reduction for event responders (0.99 kW) was 91% larger than that of pilot participants as a whole (0.52 kW); by comparison, for low temperature summer events in 2013, the event responders saved 74% more than the overall group of participants (0.76 kW vs. 0.44 kW). In addition, the high temperature summer impacts for 2012 were higher than for 2013 for both sets of participants.

Table 7. Comparison of Summer Event Demand Response Impacts

Event Type	Analysis Year	Group Type	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Average Event Day High Temp. (°F)
Summer - High	2012	All [b]	2.65	0.71	±0.02	27%	97
		Responders [c]	2.80	1.29	±0.14	46%	
	2013	All	2.57	0.52	±0.03	20%	96
		Responders	2.53	0.99	±0.11	39%	
Summer - Medium	2013	All	2.28	0.47	±0.03	21%	92
		Responders	2.22	0.82	±0.10	37%	
Summer - Low	2013	All	2.07	0.44	±0.05	21%	82
		Responders	1.94	0.76	±0.07	39%	

[a] These include estimated confidence intervals based on averages of the confidence intervals for individual on-peak hours.
[b] Pilot participants as a whole. Load reduction impacts have been discounted to account for off-line participants.
[c] Event responders

Figure 11. Comparison of Summer Event Average Load Reduction Impacts



While we have not done any direct research to determine what is happening, there are a few possibilities that we can think of that might be causing this. This decrease over time could be due to a smaller percentage of pilot participants taking manual actions during events from one year to the next. It could also be due to participants changing thermostat settings over time from the default cooling offset of 5°F to something smaller – there was some evidence that as the pilot period wore on, some participants reduced the offset. It could also be related to other energy conservation actions taken by the participants across the span of the pilot. Because the demand impacts are relative to participant energy use on non-event days, any overall conservation actions taken will reduce the baseline load. This could reduce the incremental demand impact over time. Given the magnitude of the estimates we have of energy savings, this is not likely responsible for the entire difference, but could be a contributing factor.

The kW impacts increased slightly with temperature for both set of participants, but the percentage impacts varied less across the three summer event day types. The similarity in percent load reductions is due to the fact that overall customer consumption increases on hot days, so the relatively higher demand reduction on those hotter days yields a roughly comparable percentage savings to lower temperature days, as long as the AC unit is still operating.

One thing to note is that there is a great deal of variability across individual event days, even those with similar high temperatures. Colorado's weather is notoriously unpredictable, and on an otherwise hot day, clouds can roll in during the afternoon and drop the temperature dramatically (this appears to have been the case on August 1 in both years). When during the course of the summer the event days are called also affects the savings – a mild day in the middle of several hot days in July will show a very different impact from a day with the same temperature in the midst of mild days in September (compare the summer low days from 2013, which were in July, with the summer low day in 2012, which was in September). Importantly, when considering the impact on the system peak day, which for Public Service is on a very hot July or August afternoon, the load reduction will likely be higher than on the average of the summer hot days. There can also be a surprisingly wide range of temperature variation across the Denver metro area. We used temperatures from NOAA's Denver weather station at Denver International Airport (DIA), but the temperature in the areas where the pilot customers are located can be quite different from DIA on some days, which can cause variation across the different days as well. But again, it is important to note that the system peak tends to happen when it is hot everywhere, and on those days, we expect that the savings will be consistently higher than on the average hot day.

The variation between event days may also explain part of the differences between the load impacts on similar days across the two years.

Energy Impacts

As discussed in the Analysis Methods chapter, we first estimated the energy impacts using a difference of differences method, but that did not show statistically significant energy savings. We then used a fixed effects regression model, which did show statistically significant results. In this section, we first describe the difference of differences analysis, and then cover the regression analysis. The results from the regression analysis represent the best estimates of energy savings for the pilot.

Initial Difference of Differences Results

Table 8 summarizes the per-participant energy impacts estimated with the difference of differences approach for all pilot participants from June 2012 through September 2013.[3] The table includes the number of participants included in the analysis month, average per-participant adjusted control group billing energy use, and average per-participant estimated energy savings in terms of kWh and percentage. The table also indicates whether or not the savings estimates are statistically significant for the given month.

Table 8. Monthly Ex Post Energy Savings Estimates: Difference of Differences

Month	No. of Participants	Average Adjusted Control Group Billing Energy, kWh	Average Estimated Savings, kWh		Percent Savings	Significant Savings?
Summer 2012						
Jun-2012	602	902	41	±61	4.6%	No
Jul-2012	778	1,262	63	±70	5.0%	No
Aug-2012	889	1,159	45	±62	3.9%	No
Sep-2012	933	958	29	±52	3.1%	No
Non-Summer						
Oct-2012	923	698	18	±35	2.6%	No
Nov-2012	915	741	27	±34	3.6%	No
Dec-2012	910	898	23	±46	2.5%	No
Jan-2013	908	972	26	±45	2.7%	No
Feb-2013	901	774	26	±39	3.3%	No
Mar-2013	892	739	21	±35	2.9%	No
Apr-2013	890	745	19	±35	2.6%	No
May-2013	885	691	10	±36	1.5%	No
Summer 2013						
Jun-2013	879	818	19	±48	2.4%	No
Jul-2013	869	1,140	46	±64	4.0%	No
Aug-2013	865	1,005	38	±60	3.8%	No
Sep-2013	855	973	30	±54	3.1%	No
Pilot Total		**14,475**	**482**	**±776**	**3.3%**	**No**

The table shows the per-participant "savings" appear to range from a minimum of 1.5% in May 2013 to a maximum of 5% in June 2012. Overall, the analysis indicates an average savings across the pilot of about 3.3%, and the savings are fairly consistent throughout the period, with higher savings in the summer. However, the results are not statistically significant for any month.

[3] We assessed the energy impacts beginning in June 2012, since the majority of devices were installed by then. The pilot ended in September 30, 2013.

Figure 12 and Figure 13 plot the average per-participant monthly energy results based on the difference of differences results. The first figure compares the monthly energy use for the treatment and control groups. Recall that we created the control group for the energy analysis by matching participants with similar customers from a large pool of non-participants. Note the peak in energy use in winter (January 2013), as well as the two larger peaks in summer (July 2012 and 2013). The second figure shows the monthly energy savings and 90% confidence intervals. In all cases, the confidence intervals include zero, indicating that the savings are not statistically significant.

Figure 12. Difference of Differences Average Per-Participant Monthly Energy Use

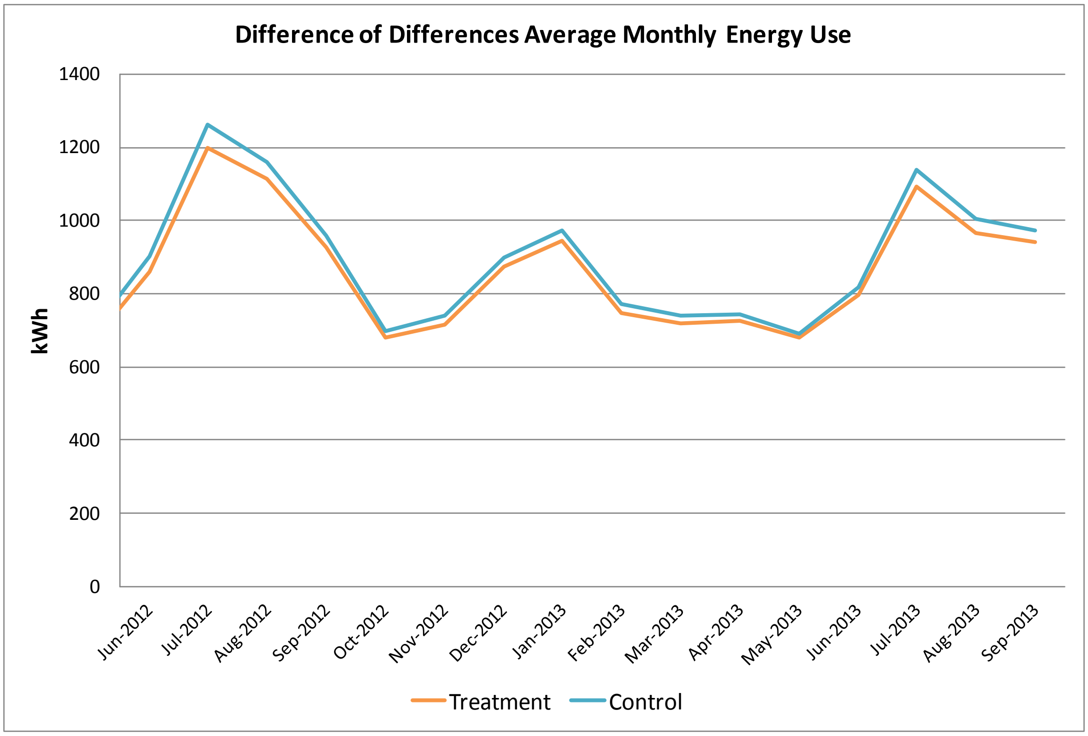
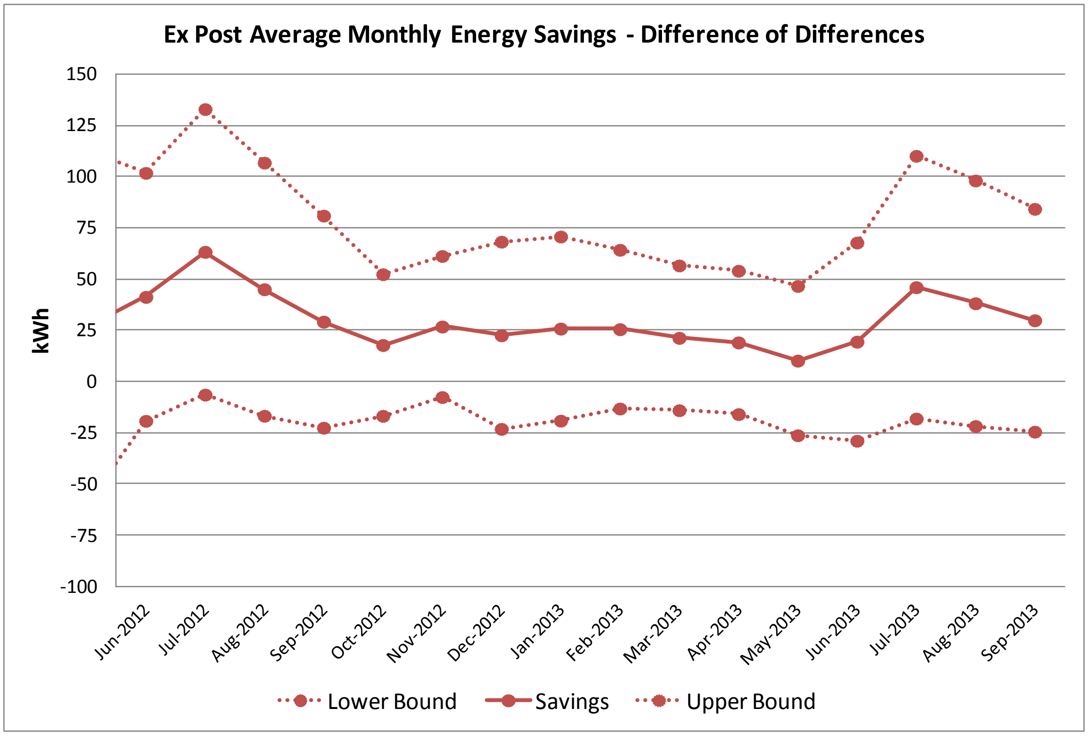


Figure 13. Difference of Differences Average Per-Participant Energy Savings Estimates



Regression Analysis

Table 9 summarizes the per-participant and population-level energy impacts estimated with the regression model approach for all pilot participants for June 2012 through September 2013. The table includes the average per-participant baseline billing energy use, average per-participant estimated energy savings, percent energy savings, number of participants included in the analysis month, and total estimated savings for the population of participants. The table also indicates whether or not the savings estimates are statistically significant for the given month.

The table shows the per-participant "savings" range from a minimum of 2.0% in Dec 2012 to a maximum of 4.6% in July 2012. Overall, the analysis yields an average savings across the pilot period of about 3.3%. The savings are fairly consistent throughout the period, with higher savings in the summer. The magnitudes of these results are very similar to the difference of difference results; but, unlike the difference of differences estimates, the regression estimates are statistically significant throughout the analysis period. The savings for both methods are clearly related to CDD. There are higher demand reductions in the summer months, with the highest reductions in July and August, the hottest summer months. The regression model captures this relationship explicitly, with a savings term that is constant throughout the pilot period, and another term that depends on CDD.

Table 9. Monthly Ex Post Energy Savings Estimates: Regression Analysis

Month	Average Baseline Billing Energy, kWh	Average Estimated Savings, kWh		Percent Savings	Significant Savings?	No. of Participants	Total Estimated Savings, kWh
Summer 2012							
Jun-2012	1,120	46	±7	4.1%	Yes	651	30,033
Jul-2012	1,330	61	±11	4.6%	Yes	844	51,222
Aug-2012	1,083	46	±7	4.3%	Yes	979	45,287
Sep-2012	777	27	±5	3.5%	Yes	1,031	27,813
Non-Summer							
Oct-2012	698	18	±6	2.5%	Yes	1,027	18,251
Nov-2012	734	18	±6	2.4%	Yes	1,025	18,215
Dec-2012	880	18	±6	2.0%	Yes	1,021	18,144
Jan-2013	863	18	±6	2.1%	Yes	1,017	18,073
Feb-2013	789	18	±6	2.3%	Yes	1,016	18,055
Mar-2013	732	18	±6	2.4%	Yes	1,004	17,842
Apr-2013	703	18	±6	2.5%	Yes	997	17,718
May-2013	675	20	±6	2.9%	Yes	994	19,643
Summer 2013							
Jun-2013	969	36	±6	3.8%	Yes	992	36,140
Jul-2013	1,109	43	±7	3.9%	Yes	985	42,624
Aug-2013	1,106	45	±7	4.1%	Yes	971	43,951
Sep-2013	812	29	±5	3.5%	Yes	961	27,479
Pilot Total	**14,379**	**478**	**±27**	**3.3%**	**Yes**		**450,489**

Figure 14 and Figure 15 plot the average per-participant monthly energy results based on the regression analysis. The first figure compares the monthly energy use for the treatment and control groups. This figure is very similar to Figure 12. The second figure compares the monthly energy savings estimated with the regression model and the difference of differences approach. The graphs are very similar for the Summer 2012 months, but differ slightly for the Non-Summer and Summer 2013 periods. However, across the whole pilot period, the energy savings are very similar. Note how the confidences intervals for the regression results are much smaller and they do not include zero; this highlights the large improvement in precision with that method.

Figure 14. Regression Analysis Average Per-Participant Monthly Energy Use

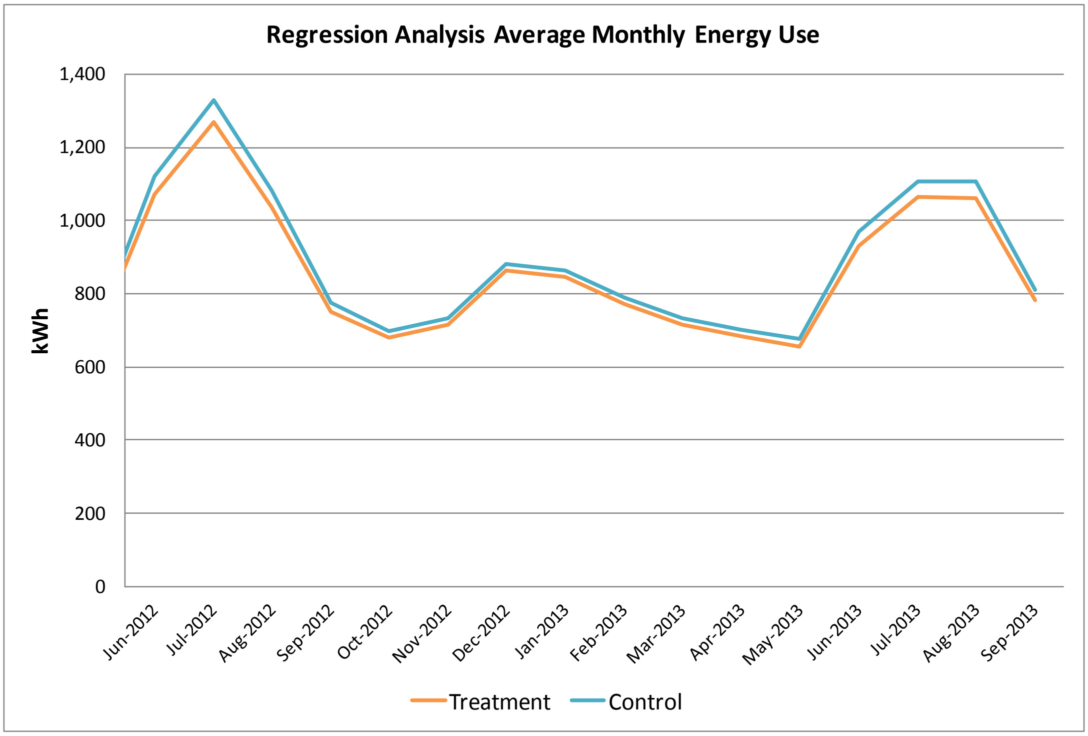


Figure 15. Average Per-Participant Energy Savings Estimates: Comparison of Regression and Difference of Differences Results

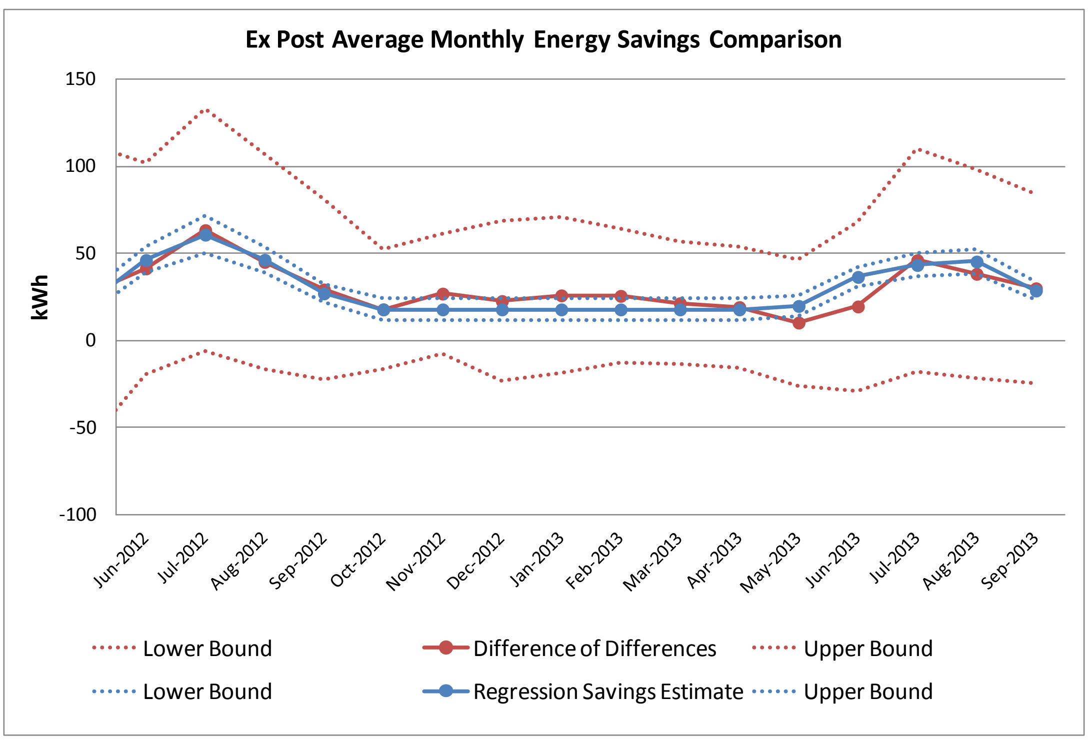


Figure 16 shows the monthly savings estimates from the regression model across the entire pilot period. It also plots the average annual energy savings achieved during the last 12 months of the pilot based on the regression results (3.0%).

Note that the average savings across the whole pilot period of 3.3% are slightly higher than the annual savings of 3.0%, based on the last twelve months of the pilot. This is because the pilot period included two summers, which have higher savings, but only one non-summer period.

