CADMUS

Smart Cycle Program 2018 Evaluation Report

April 11, 2019

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Executive Summary

In 2018, Vectren launched the Smart Cycle Program to enable control of selected residential central air conditioning (CAC) loads during summer hours of system peak demand via Nest smart thermostats. Vectren recruited participants from the 2016 Smart Thermostat Pilot and the long-running Summer Cycler Program.[1,2] Smart Thermostat Pilot participants with a Nest smart thermostat were automatically enrolled. Summer Cycler participants received complimentary removal of their load control switches and a Nest thermostat installed by a technician at no additional cost.

From June through September 2018, Vectren initiated 10 load control events. Participants received a monthly $5 bill credit (or up to a $20 bill credit annually) during the summer 2018 season. Participants had the ability to override the load control during events by adjusting thermostat settings.

Research Approach

Cadmus conducted the following research activities for its evaluation of the 2018 Smart Cycle Program:

- Process evaluation activities
  - Telephone interview with two Vectren program staff members
  - Telephone interview with one smart thermostat installation technician
  - Online surveys with 163 test group (experienced a load control event) and 88 control group (did not experience an event) customers, achieving a 90% confidence at ±10% precision
- Impact evaluation activities
  - Demand response analysis
  - Energy savings analysis
- Market effects evaluation activities
  - Logic model development
  - Key performance indicator (KPI) tracking

Evaluated Program Impacts Summary

Table 1 shows overall evaluated program savings by thermostat, total savings achieved across all thermostats assigned to the test group, and total savings that could have been achieved (achievable) if

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[1] The 2016 Smart Thermostat Pilot tested peak load reductions, energy savings, and customer acceptance of Nest and Honeywell thermostats. Customers received an installation of a Wi-Fi-enabled thermostat at no additional cost and $25 in bill credits for participating in events.

[2] The Summer Cycler Program is another Vectren program designed to reduce residential and small commercial air-conditioning and water-heating electricity loads during summer peak hours. Through this program, customers receive bill credits for allowing Vectren to cycle off selected appliances during the summer.

all thermostats currently enrolled in the program had been in the test group (excluding control customers).

Table 1. 2018 Smart Cycle Program Evaluated Electric Energy and Demand Savings

	Per Thermostat	Total Achieved Program Impact (n=801)*	Total Achievable Program Impact (n=1,611)**
Average Event kW Impact	**-1.14**	**-913**	**-1,839**
Average Event kW Hour 1	-1.21	-973	-1,955
Average Event kW Hour 2	-1.07	-858	-1,725
Average Precooling kW Impact	0.56	422	850
Average Post-Event Hour 1 kW Impact	0.37	314	631
Average Event Energy kWh Savings	**-0.88**	**-706**	**-1,421**

*Number of thermostats in the assigned test group. Number of test group customers is 760, some customers have multiple thermostat.

** Number of thermostats currently enrolled in the Smart Cycle Program (excluding control customers) as of the end of 2018.

Table 2 presents the expected impacts per thermostat per month for a MISO event.[3]

Table 2. Estimated MISO Event Impacts per Month

Month	Expected Temperature During MISO Event (2 p.m.-6 p.m.)	Expected Average Impact per Thermostat (kW)
June	89°F	-1.113
July	90°F	-1.161
August	89°F	-1.119
September	85°F	-0.984

Summary of Key Findings, Conclusions, and Recommendations

Conclusion: The Smart Cycle Program achieved savings similar to the 2016 Smart Thermostat Pilot and higher demand reduction impacts than the legacy Summer Cycler Program.

Across all 10 events during summer 2018, the program achieved an average event-hour savings of 1.1 kW, with an average of 1.1 kW for event days 1–6 and 9–10, and 1.3 kW for events 7 and 8. These savings were similar to the 2016 pilot savings of 1.0 kW. Vectren was successful in curtailing demand, achieving statistically significant savings across all events. These savings were more than twice as high as the per-unit savings typically achieved in the Summer Cycler Program. The Smart Cycle Program setback technology is more effective than the Summer Cycler Program's methodology.