Figure 16. Monthly Energy Savings Estimates: Percentage Savings

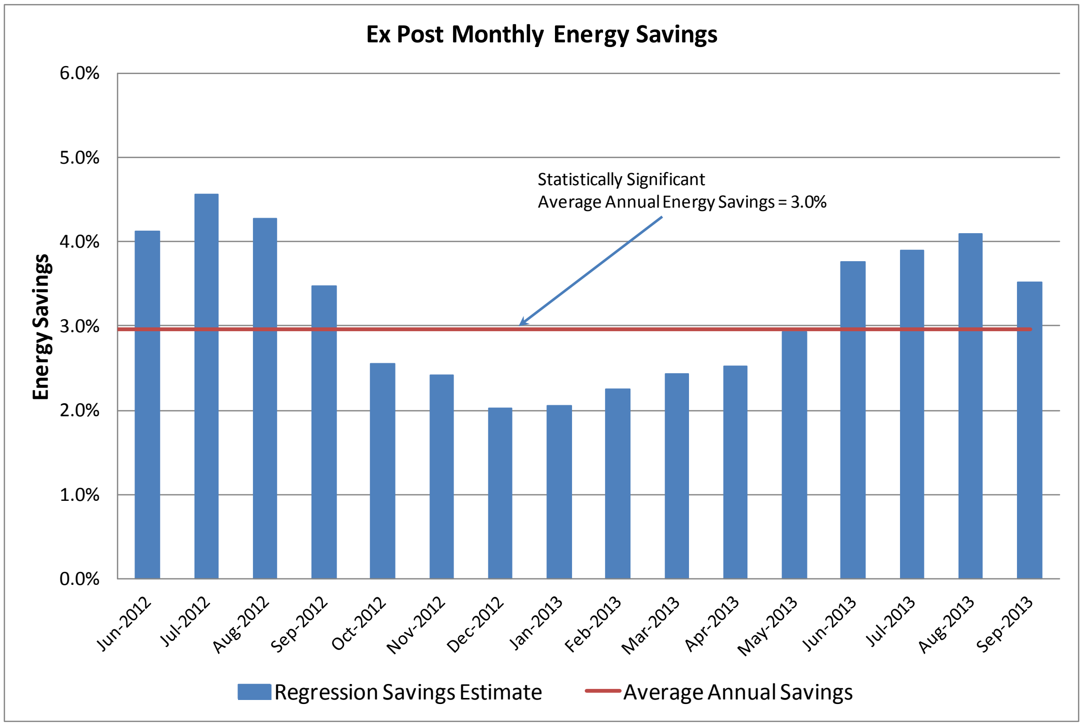


Table 10 shows the average per-participant monthly energy impacts for a normal weather year. The savings values reflect the economic conditions of September 2012 through August 2013, but the weather for a typical meteorological year (TMY3) based on weather data from the National Oceanic and Atmospheric Administration. The percentage savings vary from 2.1% in winter (December and January) to 3.9% in summer (June and August). The average annual savings is 2.9% for the normal weather year.

The savings for a normal weather year are similar to the actual savings, and show a similar pattern across the seasons, as expected.

Table 10. Monthly Energy Savings Estimates: Normal Weather Year

Month	Average Baseline Billing Energy, kWh	Average Estimated Savings, kWh		Percent Savings	Significant Savings?
September	774	27	±5	3.5%	Yes
October	694	18	±6	2.6%	Yes
November	775	18	±6	2.3%	Yes
December	847	18	±6	2.1%	Yes
January	843	18	±6	2.1%	Yes
February	769	18	±6	2.3%	Yes
March	697	18	±6	2.5%	Yes
April	697	18	±6	2.5%	Yes
May	657	19	±6	2.9%	Yes
June	1,005	39	±6	3.9%	Yes
July	1,027	38	±6	3.7%	Yes
August	1,021	40	±6	3.9%	Yes
Total	**9,807**	**287**	**±73**	**2.9%**	**Yes**

Chapter 5 – Additional Analysis

Snapback Effect

As the summer event graphs in Chapter 4 and the appendices show, there was a period of higher usage after the events, which shows up as negative savings. This is a "snapback" effect, which is caused by the participants' AC systems using more energy after the event to "catch up" on cooling the space once the thermostat set points have returned to normal (non-event) settings after the event ends.

Table 11 summarizes the average per-participant snapback results by year and summer event day type for pilot participants as a whole and for event responders. The snapback effects include maximum demand increase in kW, and overall energy use increase in kWh, between the hours of 8 PM and midnight. While it appears that the snapback may continue in some cases at low levels after midnight, we only consider the increase in use on the actual event day here. All of the snapback effects listed in the table are statistically significant. The maximum snapback demand increase almost always occurred at the hour ending 9 PM, the first hour after the end of the event. For pilot participants as a whole, this maximum demand increase ranged from an average of 0.30 kW for the low temperature summer event day type to 0.48 kW for the high temperature event day type. For the subset of event responders, the maximum demand increase ranged from 0.49 to 0.77 kW across the different event day types. Over the four-hour period after the events (8 PM to midnight), the average total kWh increase ranged from 0.76 to 1.26 kWh for pilot participants as a whole, and from 1.17 to 2.10 kWh for event responders, with the higher snapback kWh increases occurring for hotter event days. The snapback effect was more pronounced for the subset of event responders and tended to increase with event day temperature.

Table 11. Energy Effects of Snapback

Event Type	Analysis Year	Group Type	Maximum Snapback kW Increase, 8 PM - 12 midnight	Total Snapback kWh Increase, 8 PM - 12 midnight	Total kWh Savings During Events, 2– 8 PM	Net kWh Savings	Average Event Day High Temp. (°F)
Summer - High	2012	All [a]	0.48	1.26	4.29	3.03	97
		Responders [b]	0.76	2.01	7.73	5.72	
	2013	All	0.42	1.16	3.11	1.95	96
		Responders	0.77	2.10	5.94	3.84	
Summer - Medium	2013	All	0.40	0.95	2.82	1.87	92
		Responders	0.73	1.77	4.95	3.18	
Summer - Low	2013	All	0.30	0.76	2.63	1.87	82
		Responders	0.49	1.17	4.58	3.41	

[a] Pilot participants as a whole.
[b] Event responders

Comparing the energy increase from the snapback with the energy reduced during the event, there is still an overall decrease in energy use on event days. The snapback energy increase is about one third of the energy decrease during the event. This is consistent with most other thermostat setback programs, in that the snapback energy is much less than the energy saved during the event.

Interaction Between Energy and Demand

Public Service's IHSD Pilot delivered two types of savings – long term energy savings based on customer knowledge and awareness of energy use, and demand response savings during events. These two types of savings are not independent of each other. As shown in the section above, there is a net reduction in energy use for each event, even when including the increase due to snapback. This adds to the overall energy savings due to long term changes in customer behavior. This interaction is small, however, since the largest average (for all customers) net savings is about 3 kWh for the hot summer events in 2012, with the others all below 2 kWh. With individual customers subjected to only 15 events through the course of the pilot, the total savings from events is less than 10% of the overall energy savings from the pilot.

There are two ways to looks at the demand reduction. The short term demand reduction is what is estimated by the comparison of groups A and B. This is the difference between what customer demands were and what they would have been if an event had not been called. The long term demand reduction is the difference between what customer demands were and what they would have been without the program. This long term demand would be the combination of the short term demand savings and the part of the energy savings that happened during an event. While this long term demand reduction is important to keep in mind, we have kept the two types of savings separate in our analysis. Even so, we would expect that the incremental load reduction resulting from the energy savings would be small relative to the short term demand reduction.

Comparison to Other Programs

It is difficult to compare the demand response impacts estimated in this study to results from other pilots or programs in the industry because of the way the Public Service pilot was implemented. The Public Service IHSD pilot notified customers of events, but allowed customers to opt out of the events and had no financial incentive or penalty associated with use of the device. To our knowledge, there are no other programs operated in the same manner. That said, the shape of the demand response impacts, including snapback, is consistent with other programs using a similar technology to raise thermostat set points, all of which were also tied to a dynamic pricing program. However, the magnitudes of the average load reductions found with the IHSD pilot are somewhat smaller than observed in other programs. This is definitely driven by the lower AC usage in Colorado, but may also be in part due to the lack of financial incentives or penalties.

One notable difference, as mentioned above, is that the savings during the event are somewhat differently shaped. There is not a sharp spike in the savings during the first hour, followed by decreasing savings in the remainder of the event. There are two factors that are probably causing this difference. First, the 5°F set point change is higher than many other programs. This means that it takes longer for the internal temperature of the home to reach the new setpoint, so the drop off in savings is later, and may not happen in some homes before the end of the event. The other difference is the small but apparent increase in savings in the first half of the event. This may be due to the cumulative effect across the event of plug loads being shut off (most other programs only involve a thermostat) and/or manual actions that customers are taking to reduce load during events. It also may be due to the reality that at the beginning of the event, because of Colorado's milder temperatures, not all AC units are running continuously. So as the day gets hotter, the AC units in the control group use more energy as they run more frequently, but the AC units for the customers whose thermostats have been reset are still idle. This is unlike many other pilots in hotter climates, where the AC units tend to be running continuously throughout the event. It could be that Colorado homes are better insulated, because of the cold winters, which slows the heat gain and delays the return of AC load. There is also a decrease from the middle of the event to the end, but this drop-off is not as dramatic as we have seen in other thermostat-based programs, in part because of the lack of the initial spike in savings.

The event window of 6 hours is similar to the on-peak period of many dynamic pricing programs. Demand response event periods in the industry vary, with some shorter and some of similar length. Shorter events tend to be more popular with customers and can lead to higher savings, as customers are willing to put up with more discomfort for a shorter time. Further analysis of the participation rates throughout the events, especially if combined with customer survey research, could help determine how much of an increase in savings would result from a shorter event window. Some programs, especially those that use shorter event windows, tend to have varying start times and durations. While this can be appealing from an operational standpoint, we believe that keeping the event window the same across all events helps customers know what to expect and plan, whereas differing start times and durations can cause confusion.

Chapter 6 – Key Findings and Recommendations

Key Findings

There are several key findings from the results presented above::

- **Summer Events had Significant Load Reductions:** There were statistically significant load reductions during summer demand response events. In 2013, the average per-participant load reduction across the six-hour event period was in the range of 0.44-0.52 kW (or 20-21%) for the total population of pilot participants, with slightly higher kW reductions for hotter event days. The total population of pilot participants was made up of all customers notified of an event, including those whose devices were off-line, and those who opted out of events. Thus, the reported load reduction reflects participants who contributed to load reduction averaged with those participants who did not contribute. Because of this, it is somewhat of a "worst case scenario" for per-participant savings.
- **Event Responders had Higher Demand Response Impacts:** The subset of event responders had higher load reductions relative to the pilot participants as a whole for each event day type. This effect was a little more pronounced for higher temperature events. For example, during the 2013 high temperature summer events, the average load reduction for event responders (0.99 kW) was 91% larger than that of pilot participants as a whole (0.52 kW); by comparison, for low temperature summer events in 2013, the event responders saved 74% more than the overall group of participants (0.76 kW vs. 0.44 kW). This per-customer load reduction is the best that can be expected from a broader roll-out under a similar pilot design, since it is what happens when all customers accept the event and have devices that are configured to respond.
- **Load Reductions Decreased between 2012 and 2013:** During 2012 high temperature summer events, the average per-participant load reduction for the group of pilot participants as a whole was 0.71 kW (or 27%) compared with 0.52 kW (20%) in 2013. This decrease could be due to a smaller percentage of pilot participants responding to events from one year to the next. It could also be due to participants changing thermostat settings over time from the default cooling offset of 5°F to a reduced offset. This could also be due to the cumulative effect over time of customer energy conservation efforts unrelated to events, which would tend to lower the baseline load and reduce demand savings by a small amount.
- **Non-Summer Events had Insignificant Load Reductions:** The impacts for the non-summer events were not statistically significant and appeared to be very small at best, ranging from 1% to 2% for pilot participants as a whole. These results are most likely due to the lack of any AC load to reduce during the non-summer events, implying that most of the event savings result from the thermostat cooling offset during hotter periods.
- **Customers Are Reducing Energy:** Using a regression analysis, we were able to estimate statistically significant energy savings across all months of the pilot period. The energy savings range from about 2% during non-summer months to over 4% during

most summer months. This level of energy savings is consistent with savings observed in other behavioral programs.

- **Off-Line Participants Reduce Per-Participant Impacts:** The share of off-line participants in the notified group ranged from 5% to 19% across the events. These customers' devices did not receive the signal to reduce load, and so would not be expected to contribute any savings. Accordingly, the per-participant impacts were reduced relative to what would have been achieved had all participants been connected. This is an important consideration for future deployment of an IHSD program. An effort to reduce the number of off-line participants would increase the savings for the program, and would like be warranted, since without it, similar off-line rates could also be expected in the future.
- **The Snapback Effect was Significant:** Snapback is when AC units work extra hard and consume additional energy after an event to make up for the thermostat offset in place during the event. (An analogous type of snapback can also occur with non-AC loads such as electric water heaters, washers and dryers, etc.) The results show a significant snapback effect for summer events. The effect was most pronounced for the subset of event responders, for whom the maximum demand increase in the four hours following the event ranged from an average of 0.49 to 0.77 kW across the different event day types. This increase offset about one third of the energy reduction realized during the event.

Recommendations

We have the following recommendations for any future pilots or full roll-outs of similar programs:

- **Increase Event Participation:** For any future pilot or roll-out, we recommend efforts to decrease the number of customers off-line. Begin by investigating the reasons customers were off-line during the pilot. Possible ways to reduce the number off-line could include providing alternative technologies that do not depend on the customer's WiFi and internet service, as well as continuing to offer technical support. We also recommend exploring ways to encourage more customers to configure their devices to respond to events, as well as to discourage customers from opting out of events. Offering a small monetary incentive to customers for responding to events could increase the percent responding, which would increase the per-participant savings and make the program more cost-effective. If Public Service launches another pilot, different incentives could be tested across customers to determine the most effective way to improve participation in events. Another possibility is to offer the option to configure the devices for pre-cooling homes ahead of events, which could help people be less uncomfortable during the events, and would probably make the savings last longer.
- **Call Events Only on Extreme Days:** For a pilot, it is important to call events across a variety of days to determine what the load reduction might be during different circumstances. However, if a program is rolled out to the general population, events should be called on the hottest days and other days when the electric grid is

constrained. This will provide the greatest load reduction, and will provide that reduction on the days when it is needed most.

- **Consider Shortening the Event Duration:** Given the drop off in savings at the end of the event period, if Public Service would like to raise the average load reduction throughout the event, and perhaps improve customers satisfaction with the program, the event duration could be shortened somewhat. However, care must be taken to ensure that the event still covers the system peak hour and enough of the hours around it to avoid simply shifting the peak an hour later or earlier. We also do not recommend changing the start and end times of the events during a single season, since that can cause customer confusion and reduce impacts.

Appendices

Appendix A – 2012 Demand Response Results

Pilot Participants as a Whole

Table A1 summarizes the demand response impacts for the 2012 events for pilot participants as a whole. The table categorizes the per-participant results by event date and type. It includes the group notified, average demand (in kW) for the adjusted control group, the estimated average load reduction (in kW) across the six-hour event period for the treatment group, the percent load reduction, and the average event day high temperature. It also designates the savings as statistically significant or not.

Table A1. 2012 Demand Response Impacts: Pilot Participants as a Whole

Date (2012)	Event Type	Group Notified	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Event Day High Temp. (°F)	Significant Savings?
Jul. 13	Summer - High	A	2.71	0.85	±0.17	31%	96	Yes
Jul. 20	Summer - High	B	3.49	1.15	±0.20	33%	101	Yes
Jul. 23	Summer - High	A	2.76	0.86	±0.17	31%	100	Yes
Aug. 1	Summer - High	B	1.99	0.49	±0.15	25%	94	Yes
Aug. 8	Summer - High	A	2.63	0.67	±0.11	26%	96	Yes
Sep. 14	Summer - Low	B	0.99	0.06	±0.05	6%	77	No

[a] Load reduction impacts have been discounted to account for off-line participants. These include estimated confidence intervals based on averages of the discounted confidence intervals for individual on-peak hours.

Figure A1 through Figure A6 show the load shape graphs and savings graphs for the six individual event days in analysis year 2012. The first graph for each event day is a comparison of the load shape of the notified group with the adjusted load shape for the group that was not notified. The second graph is the estimated savings based on a difference of differences analysis approach using an average of comparable non-event days as the pretreatment period. These first two graphs reflect per-participant impacts for notified customers who were on-line (connected to the Internet) during the event and therefore received the event notification. Since a portion of participants were off-line for each event, the overall per-participant impacts are lower. To account for this effect on the impacts, the third graph for each event represents the adjusted (discounted) savings for the group of notified participants as a whole, including both on-line and off-line customers.

The 2012 demand response impacts presented in this report differ from those in EnerNOC's preliminary report dated March 8, 2013 because of the way we estimate per-participant impacts.

In the previous analysis, we averaged impacts based on the count of customers with IHSDs. However, this underestimated the savings since only a portion of those customers were assigned to groups in time to be notified in the 2012 events. The revised analysis presented here averages the impacts based on the count of customers assigned to the notified group at the time of the given events.

Figure A1. Jul. 13, 2012 Event Day Graphs

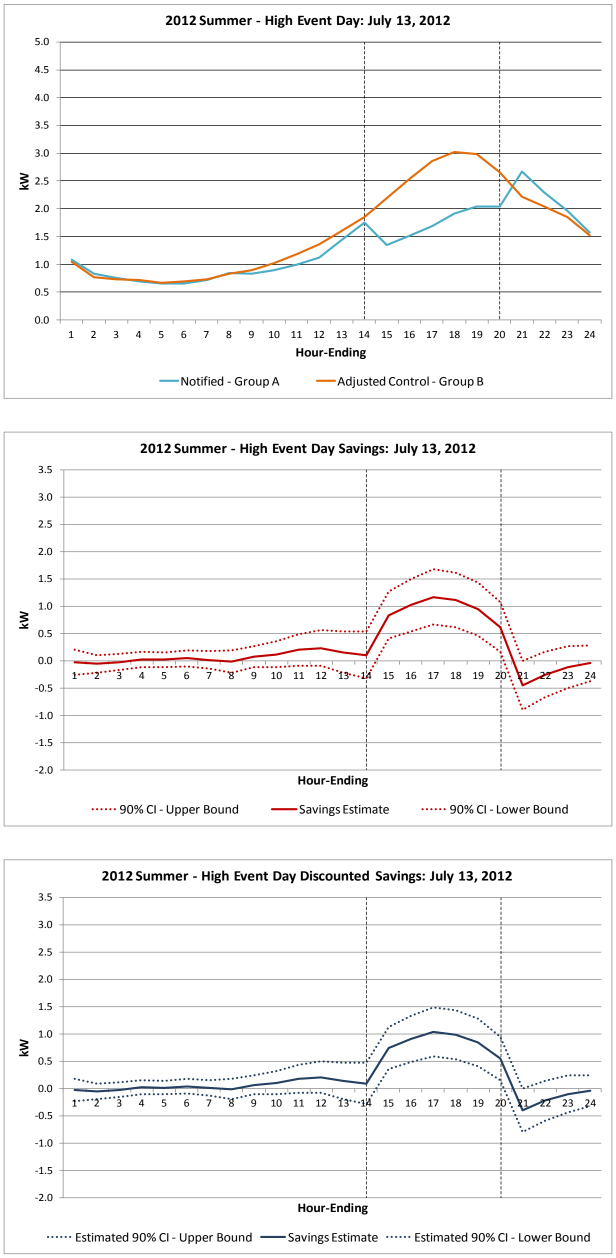


Figure A2. Jul. 20, 2012 Event Day Graphs

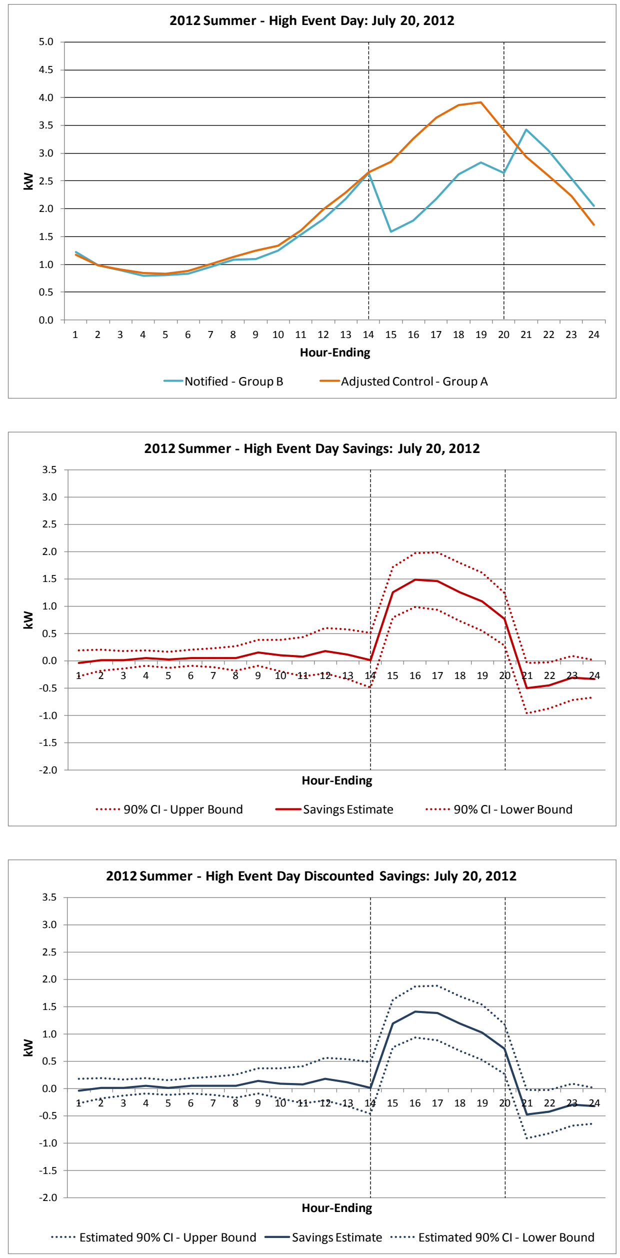


Figure A3. Jul. 23, 2012 Event Day Graphs

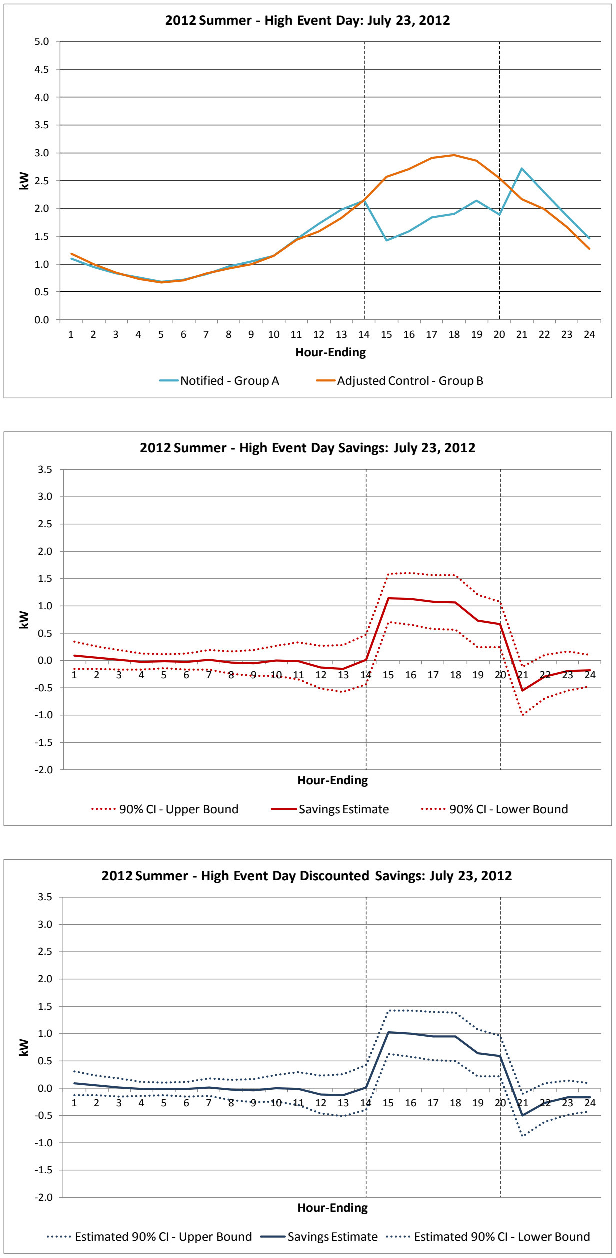


Figure A4. Aug. 1, 2012 Event Day Graphs

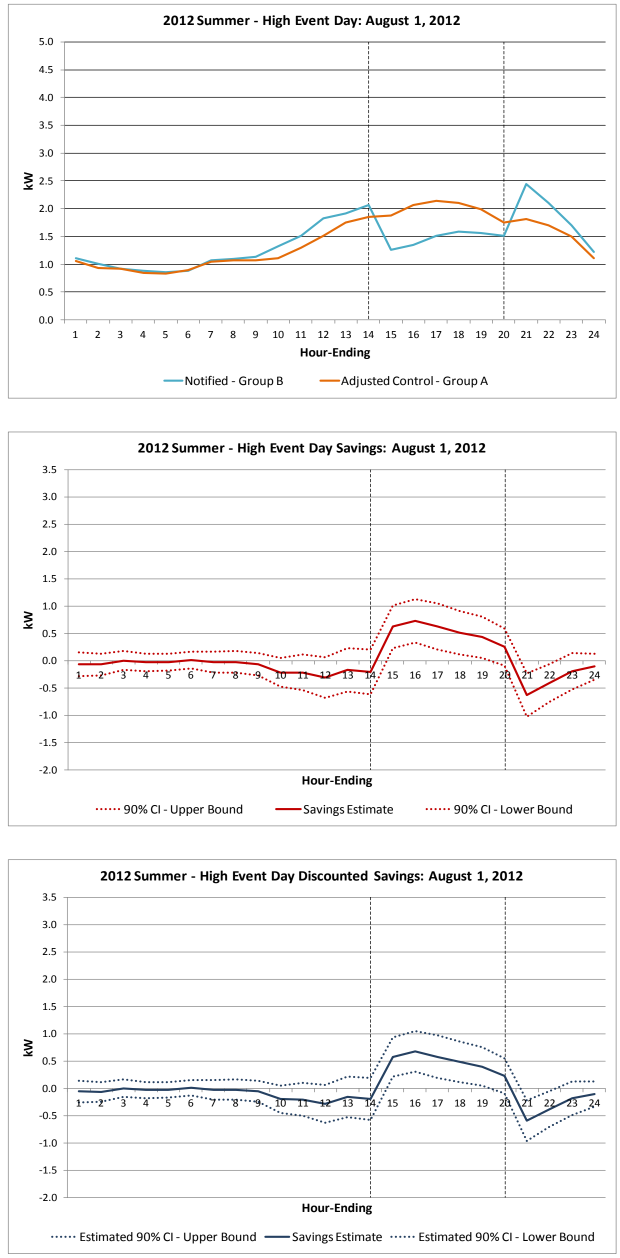


Figure A5. Aug. 8, 2012 Event Day Graphs

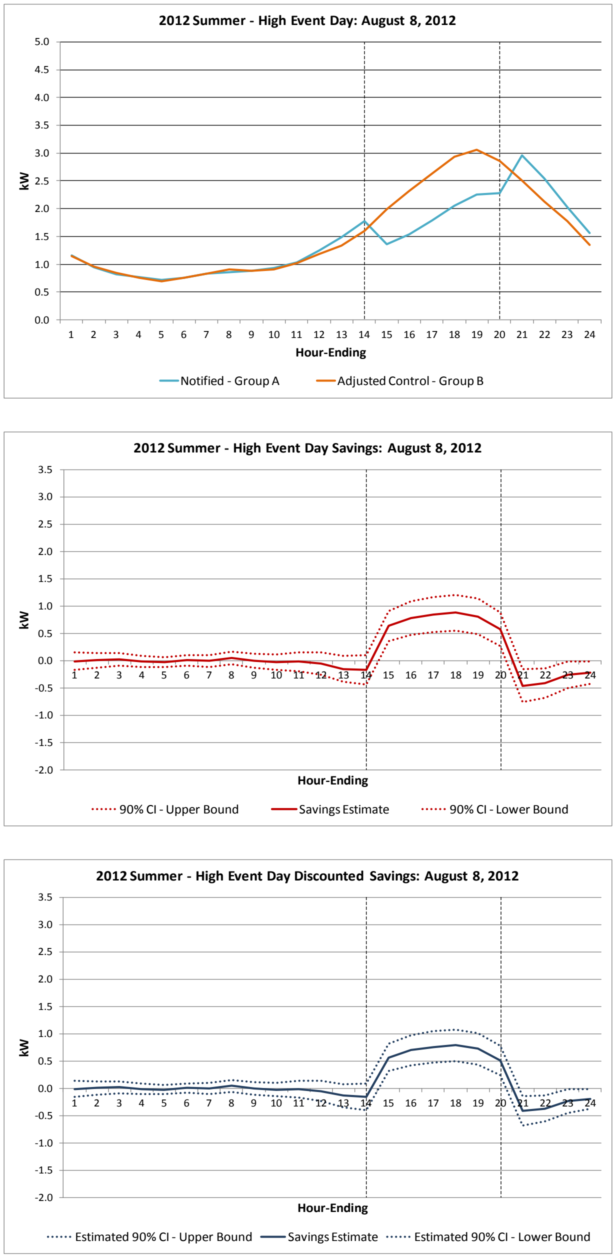
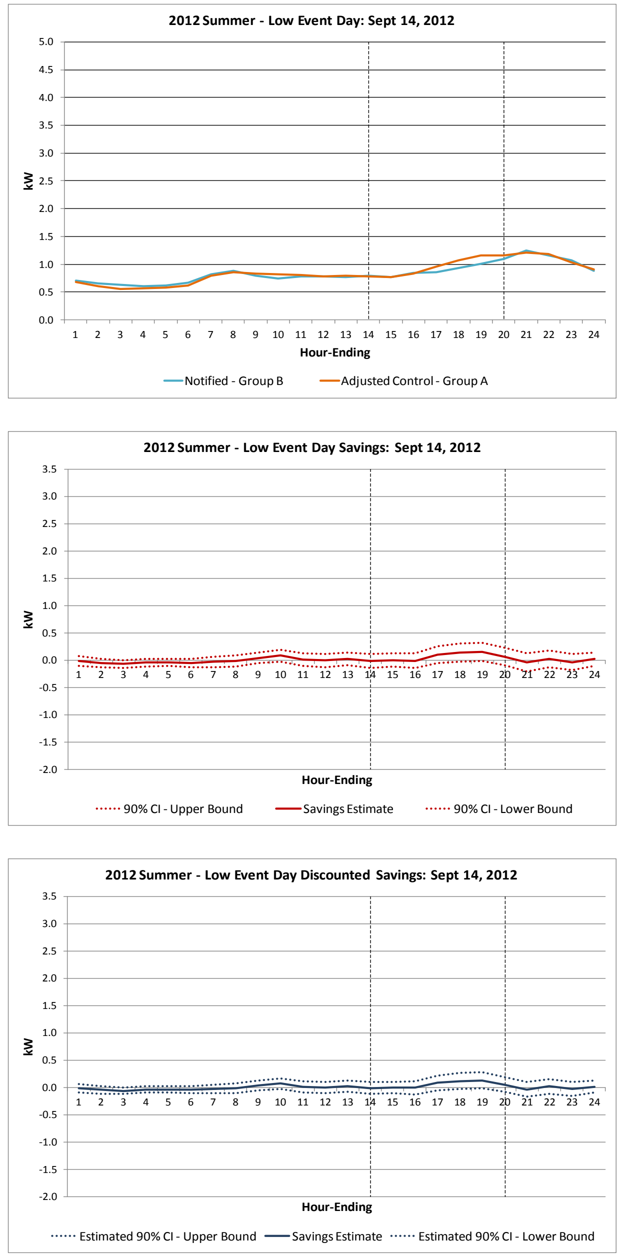


Figure A6. Sep. 14, 2012 Event Day Graphs



Event Responders

Table A2 summarizes the demand response impacts for the 2012 events for pilot participants categorized as event responders. Event responders were defined for each individual event as those either accepting the event in response to the notice, or those who did not respond to the notice by the midpoint of the event (5:00 pm), but whose devices were configured to respond. The table categorizes the per-participant results by event date and type. It includes the group notified, average demand (in kW) for the adjusted control group, the estimated average load reduction (in kW) across the six-hour event period for the treatment group, the percent load reduction, and the average event day high temperature. It also designates the savings as statistically significant or not.

Table A2. 2012 Demand Response Impacts: Event Responders

Date (2012)	Event Type	Group Notified	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Event Day High Temp. (°F)	Significant Savings?
Jul. 13	Summer - High	A	2.58	1.27	±0.15	49%	96	Yes
Jul. 20	Summer - High	B	3.60	1.77	±0.15	49%	101	Yes
Jul. 23	Summer - High	A	2.70	1.25	±0.14	46%	100	Yes
Aug. 1	Summer - High	B	2.19	0.92	±0.12	42%	94	Yes
Aug. 8	Summer - High	A	2.82	1.17	±0.13	41%	96	Yes
Sep. 14	Summer - Low	B	1.03	0.14	±0.07	14%	77	No

[a] These include estimated confidence intervals based on averages of the actual confidence intervals for individual on-peak hours.

Figure A7 through Figure A12 show the load shape graphs and savings graphs for the six individual event days in analysis year 2012. This set of graphs reflects results for pilot participants categorized as frequent event responders and the savings impacts are from the subset of participants who responded to the given event. The first graph for each event day is a comparison of the load shape of the event responders with the adjusted load shape for the subset of frequent event responders that was not notified. The second graph is the estimated savings based on a difference of differences analysis approach using an average of comparable non-event days as the pretreatment period.

Figure A7. Jul. 13, 2012 Event Day Graphs: Event Responders

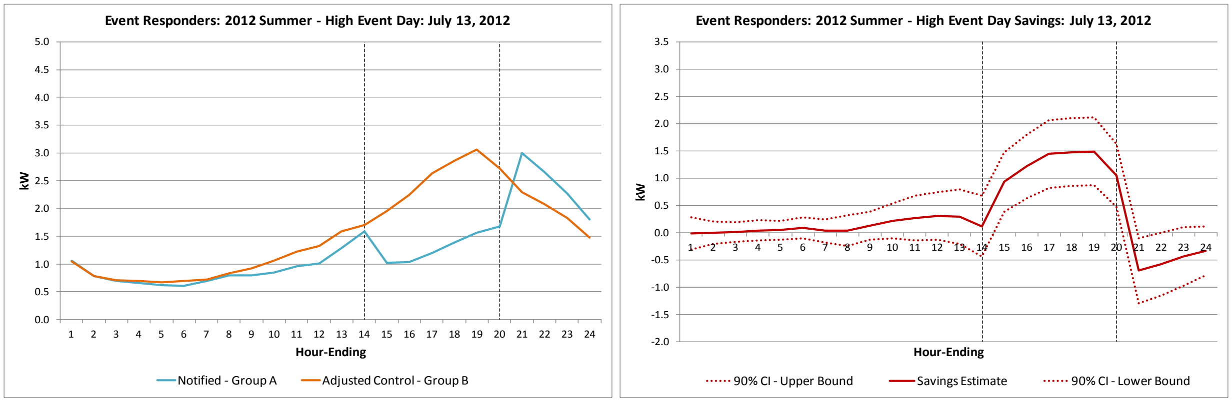


Figure A8. Jul. 20, 2012 Event Day Graphs: Event Responders

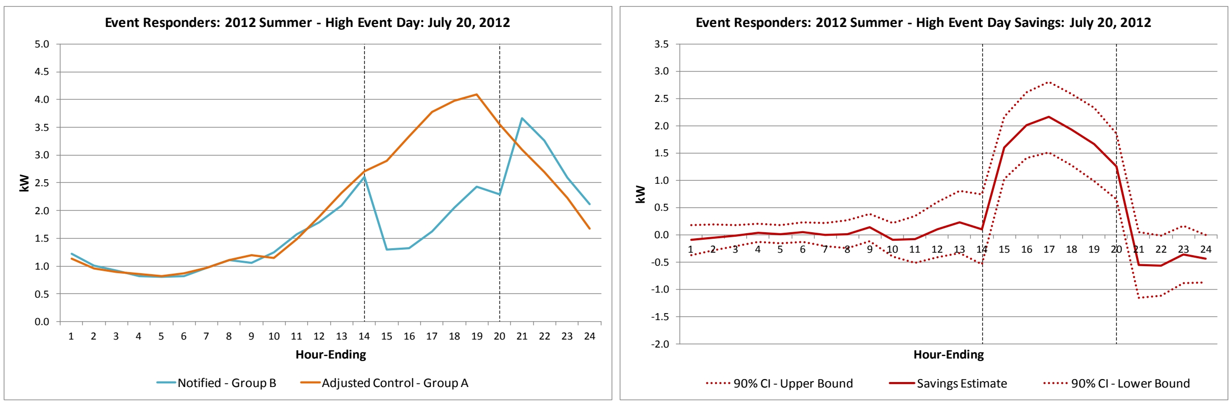


Figure A9. Jul. 23, 2012 Event Day Graphs: Event Responders

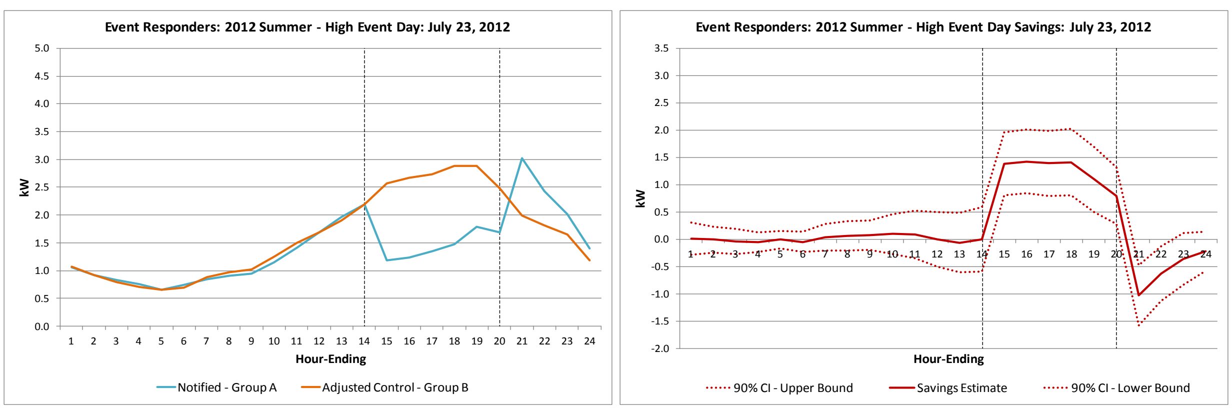


Figure A10. Aug. 1, 2012 Event Day Graphs: Event Responders

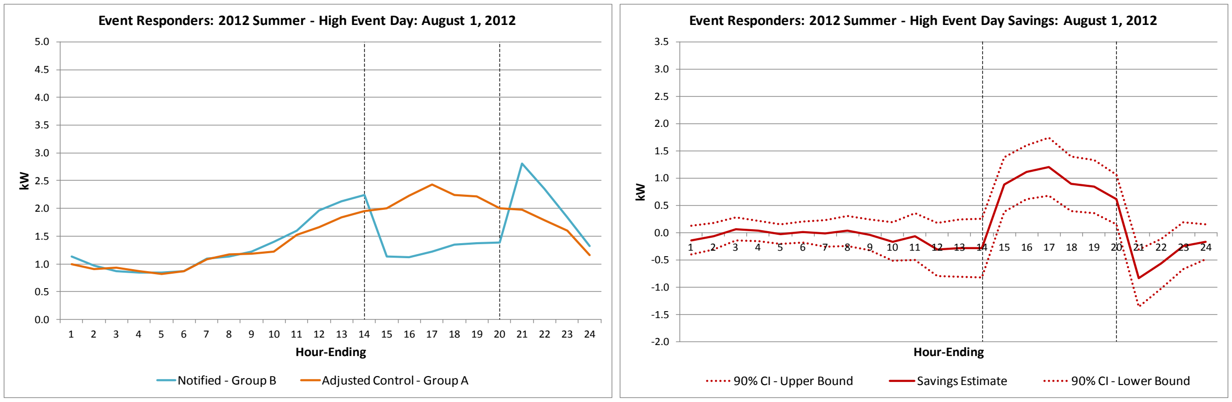


Figure A11. Aug. 8, 2012 Event Day Graphs: Event Responders

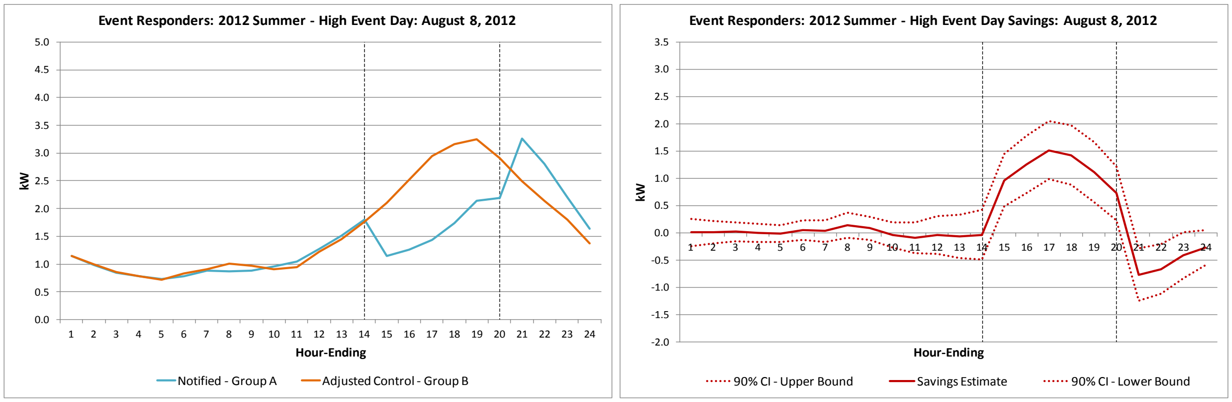
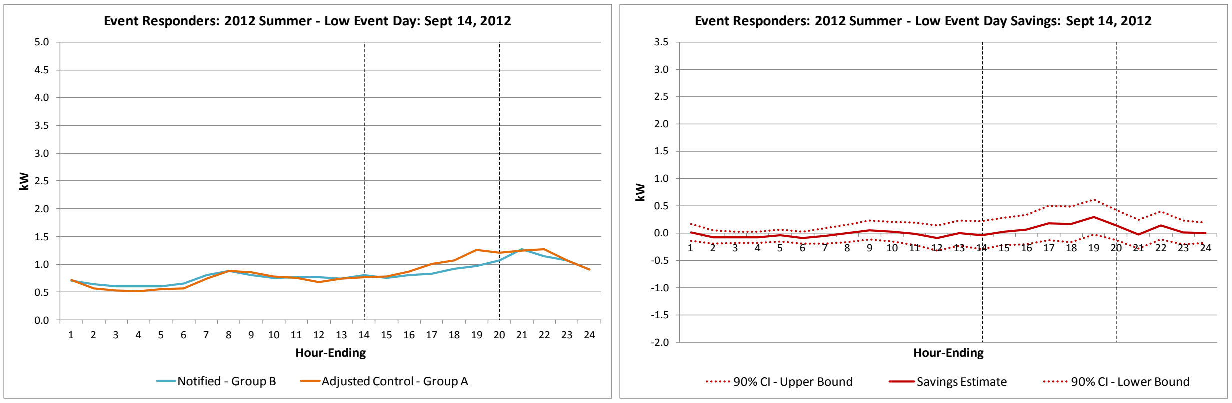


Figure A12. Sep. 14, 2012 Event Day Graphs: Event Responders



Appendix B – 2013 Demand Response Results

Pilot Participants as a Whole

Table B1 summarizes the demand response impacts for the events in analysis year 2013 (which include one non-summer event on Nov. 2, 2012). The table represents pilot participants as a whole, and categorizes the per-participant results by event date and type. It includes the group notified, average demand (in kW) for the adjusted control group, the estimated average load reduction (in kW) across the six-hour event period for the treatment group, the percent load reduction, and the average event day high temperature. It also designates the savings as statistically significant or not.