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[3] The Midcontinent Independent System Operator (MISO) is a not-for-profit Regional Transmission Organization. MISO ensures reliable and least-cost delivery of electricity to 15 U.S. states (including Indiana) and Manitoba, Canada. MISO calls load control events to manage system demand across the region.

Conclusion: Email, direct mail, and text messaging, rather than phone calls, may be the most effective recruitment channels.

Vectren aims to replace 1,000 Summer Cycler switches with Nest thermostats per year over the next three years (2018–2020). Vectren nearly met its switch-out goal in 2018 and replaced 975 switches with Nest thermostats.

Vectren promoted the direct installation of Nest thermostats at no additional cost to Summer Cycler participants through email, direct mail, and outbound calls. Summer Cycler respondents most frequently heard about the Smart Cycle Program from email (41%) and direct mail (25%). Only 5% heard from outbound calls. Overall, Summer Cycler and Smart Thermostat Pilot respondents preferred to receive communication from Vectren about programs and rebates through email (83%), direct mail (23%), and text message (20%); very few preferred phone calls (3%).

- **Recommendation: Increase email and direct mail marketing efforts to recruit Summer Cycler customers into the Smart Cycle Program.** Even though customers preferred text messages, at this time Vectren is only able to use text messages for communicating service disruptions or emergencies to customers. If corporate restrictions change in the future, consider using text messages as a way to communicate with customers about program offerings.

Conclusion: From scheduling the appointment to educating the customer, the smart thermostat installation technician delivered a positive customer experience throughout.

Respondents who received a Nest thermostat in 2018 had a positive experience with the installation process and were satisfied with the technician (95%). Most respondents agreed that the installation appointment was clearly communicated (99%), the technician arrived on time (99%), scheduling the appointment was easy (98%), and the wait was not long (96%). Most respondents said the technician clearly explained how the program worked and what the Nest thermostat would do during events (86%).

Conclusion: Customers tended to notice the events more from the Nest thermostat display and event notifications from the app rather than through a temperature change.

About half (51%) of test group respondents said they noticed the events. On average, respondents noticed 7.1 events out of the 10 events called. Respondents mostly noticed the events because of a message on the Nest thermostat display (59%) and the event notification from the Nest app (44%). Only a third of respondents (37%) noticed the events because of a temperature change.

Conclusion: Despite customers saying their home's interior temperature was comfortable during events, a sizeable proportion reported overriding the events.

Overall, 72% of test group respondents said their home's interior temperature was comfortable during the events. However, more than one-third (37%) of test group respondents said they changed the thermostat settings during events (i.e., overriding the events), most often because of discomfort.

Cadmus reviewed the online program information and found no mention of a penalty for overriding events. The program granted the $5 monthly bill credit to participants even if they overrode the events.

- **Recommendation: Communicate to customers the expected level of program participation to reduce the occurrence of overriding of events.** Before the next summer event season commences, clearly communicate to customers the number of events or hours that is expected from them (personal theme) and/or would help meet community energy goals (community theme).
- **Recommendation: Consider changing the incentive structure whereby customers who override too many events do not receive the bill credit.** Other utilities that Cadmus has evaluated (Consumers Energy and Portland General Electric) stipulate in their demand response program requirements that customers must participate in a minimum number of events or event hours to receive the incentive.

Conclusion: Having their thermostats controlled did not affect customer satisfaction with Vectren; however, customers were more satisfied with the program and the bill credit when their thermostats were not controlled.

The majority of participant respondents (83%) were satisfied with Vectren. The percentage of *very satisfied* and *somewhat satisfied* did not differ between test and control group respondents.

The majority of participant respondents (79%) were satisfied with the monthly $5 bill credit. Not surprisingly, more control group respondents were *very satisfied* (58%) than test group respondents (42%). Participants in the control group never experienced an event because their thermostats were not controlled. Overall, 85% of participant respondents were satisfied with the program. Similar to the pattern observed with the bill credit, more control group respondents were *very satisfied* (60%) compared to test group respondents (48%).