Table B1. 2013 Demand Response Impacts: Pilot Participants as a Whole

Date (2013)	Event Type	Group Notified	Adjusted Control Group Average kW	Estimated Average kW Reduction		Percent Reduction	Event Day High Temp. (°F)	Significant Savings?
Nov. 2, (2012)	Non-Summer - High	A	1.09	0.02	±0.04	1%	56	No
Jan. 29	Non-Summer - Low	B	1.27	0.01	±0.04	1%	30	No
Jan. 30	Non-Summer - Low	A	1.27	0.05	±0.04	4%	37	No
Feb. 21	Non-Summer - Low	B	1.29	0.00	±0.04	0%	23	No
Feb. 22	Non-Summer - Low	A	1.15	0.03	±0.04	3%	32	No
Jun. 10	Summer - High	B	2.67	0.54	±0.15	20%	99	Yes
Jun. 11	Summer - High	A	2.72	0.70	±0.15	26%	100	Yes
Jun. 12	Summer - Medium	B	2.54	0.54	±0.14	21%	93	Yes
Jun. 13	Summer - High	A	1.81	0.32	±0.14	18%	94	Yes
Jun. 20	Summer - Medium	A	1.98	0.35	±0.14	18%	91	Yes
Jun. 21	Summer - High	B	2.40	0.49	±0.14	21%	96	Yes
Jun. 24	Summer - Medium	A	1.78	0.35	±0.14	20%	91	Yes
Jun. 27	Summer - High	B	3.29	0.68	±0.15	21%	97	Yes
Jun. 28	Summer - High	A	2.75	0.56	±0.15	20%	96	Yes
Jul. 16	Summer - Low	B	1.91	0.29	±0.12	15%	82	No

Date (2013)	Event Type	Group Notified	Adjusted Control Group Average kW	Estimated Average kW Reduction		Percent Reduction	Event Day High Temp. (°F)	Significant Savings?
Jul. 19	Summer - Low	A	2.24	0.59	±0.13	26%	81	Yes
Jul. 22	Summer - High	B	3.15	0.59	±0.15	19%	94	Yes
Aug. 1	Summer - High	A	1.76	0.34	±0.14	20%	95	Yes
Aug. 19	Summer - High	B	2.92	0.64	±0.12	22%	95	Yes
Aug. 21	Summer - Medium	A	2.02	0.29	±0.11	14%	92	Yes
Aug. 28	Summer - Medium	B	2.76	0.70	±0.11	25%	93	Yes
Aug. 29	Summer - High	A	2.37	0.46	±0.12	19%	95	Yes
Sep. 4	Summer - Medium	B	2.52	0.52	±0.11	21%	93	Yes
Sep. 5	Summer - High	A	2.17	0.31	±0.12	15%	97	Yes

[a] Load reduction impacts have been discounted to account for off-line participants. These include estimated confidence intervals based on averages of the discounted confidence intervals for individual on-peak hours.

Figure B1 through Figure B24 show the load shape graphs and savings graphs for the 25 individual event days in analysis year 2013. The first graph for each event day is a comparison of the load shape of the notified group with the adjusted load shape for the group that was not notified. The second graph is the estimated savings based on a difference of differences analysis approach using an average of comparable non-event days as the pretreatment period. These first two graphs reflect per-participant impacts for notified customers who were on-line (connected to the Internet) during the event and therefore received the event notification. Since a portion of participants were off-line for each event, the overall per-participant impacts are lower. To account for this effect on the impacts, the third graph for each event represents the adjusted (discounted) savings for the group of notified participants as a whole, including both on-line and off-line customers.

Figure B1. Nov. 2, 2012 Event Day Graphs

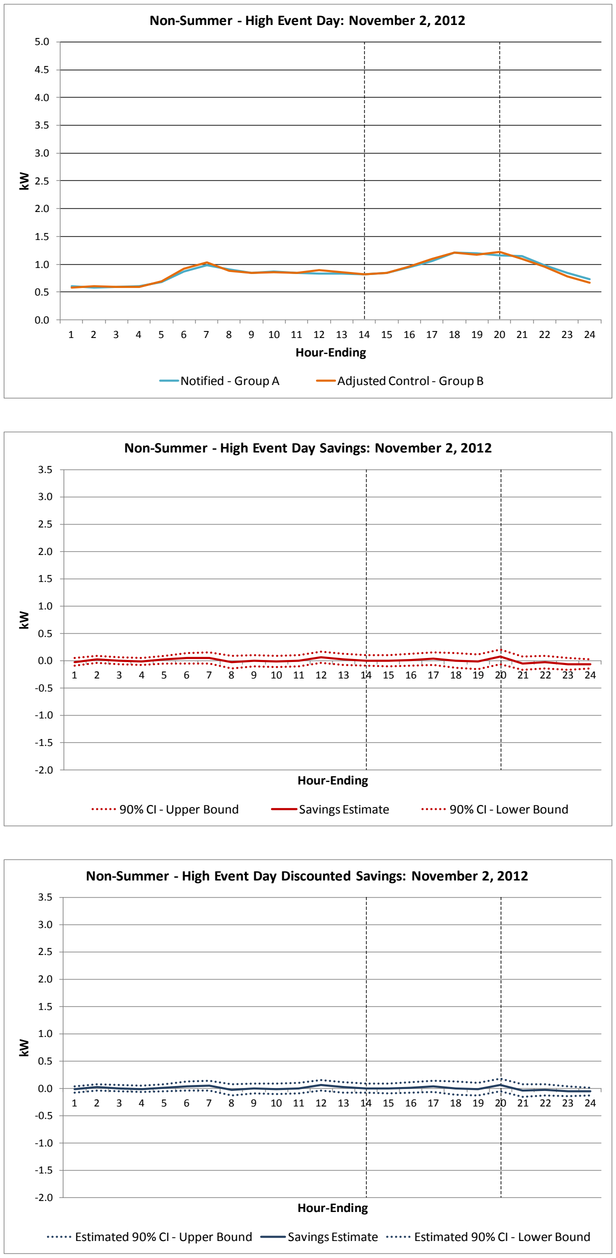


Figure B2. Jan. 29, 2013 Event Day Graphs

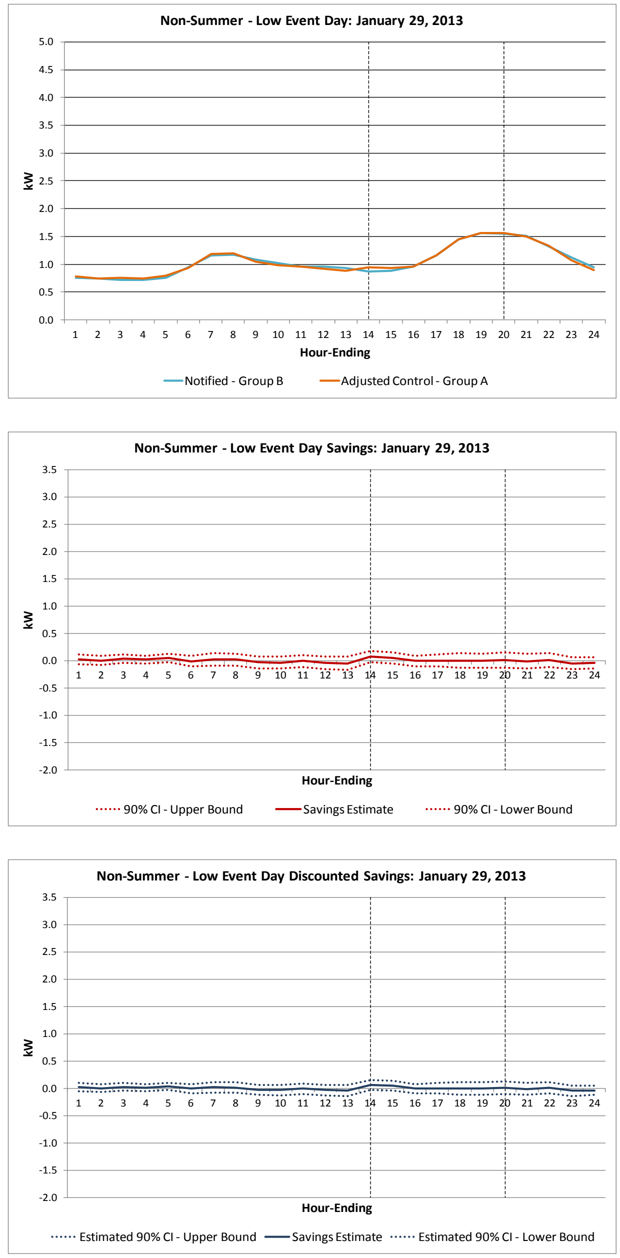
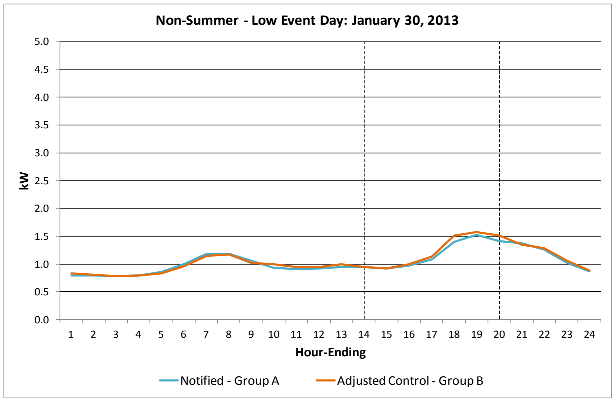
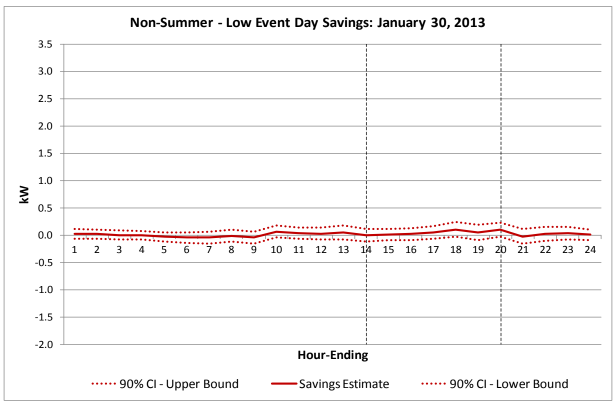


Figure B3. Jan. 30, 2013 Event Day Graphs





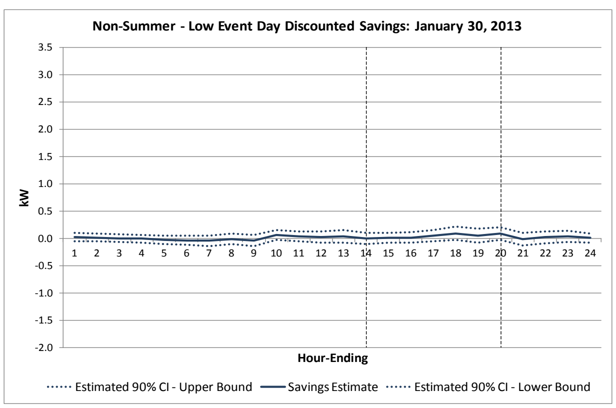
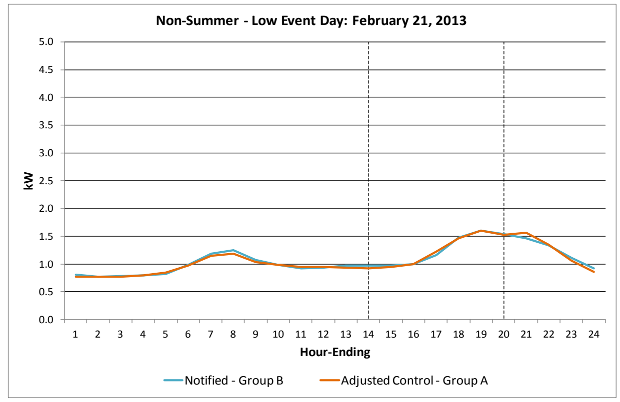
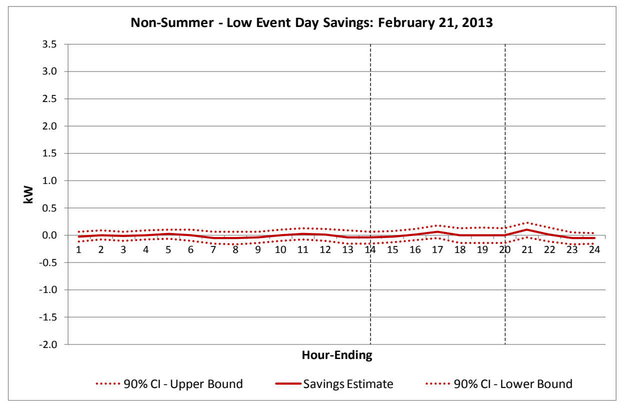


Figure B4. Feb. 21, 2013 Event Day Graphs





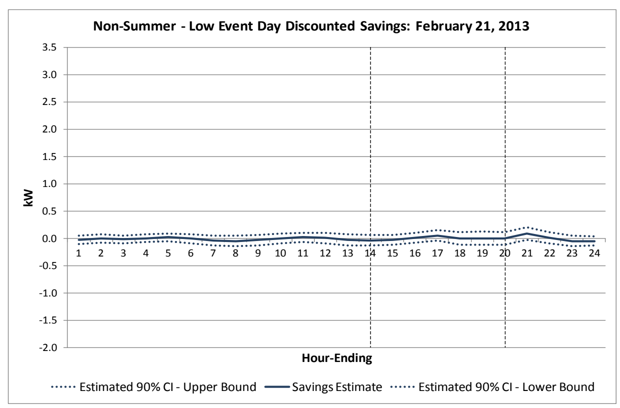
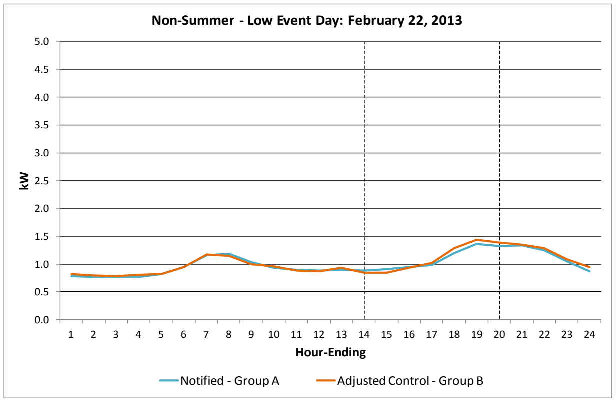
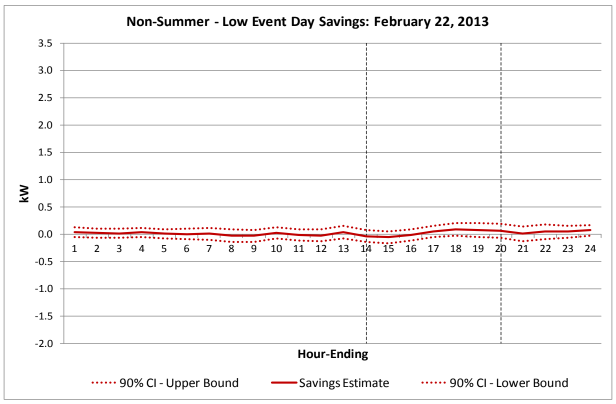


Figure B5. Feb. 22, 2013 Event Day Graphs





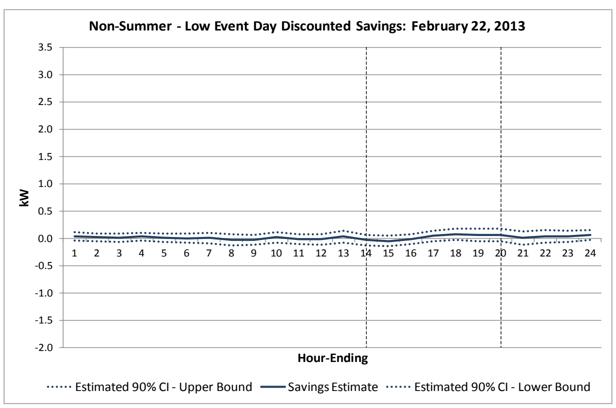
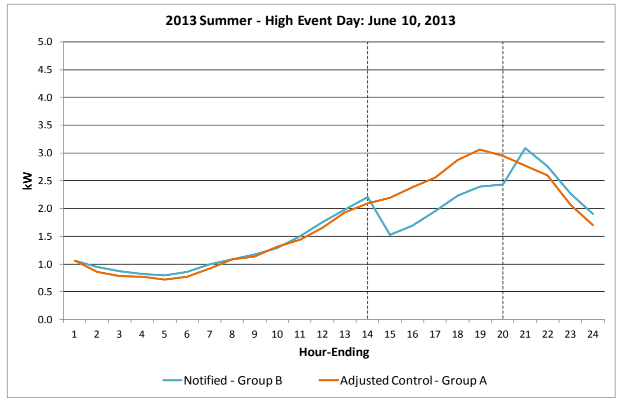
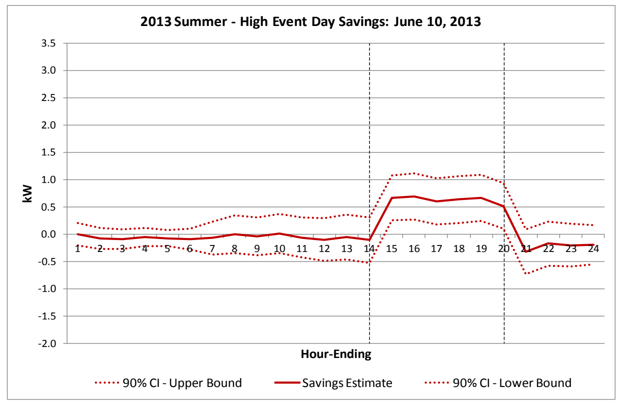


Figure B6. Jun. 10, 2013 Event Day Graphs





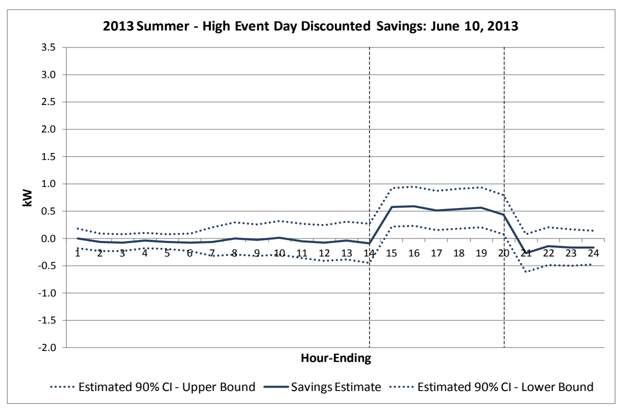
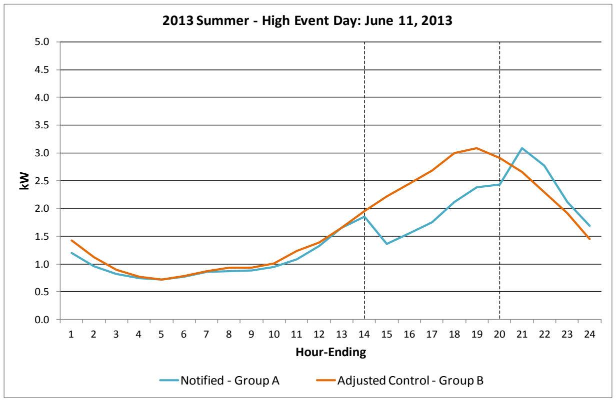
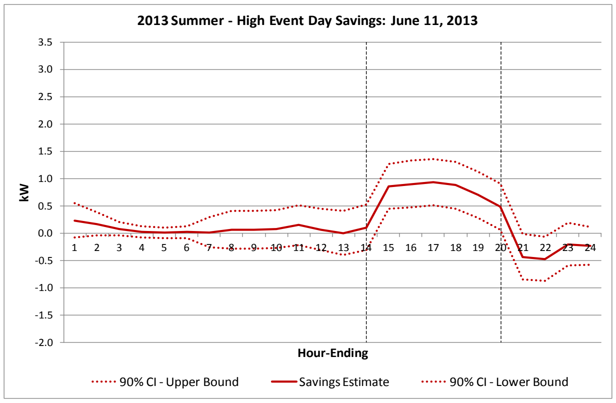


Figure B7. Jun. 11, 2013 Event Day Graphs





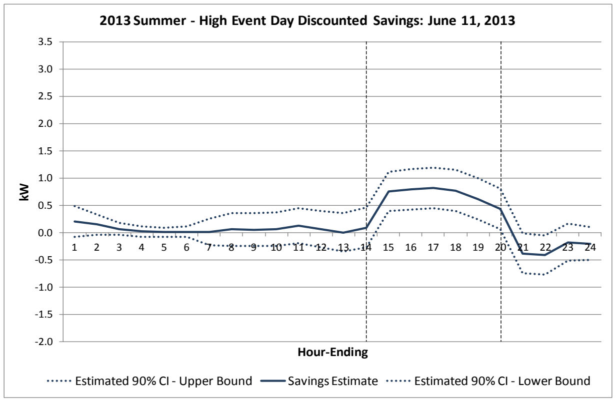
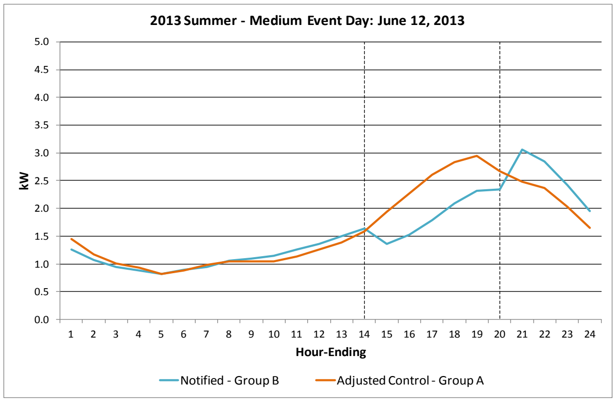
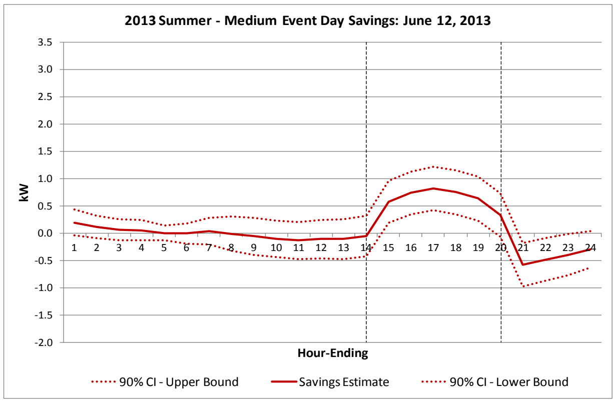


Figure B8. Jun. 12, 2013 Event Day Graphs





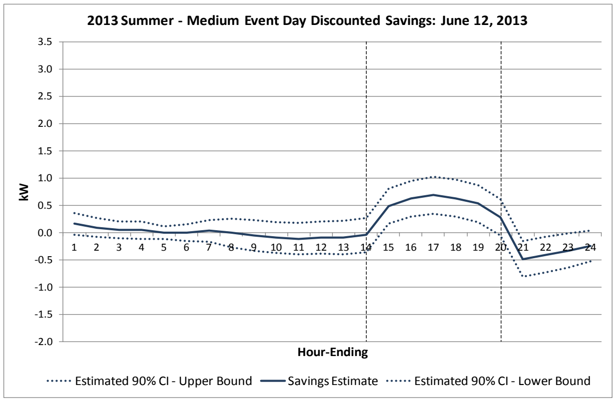


Figure B9. Jun. 13, 2013 Event Day Graphs

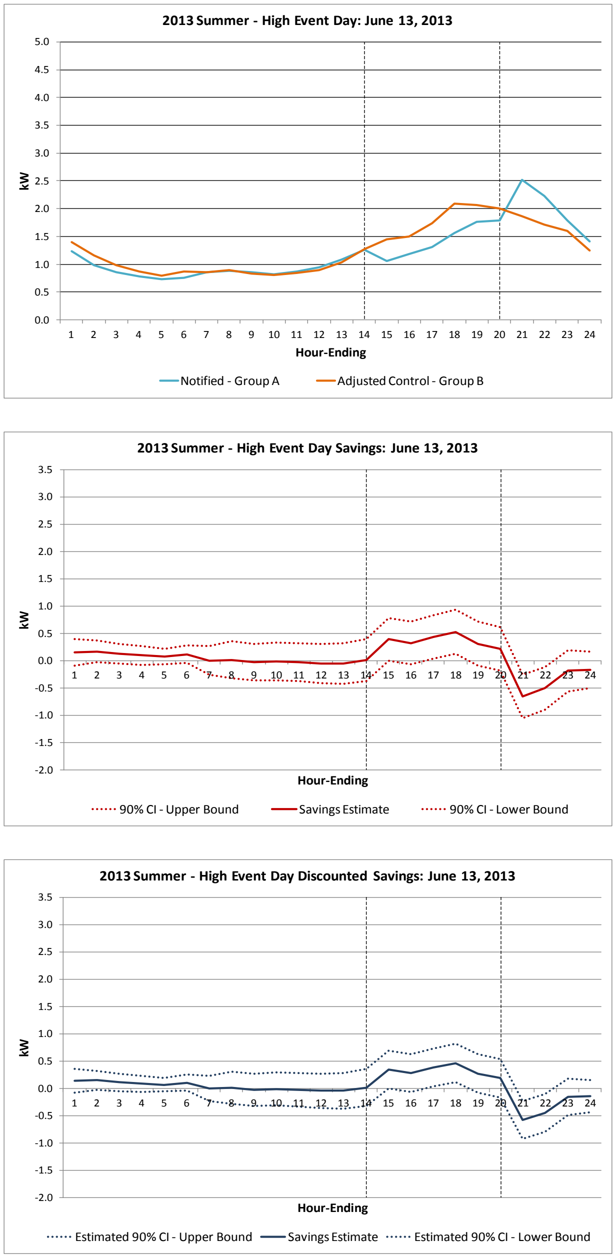


Figure B10. Jun. 20, 2013 Event Day Graphs

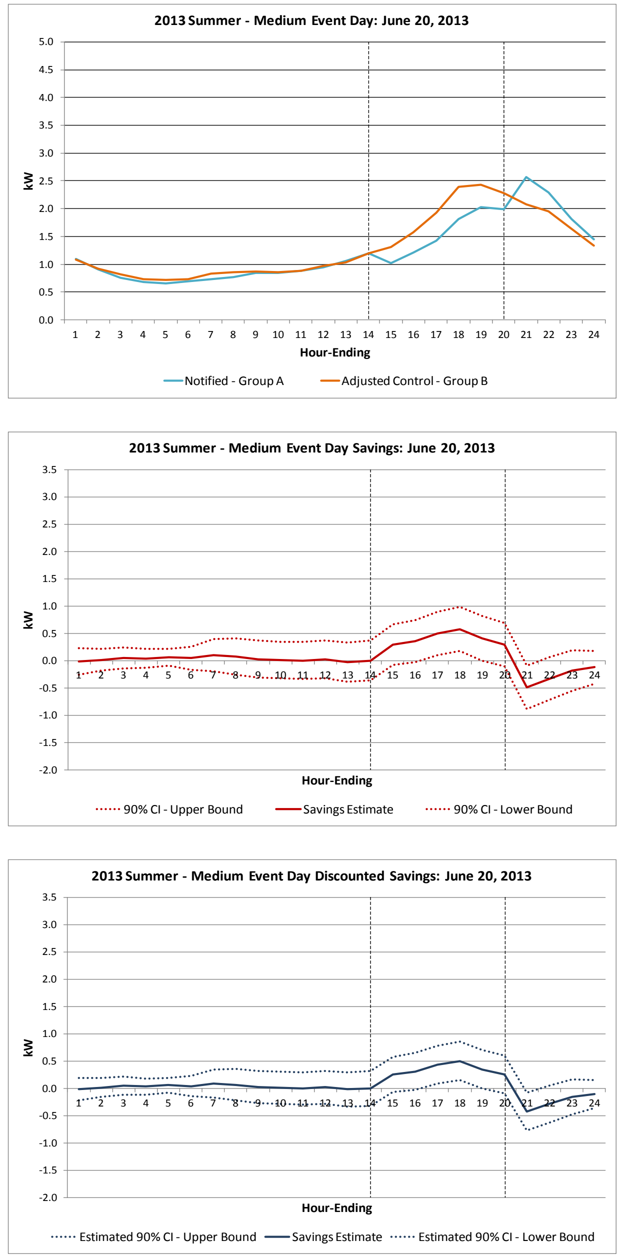


Figure B11. Jun. 21, 2013 Event Day Graphs

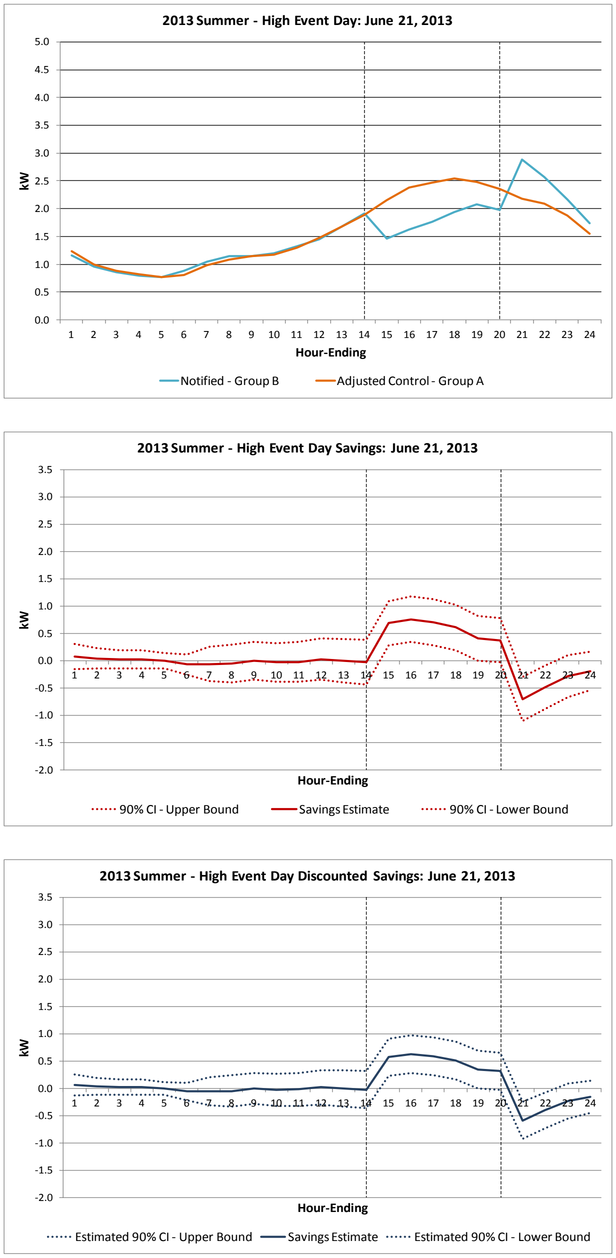


Figure B12. Jun. 24, 2013 Event Day Graphs

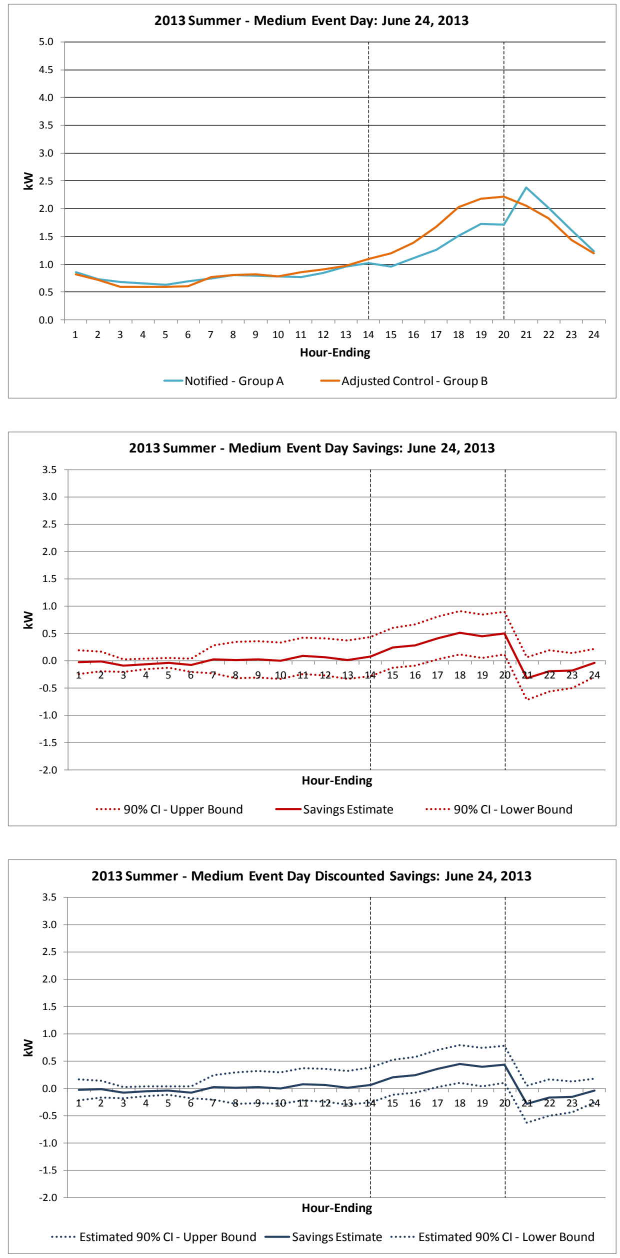


Figure B13. Jun. 27, 2013 Event Day Graphs

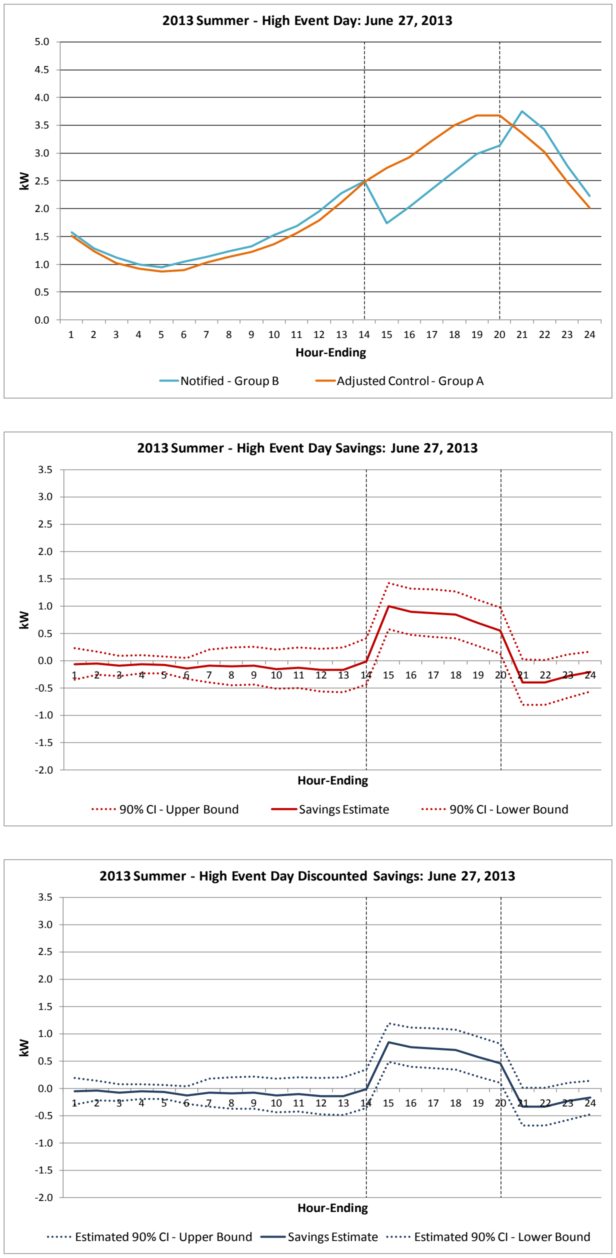


Figure B14. Jun. 28, 2013 Event Day Graphs

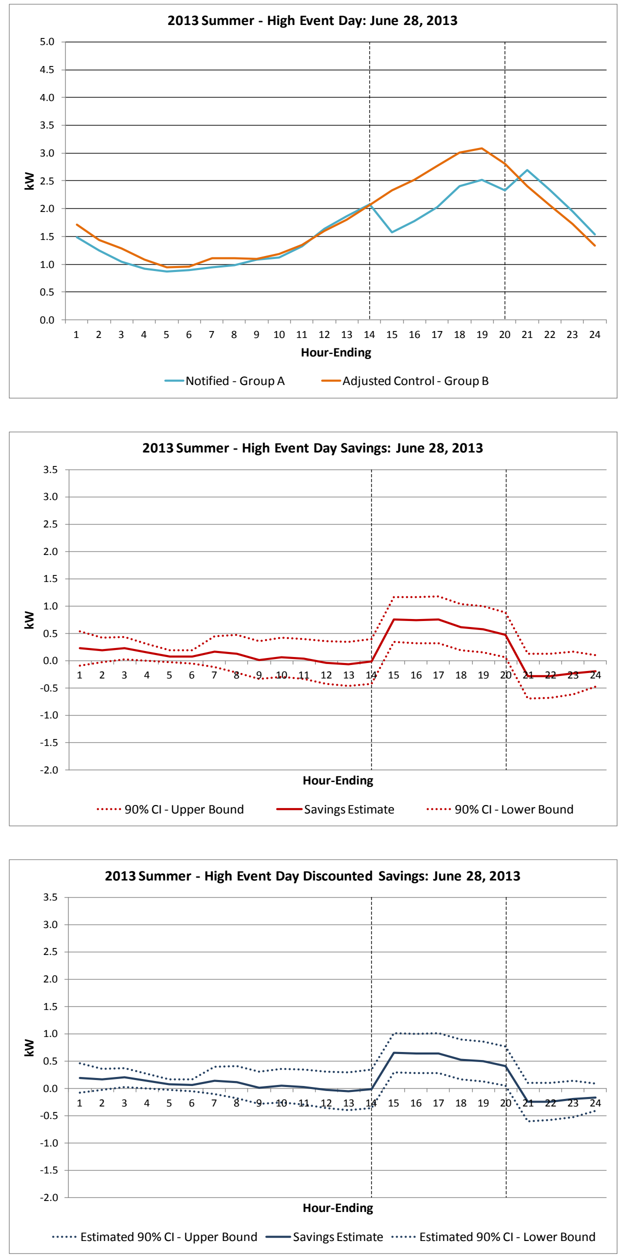
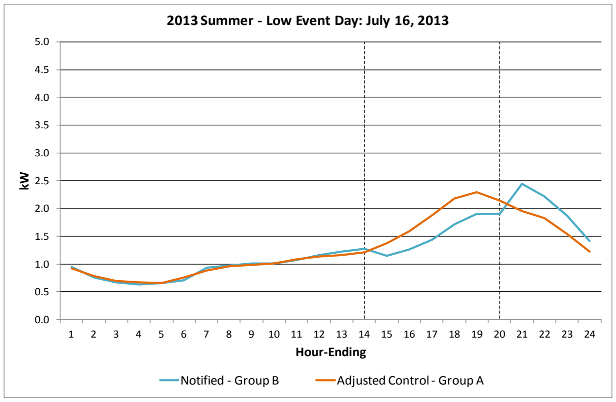
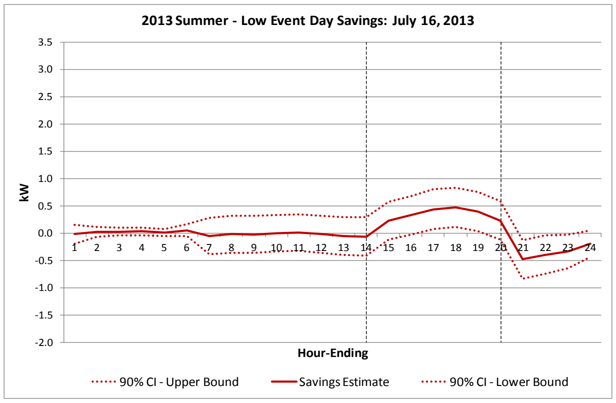


Figure B15. Jul. 16, 2013 Event Day Graphs





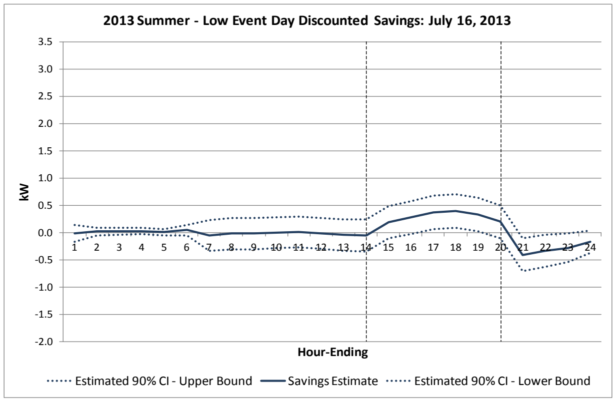
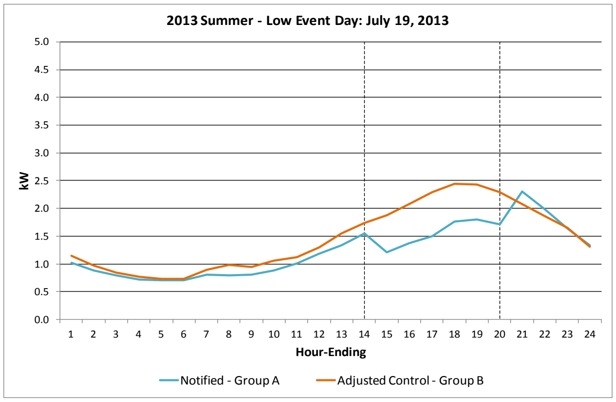
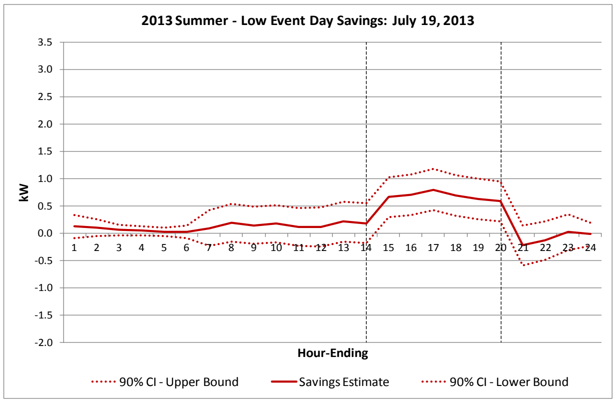


Figure B16. Jul. 19, 2013 Event Day Graphs





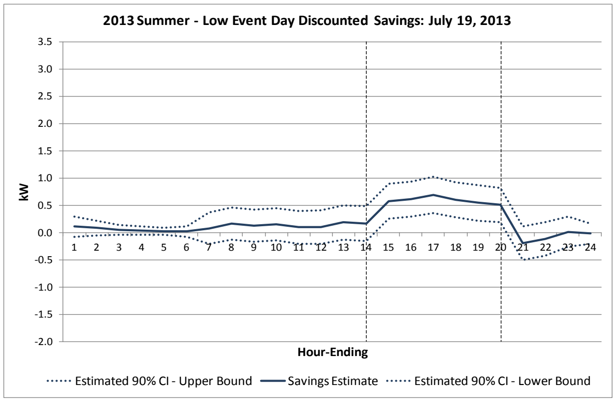
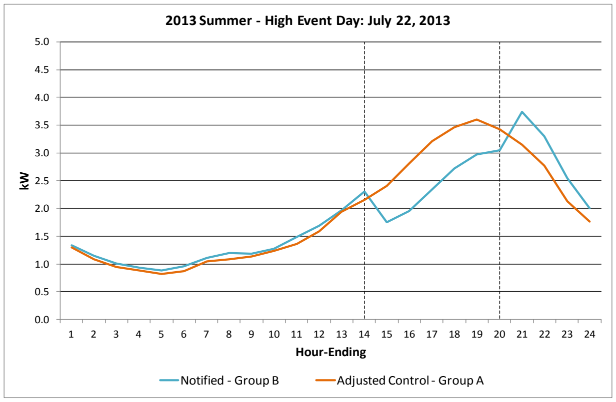
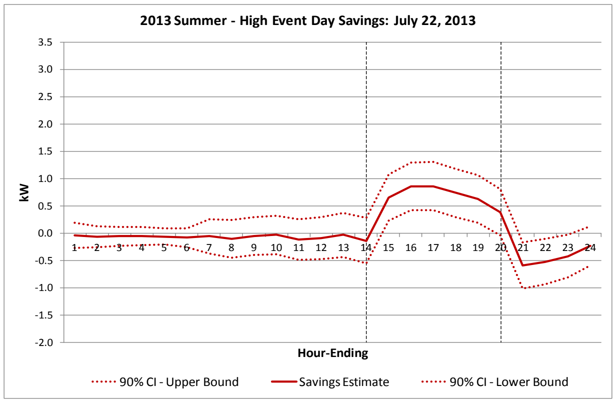


Figure B17. Jul. 22, 2013 Event Day Graphs





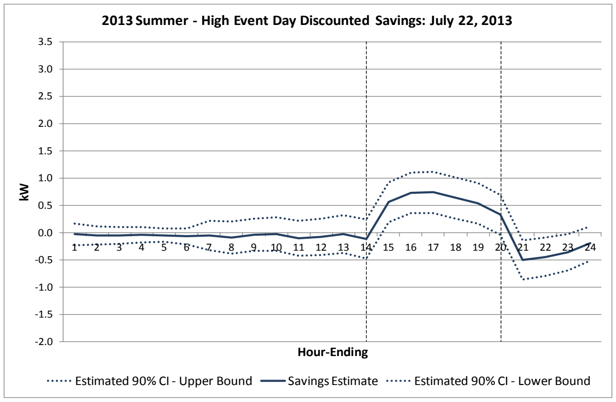
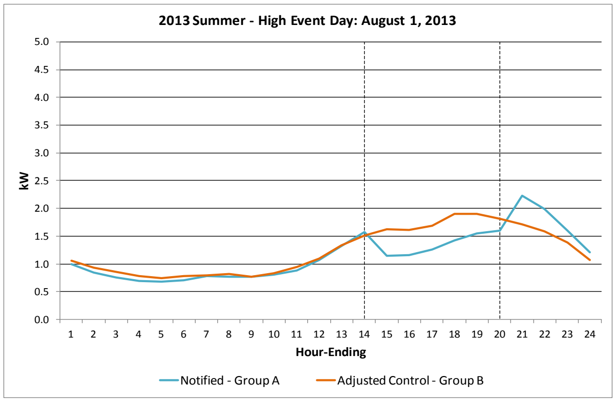
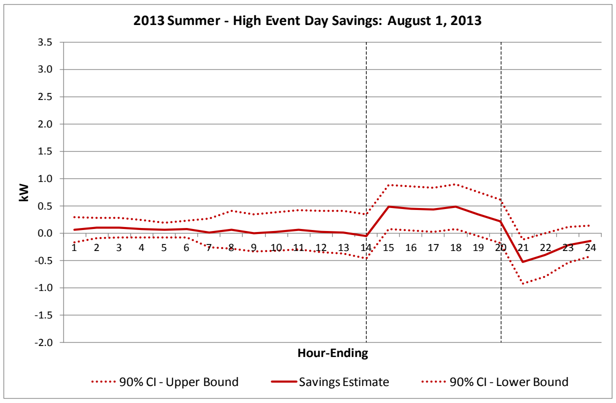


Figure B18. Aug. 1, 2013 Event Day Graphs





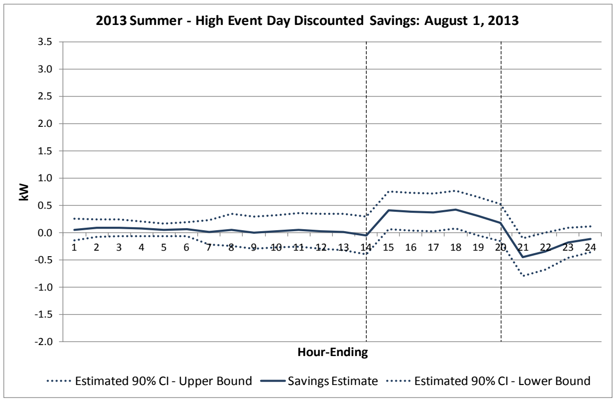


Figure B19. Aug. 19, 2013 Event Day Graphs

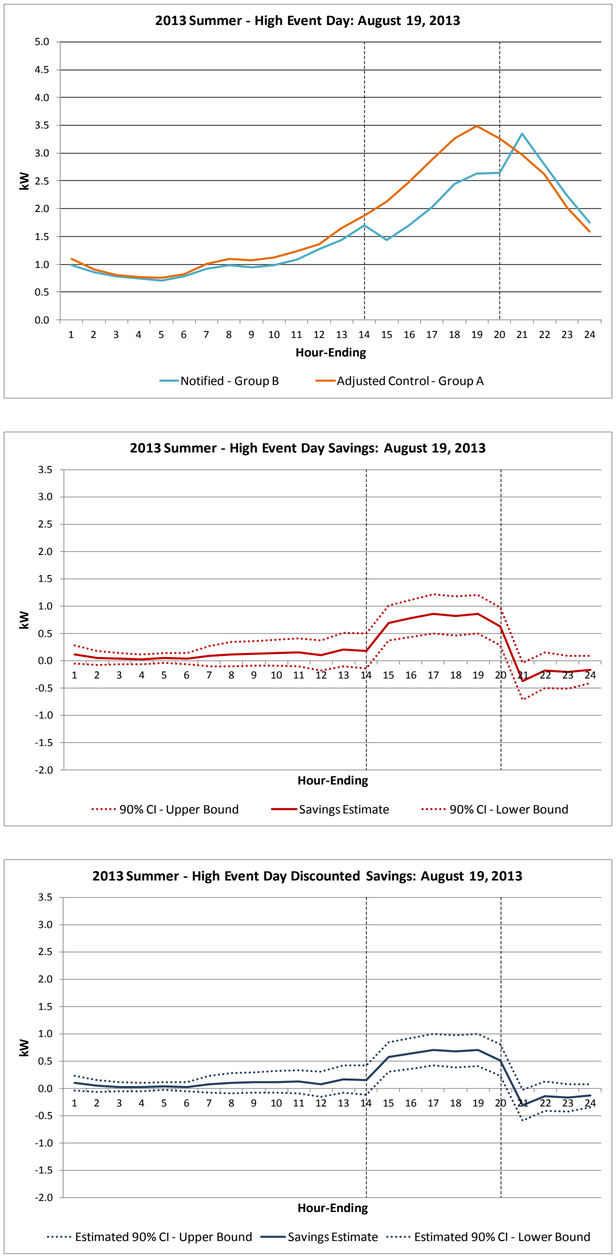


Figure B20. Aug. 21, 2013 Event Day Graphs

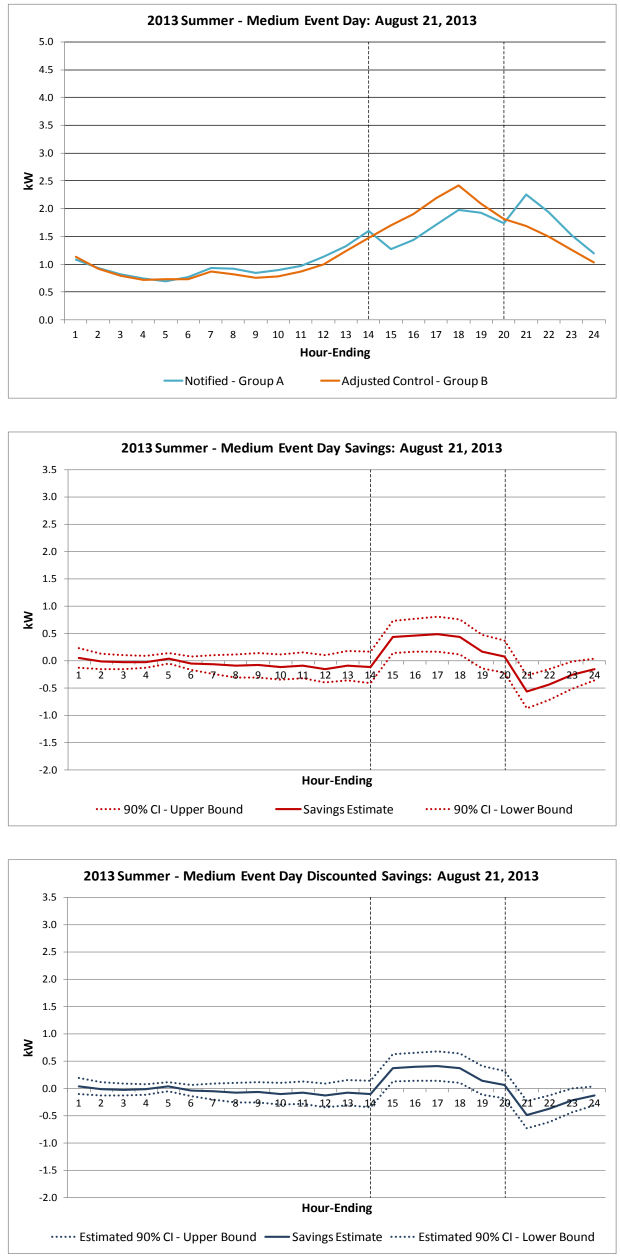


Figure B21. Aug. 28, 2013 Event Day Graphs

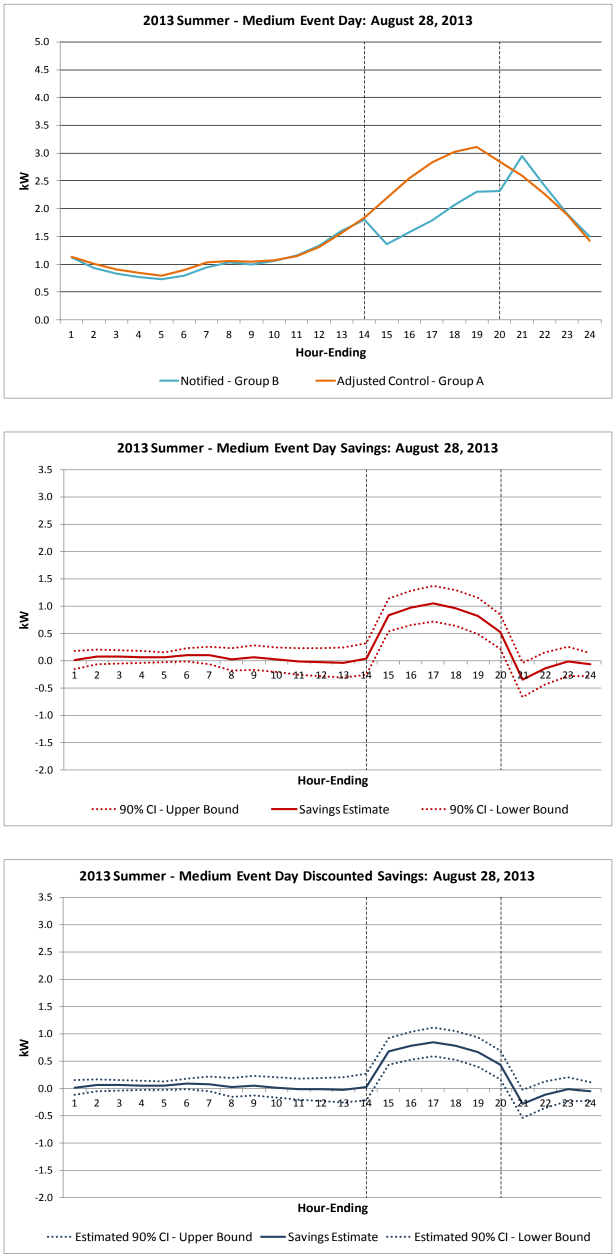


Figure B22. Aug. 29, 2013 Event Day Graphs

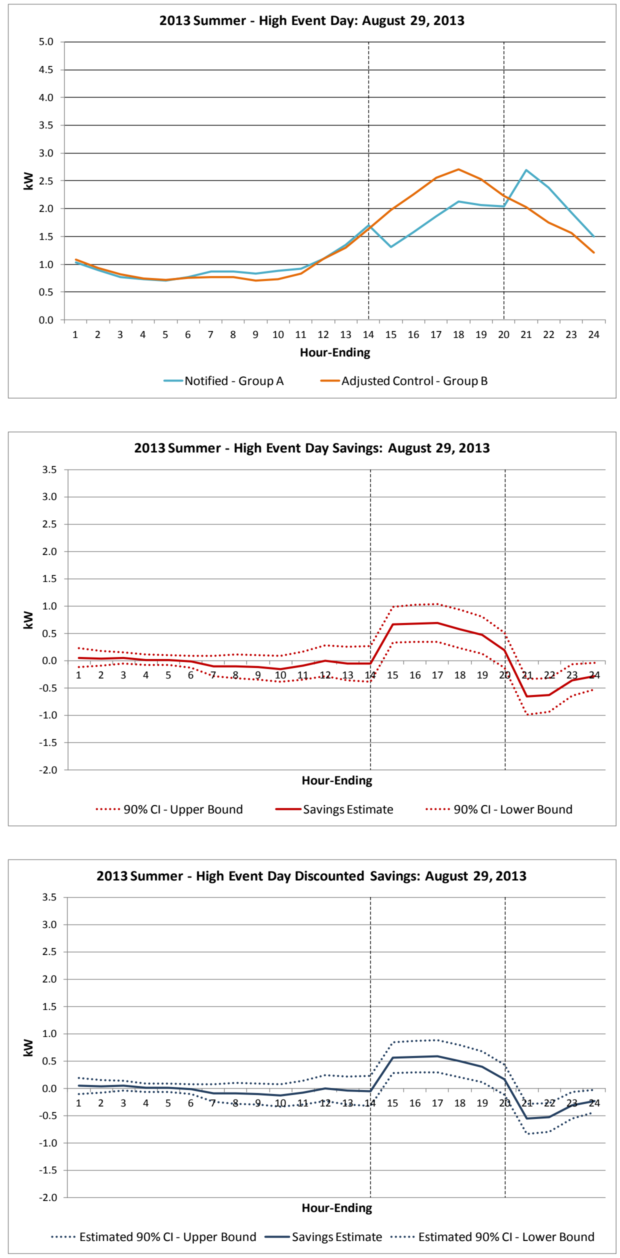
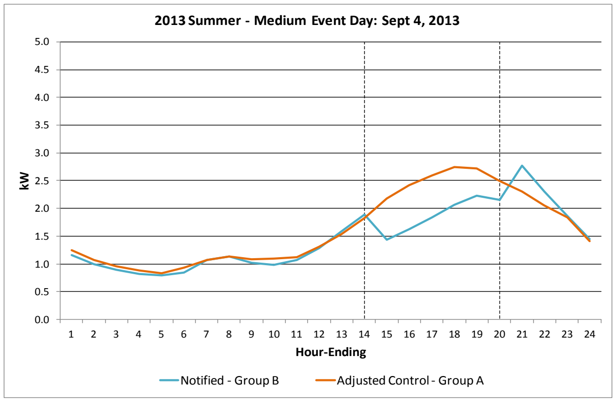
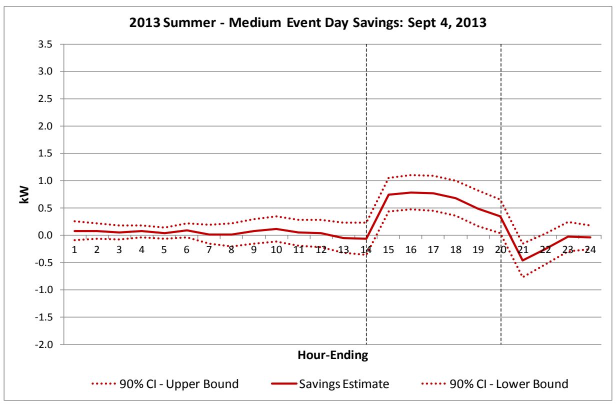


Figure B23. Sep. 4, 2013 Event Day Graphs





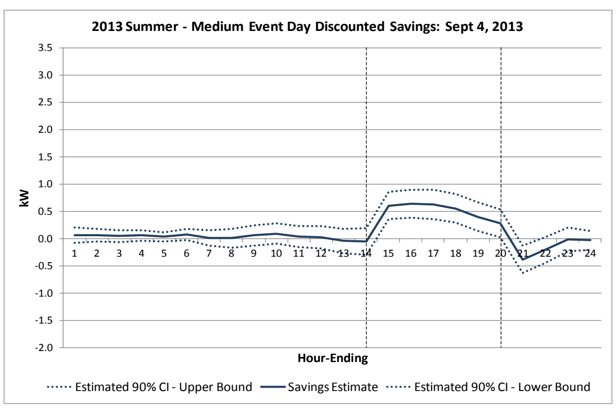
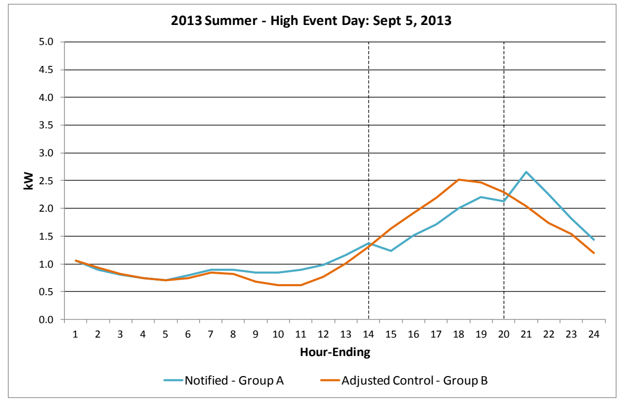
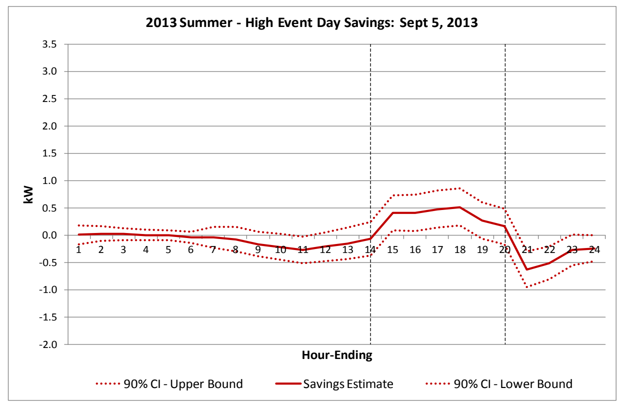
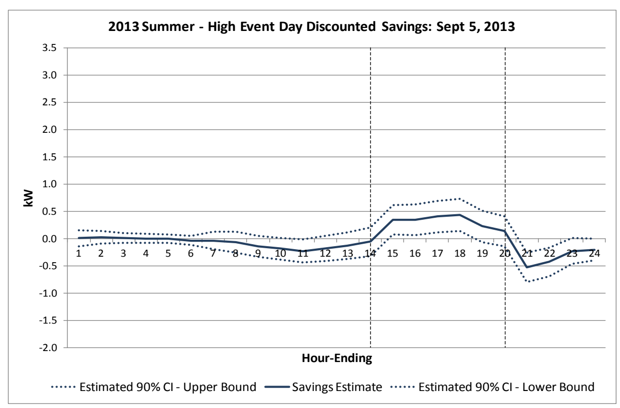


Figure B24. Sep. 5, 2013 Event Day Graphs







Event Responders

Table B2 summarizes the demand response impacts for the 2013 summer events for pilot participants categorized as event responders. Event responders were defined for each individual event as those either accepting the event in response to the notice, or those who did not respond to the notice by the midpoint of the event (5:00 pm), but whose devices were configured to respond. The table categorizes the per-participant results by event date and type. It includes the group notified, average demand (in kW) for the adjusted control group, the estimated average load reduction (in kW) across the six-hour event period for the treatment group, the percent load reduction, and the average event day high temperature. It also designates the savings as statistically significant or not.

Table B2. 2013 Demand Response Impacts: Event Responders

Date (2013)	Event Type	Group Notified	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Event Day High Temp. (°F)	Significant Savings?
Jun. 10	Summer - High	B	2.49	0.91	±0.05	37%	99	Yes
Jun. 11	Summer - High	A	2.58	1.07	±0.04	41%	100	Yes
Jun. 12	Summer - Medium	B	2.60	0.91	±0.05	35%	93	Yes
Jun. 13	Summer - High	A	1.78	0.65	±0.04	36%	94	Yes
Jun. 20	Summer - Medium	A	1.97	0.70	±0.05	35%	91	Yes
Jun. 21	Summer - High	B	2.22	0.92	±0.10	41%	96	Yes
Jun. 24	Summer - Medium	A	1.72	0.62	±0.10	36%	91	Yes
Jun. 27	Summer - High	B	3.44	1.30	±0.16	38%	97	Yes
Jun. 28	Summer - High	A	2.78	1.11	±0.09	40%	96	Yes
Jul. 16	Summer - Low	B	1.81	0.62	±0.09	34%	82	Yes
Jul. 19	Summer - Low	A	2.07	0.91	±0.09	44%	81	Yes
Jul. 22	Summer - High	B	3.01	1.19	±0.08	40%	94	Yes
Aug. 1	Summer - High	A	1.78	0.68	±0.18	38%	95	Yes
Aug. 19	Summer - High	B	2.65	1.01	±0.10	38%	95	Yes
Aug. 21	Summer - Medium	A	2.07	0.76	±0.07	37%	92	Yes
Aug. 28	Summer - Medium	B	2.64	1.07	±0.07	41%	93	Yes

Date (2013)	Event Type	Group Notified	Adjusted Control Group Average kW	Estimated Average kW Reduction[a]		Percent Reduction	Event Day High Temp. (°F)	Significant Savings?
Aug. 29	Summer - High	A	2.50	1.11	±0.11	44%	95	Yes
Sep. 4	Summer - Medium	B	2.33	0.89	±0.09	38%	93	Yes
Sep. 5	Summer - High	A	2.39	0.88	±0.10	37%	97	Yes

[a] These include estimated confidence intervals based on averages of the actual confidence intervals for individual on-peak hours.

Figure B25 through Figure B43 show the load shape graphs and savings graphs for the summer event days in analysis year 2013. This set of graphs reflects results for pilot participants categorized as frequent event responders and the savings impacts are from the subset of participants who responded to the given event. The first graph for each event day is a comparison of the load shape of the event responders with the adjusted load shape for the subset of frequent event responders that was not notified. The second graph is the estimated savings based on a difference of differences analysis approach using an average of comparable non-event days as the pretreatment period.

Figure B25. Jun. 10, 2013 Event Day Graphs: Event Responders

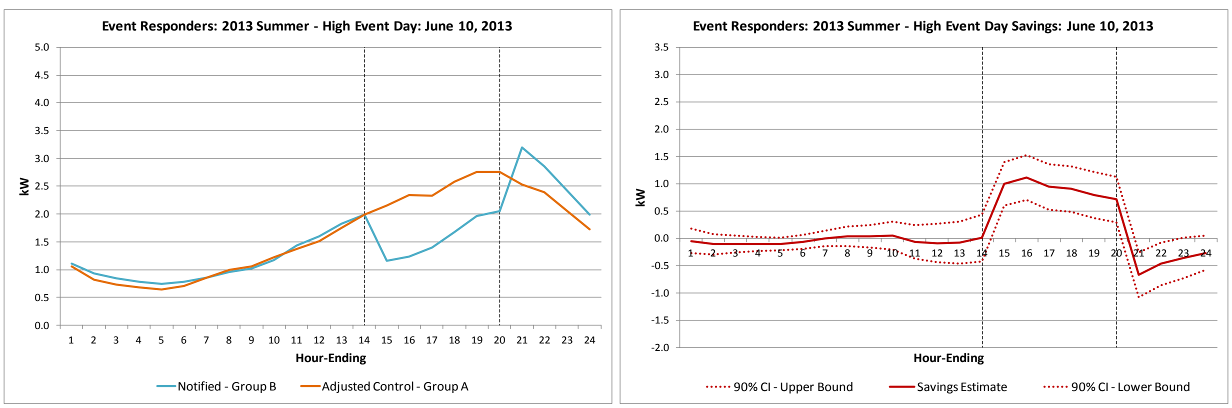


Figure B26. Jun. 11, 2013 Event Day Graphs: Event Responders

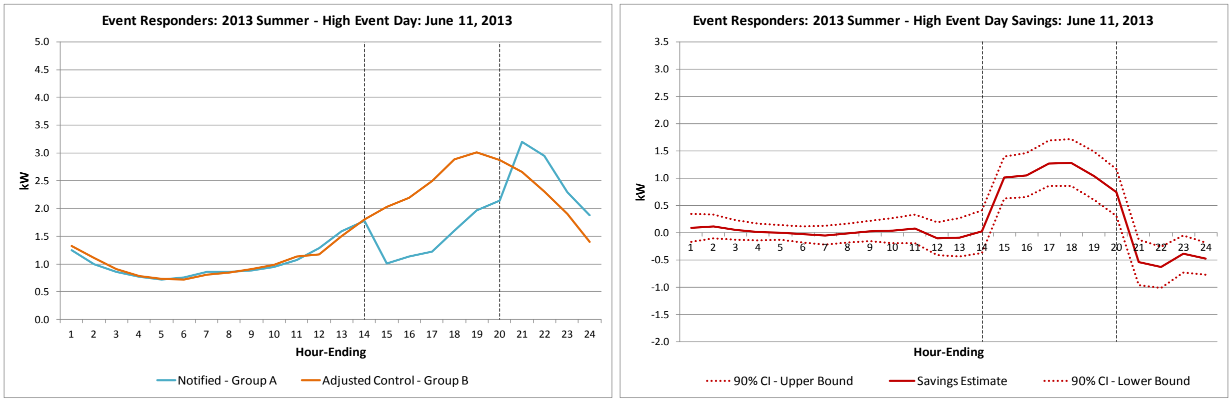


Figure B27. Jun. 12, 2013 Event Day Graphs: Event Responders

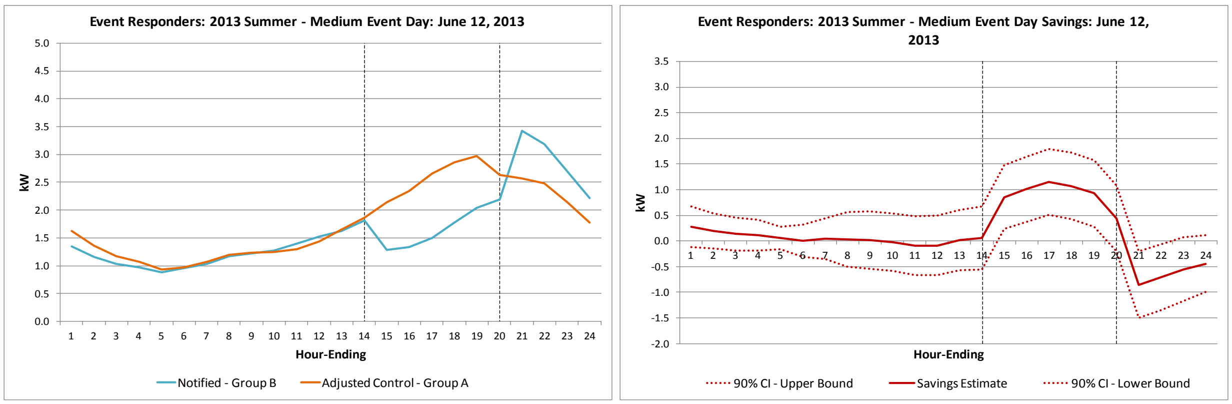


Figure B28. Jun. 13, 2013 Event Day Graphs: Event Responders

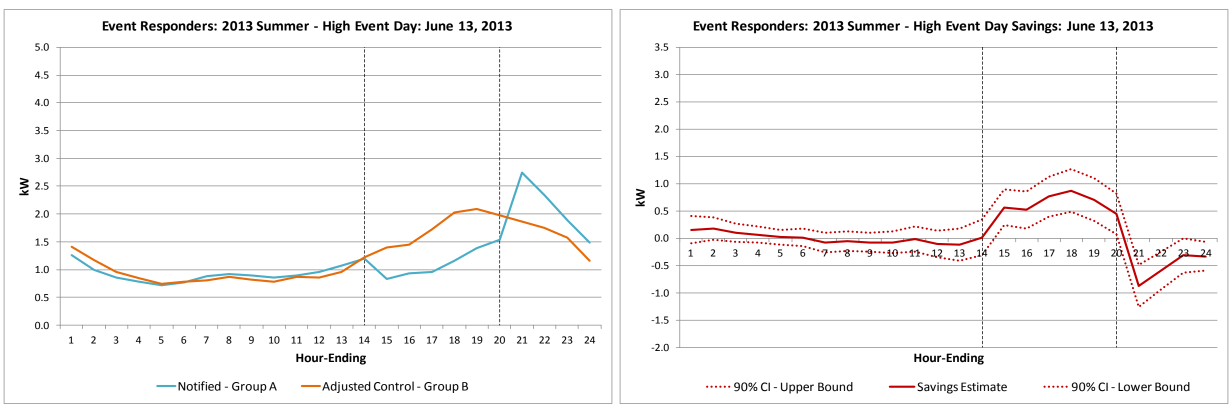


Figure B29. Jun. 20, 2013 Event Day Graphs: Event Responders

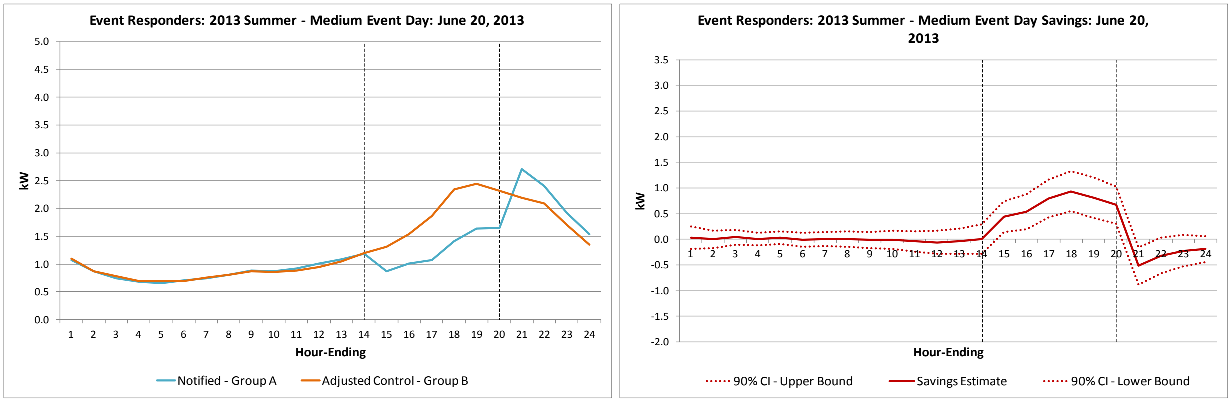


Figure B30. Jun. 21, 2013 Event Day Graphs: Event Responders

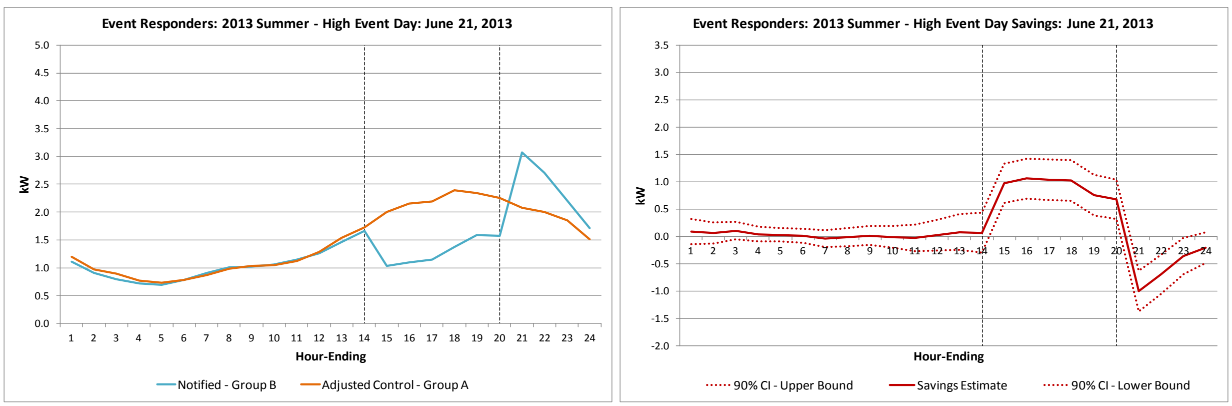


Figure B31. Jun. 24, 2013 Event Day Graphs: Event Responders

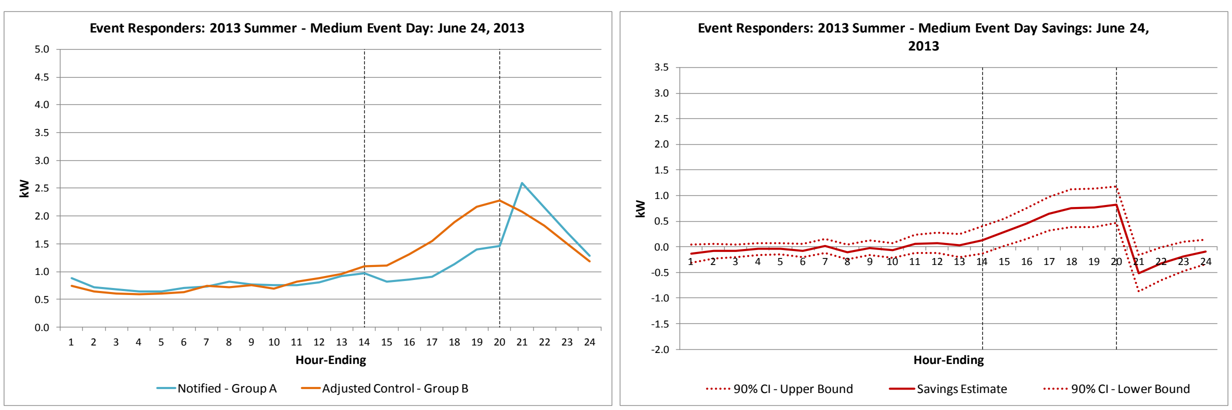


Figure B32. Jun. 27, 2013 Event Day Graphs: Event Responders

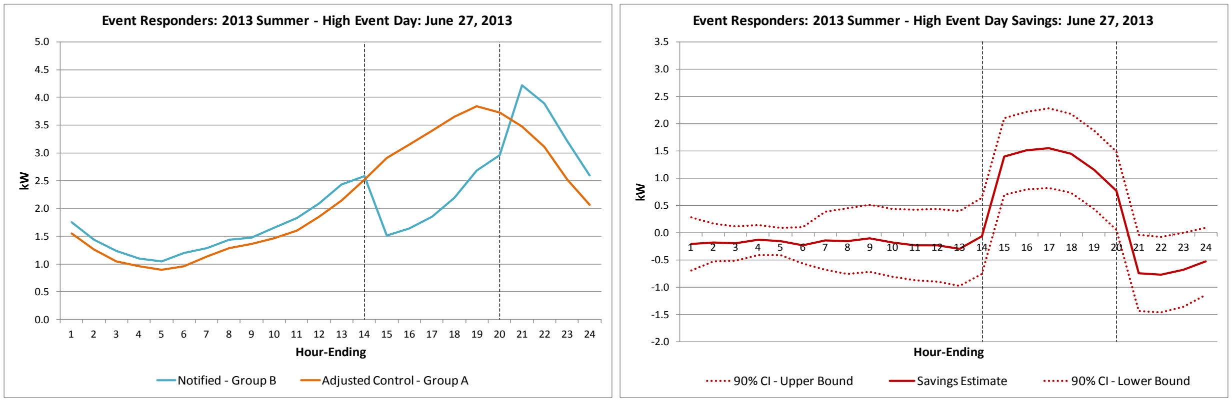


Figure B33. Jun. 28, 2013 Event Day Graphs: Event Responders

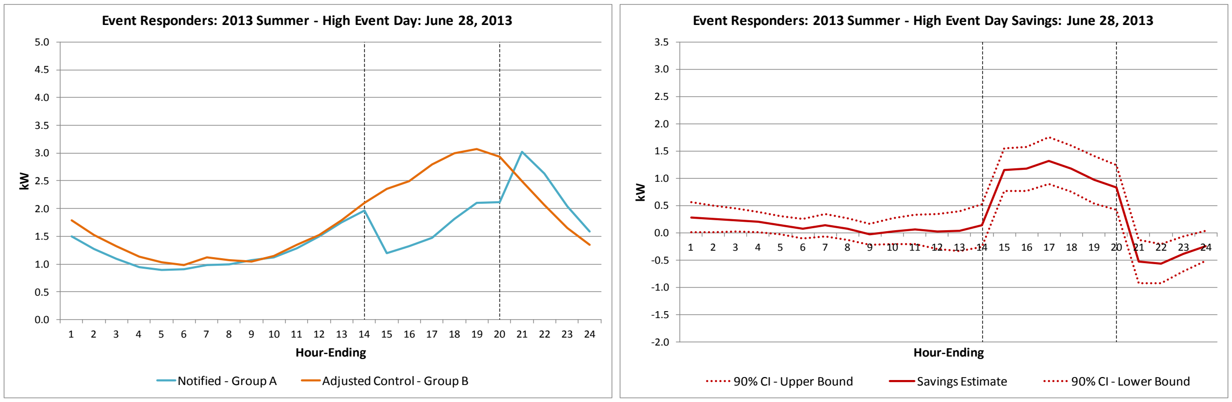


Figure B34. Jul. 16, 2013 Event Day Graphs: Event Responders

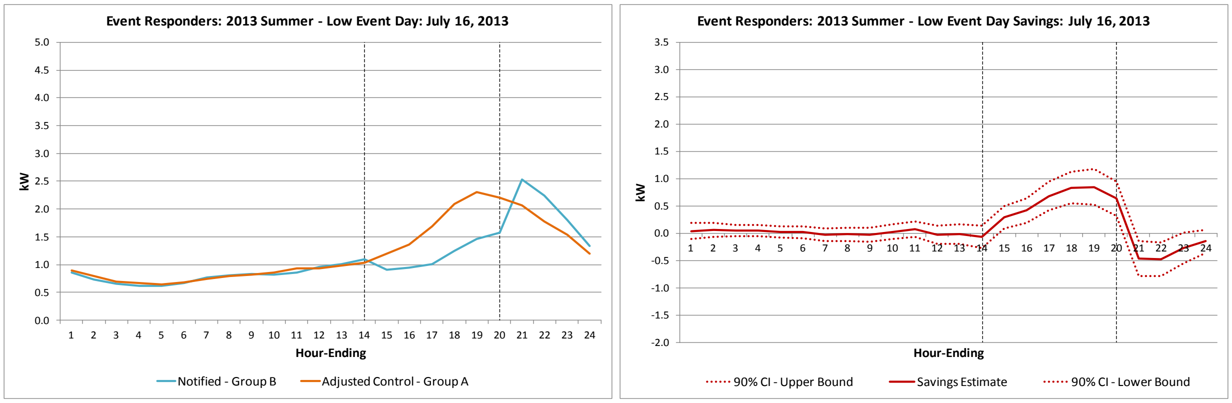


Figure B35. Jul. 19, 2013 Event Day Graphs: Event Responders

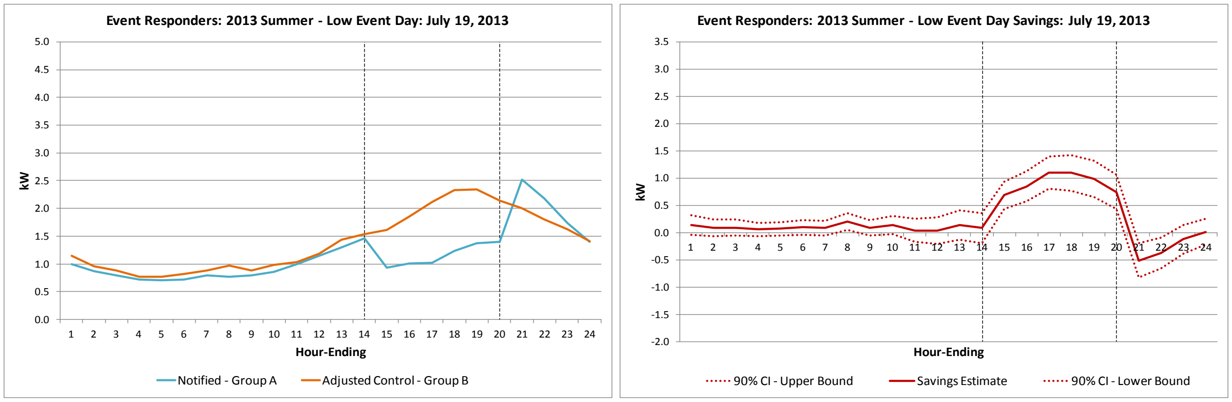


Figure B36. Jul. 22, 2013 Event Day Graphs: Event Responders

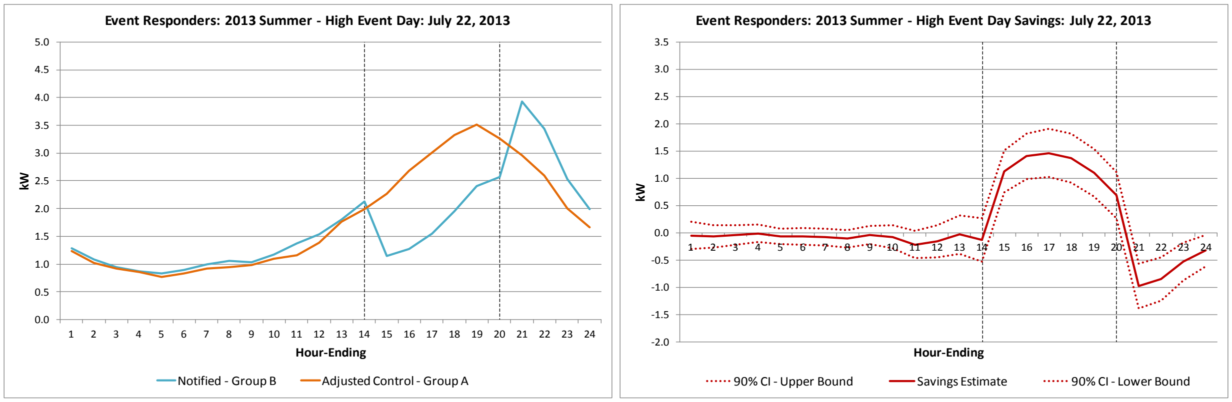


Figure B37. Aug. 1, 2013 Event Day Graphs: Event Responders

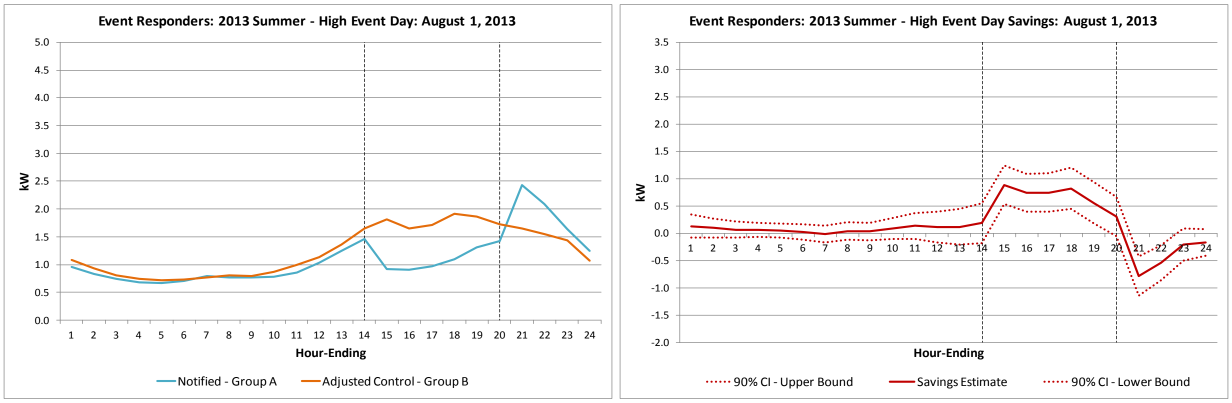


Figure B38. Aug. 19, 2013 Event Day Graphs: Event Responders

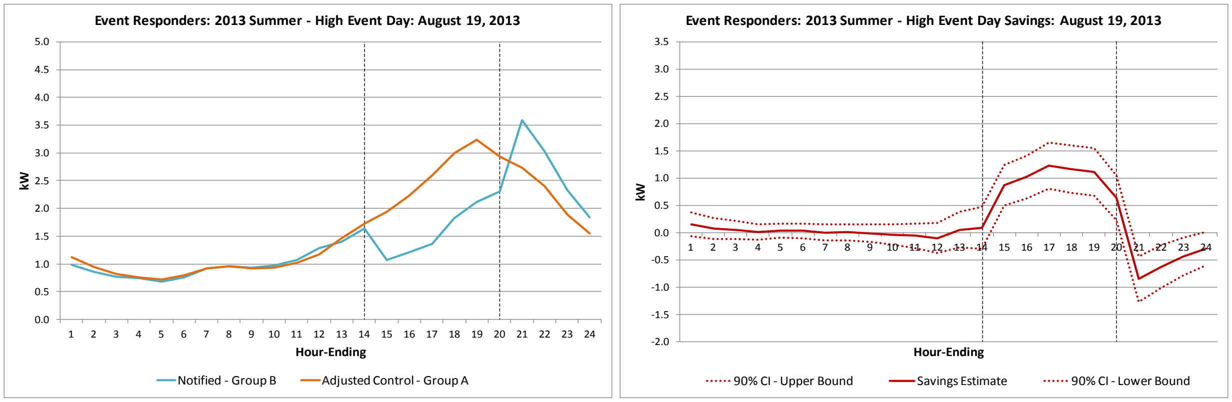


Figure B39. Aug. 21, 2013 Event Day Graphs: Event Responders

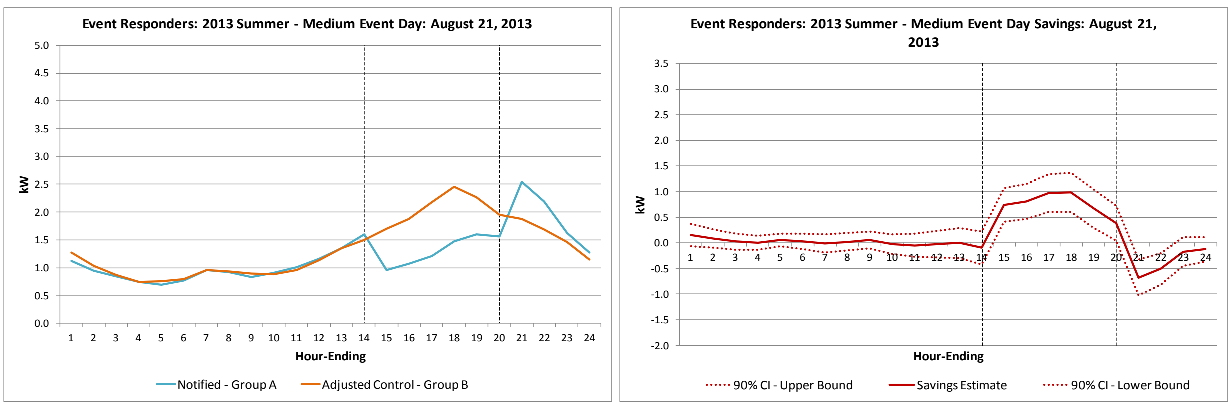


Figure B40. Aug. 28, 2013 Event Day Graphs: Event Responders

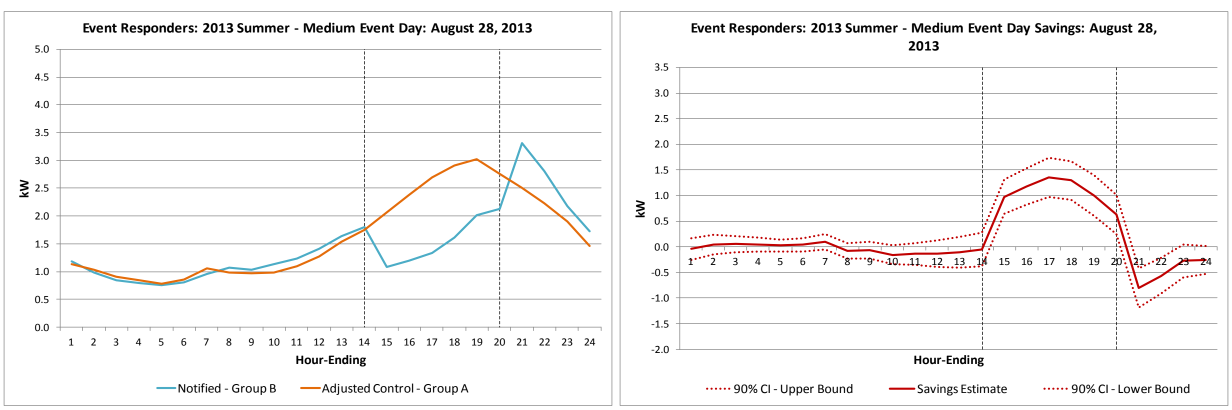


Figure B41. Aug. 29, 2013 Event Day Graphs: Event Responders

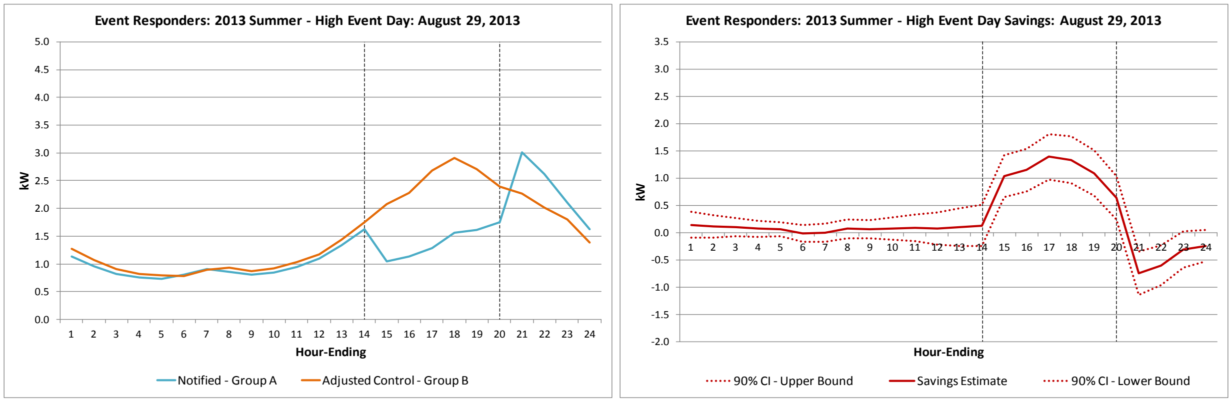


Figure B42. Sep. 4, 2013 Event Day Graphs: Event Responders

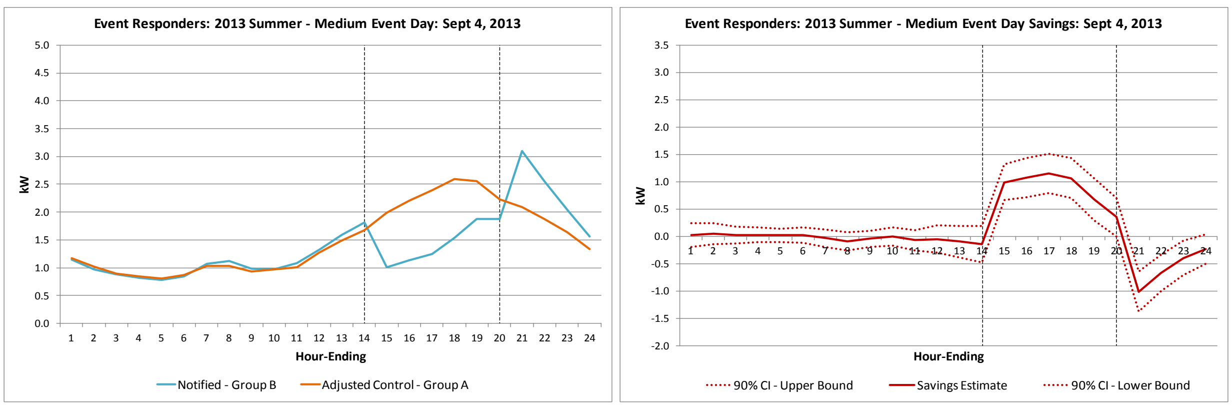
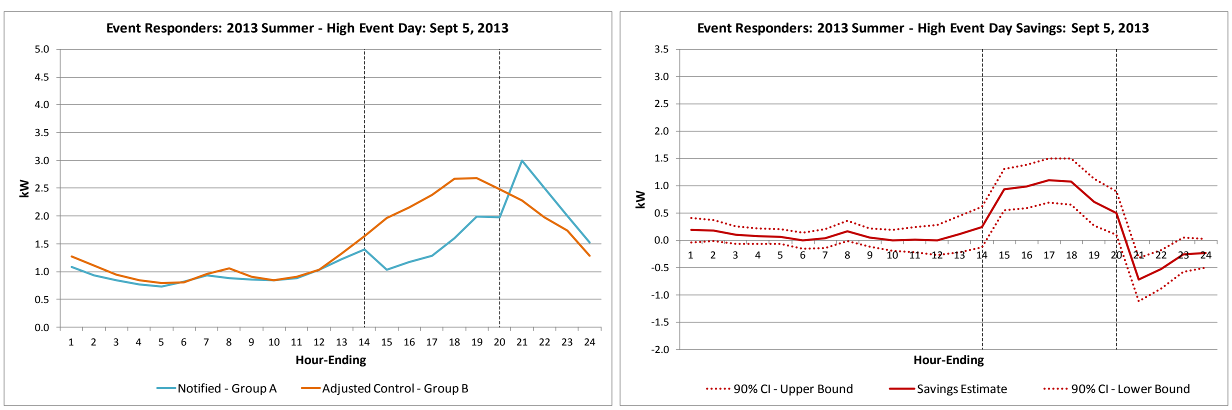


Figure B43. Sep. 5, 2013 Event Day Graphs: Event Responders



Appendix C – Regression Model Output

The PANEL Procedure
Fixed Two Way Estimates

Dependent Variable: Norm_KWH

Model Description

Estimation Method	FixTwo
Number of Cross Sections	1886
Time Series Length	33

Fit Statistics

SSE	2474067905	DFE	58666
MSE	42172.0912	Root MSE	205.3584
R-Square	0.7845		

F Test for No Fixed Effects

Num DF	Den DF	F Value	Pr > F
1917	58666	92.31	<.0001

Parameter Estimates

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|	Label
TS1	1	119.2032	12.5304	9.51	<.0001	Time Series Effect 1
TS2	1	17.64581	12.0695	1.46	0.1437	Time Series Effect 2
TS3	1	-5.13183	10.2047	-0.50	0.6150	Time Series Effect 3
TS4	1	-11.1586	9.1401	-1.22	0.2222	Time Series Effect 4
TS5	1	-0.64548	8.9291	-0.07	0.9424	Time Series Effect 5
TS6	1	61.84576	8.3445	7.41	<.0001	Time Series Effect 6
TS7	1	85.41136	7.0844	12.06	<.0001	Time Series Effect 7
TS8	1	53.77949	7.5731	7.10	<.0001	Time Series Effect 8
TS9	1	21.26222	7.0912	3.00	0.0027	Time Series Effect 9
TS10	1	1.382492	8.3117	0.17	0.8679	Time Series Effect 10
TS11	1	-1.86795	9.5150	-0.20	0.8444	Time Series Effect 11
TS12	1	42.43338	11.3942	3.72	0.0002	Time Series Effect 12
TS13	1	55.65365	11.2220	4.96	<.0001	Time Series Effect 13
TS14	1	-8.85774	11.6173	-0.76	0.4458	Time Series Effect 14
TS15	1	-2.57649	9.8361	-0.26	0.7934	Time Series Effect 15
TS16	1	-4.39155	8.8246	-0.50	0.6187	Time Series Effect 16
TS17	1	10.98241	8.5642	1.28	0.1997	Time Series Effect 17
TS18	1	36.51271	7.2058	5.07	<.0001	Time Series Effect 18
TS19	1	19.88695	7.9158	2.51	0.0120	Time Series Effect 19
TS20	1	-1.69979	7.4277	-0.23	0.8190	Time Series Effect 20
TS21	1	-7.70636	6.8730	-1.12	0.2622	Time Series Effect 21
TS22	1	5.416717	8.3417	0.65	0.5161	Time Series Effect 22
TS23	1	14.07853	9.1322	1.54	0.1232	Time Series Effect 23
TS24	1	68.3315	10.0917	6.77	<.0001	Time Series Effect 24
TS25	1	45.106	12.1761	3.70	0.0002	Time Series Effect 25
TS26	1	-14.3566	11.4000	-1.26	0.2079	Time Series Effect 26
TS27	1	-33.2276	11.1332	-2.98	0.0028	Time Series Effect 27
TS28	1	-33.4507	10.0086	-3.34	0.0008	Time Series Effect 28
TS29	1	-15.4329	8.7895	-1.76	0.0791	Time Series Effect 29
TS30	1	37.00979	7.5921	4.87	<.0001	Time Series Effect 30
TS31	1	70.43047	6.9794	10.09	<.0001	Time Series Effect 31
TS32	1	36.82978	6.9620	5.29	<.0001	Time Series Effect 32
Intercept	1	947.8563	42.5627	22.27	<.0001	Intercept
Norm_CDD	1	1.942034	0.0310	62.66	<.0001	
Norm_HDD	1	0.234967	0.0113	20.76	<.0001	
Trt_Period	1	-17.771	3.7786	-4.70	<.0001	
TRT_CDD	1	-0.1244	0.0220	-5.64	<.0001	

About EnerNOC Utility Solutions

EnerNOC Utilities Solutions™ is a comprehensive suite of demand-side management (DSM) program implementation and consulting services, technology platforms, and applications designed to address the evolving needs of utilities and grid operators worldwide. Hundreds of utilities have leveraged our technology, our people, and our proven processes to make their energy efficiency (EE) and demand response (DR) initiatives a success. Utilities trust EnerNOC to work with them at every stage of the DSM program lifecycle – assessing market potential, designing effective programs, supporting program implementation, and measuring program results.

The EnerNOC Utility Solutions consulting team has decades of combined experience in the utility DSM industry. We provide expertise, insight and analysis to support a broad range of utility DSM activities, including: potential assessments; end-use forecasts; integrated resource planning; EE, DR, and smart grid pilot and program design and administration; load research; technology assessments and demonstrations; EE project reviews; EE and DR program evaluation; and regulatory support.

Our consulting engagements are managed and delivered by a seasoned, interdisciplinary team comprised of professional electrical, mechanical, chemical, civil, industrial, and environmental engineers as well as economists, business planners, project managers, market researchers, load research professionals, and statisticians. Utilities view EnerNOC's experts as trusted advisors, and we work together collaboratively to make any DSM initiative a success.

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