Introduction

The Smart Cycle Program launched in 2018 to help Vectren manage summer peak loads by enabling it to control selected residential central air conditioner (CAC) loads during hours of system peak demand. By the start of the 2018 summer season, Vectren recruited 753 customers who participated in the 2016 Smart Thermostat Pilot and 257 customers who participated in the long-running Summer Cycler Program, for a total of 1,010 participants. Smart Thermostat Pilot participants with Nest smart thermostats were automatically enrolled. Vectren arranged for Summer Cycler participants to have their load control switches removed and replaced with Nest thermostats by a technician at no additional cost. According to the 2018 Electric DSM Operating Plan,[4] Vectren aims to replace 1,000 Summer Cycler switches with Nest thermostats per year over the next three years (2018–2020).

Vectren oversaw the program and was responsible for marketing, recruitment, program information, and calling events. Vectren contracted with a local HVAC company, A+Derr, to schedule and install Nest thermostats and educate customers on how to use the device and about load control events.

Cadmus randomly assigned participants to demand response test and control groups prior to the summer season. Vectren employed Nest to provide the turnkey demand response services of activating events on the smart thermostat devices and aggregate the load data.

From June through September 2018, Vectren called 10 two-hour events as listed in Table 3. During an event, the temperature setpoint of the test group's Nest thermostats was raised by up to three degrees above its normal level (referred to as thermostat setback). The control group did not have their CAC load controlled, and their setpoints remained unchanged during events. The test group had the ability to override the load control during events by adjusting their thermostat settings. All participants received a monthly $5 bill credit (or up to a $20 bill credit per summer season).

Table 3. 2018 Smart Cycle Program Load Control Events

Event Day	Date	Day of the Week	Time	Avg. Outside Temperature (°F) During Event
1	July 5, 2018	Thursday	2:00 p.m. - 4:00 p.m.	94
2	July 13, 2018	Friday	2:00 p.m. - 4:00 p.m.	91
3	August 3, 2018	Friday	2:00 p.m. - 4:00 p.m.	87
4	August 6, 2018	Monday	2:00 p.m. - 4:00 p.m.	89
5	August 9, 2018	Thursday	2:00 p.m. - 4:00 p.m.	82
6	August 13, 2018	Monday	2:00 p.m. - 4:00 p.m.	89
7	August 27 2018	Monday	4:00 p.m. - 6:00 p.m.	89
8	August 28, 2018	Tuesday	4:00 p.m. - 6:00 p.m.	91
9	September 4, 2018	Tuesday	2:00 p.m. - 4:00 p.m.	92
10	September 5, 2018	Wednesday	2:00 p.m. - 4:00 p.m.	90

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[4] Southern Indiana Gas & Electric Company. *Vectren South 2018 Electric DSM Operation Plan.* November 20, 2017.

Methodology

This section describes Cadmus' process, impact, and market effects evaluation methodology for the 2018 Smart Cycle Program.

Process Evaluation

Cadmus conducted these process evaluation activities:

- Telephone interview with two Vectren program staff members
- Telephone interview with one smart thermostat installation technician
- Online surveys with 163 test group and 88 control group customers

Stakeholder Interviews

To gain a thorough understanding of the program design and implementation, Cadmus conducted a telephone interview with two Vectren program staff members who gave their perspectives on program performance, successes, challenges, and plans for the future.

Cadmus also conducted a telephone interview with the smart thermostat installation technician to gain a better understanding of the scheduling and installation process, practices, and challenges.

Customer Surveys

Cadmus conducted online surveys with participants in the test and control groups to collect data about the following:

- Event awareness and participation
- Comfort during events and reasons for overriding events
- Installation process and education
- Smart thermostat connectivity and use
- Satisfaction with the smart thermostat, bill credit, overall program, and Vectren

Because participants in the control group did not have their thermostats controlled by Vectren during events, they were not asked the questions about event awareness and participation and comfort during events.

From the population of 956 participants with valid email addresses, the surveys obtained 251 responses (163 from the test group and 88 from the control group), a 26% response rate. Cadmus analyzed the responses and generated frequency outputs, coded open-end responses, and ran statistical tests to determine whether responses differed significantly between the groups.

Impact Evaluation

This section describes the impact evaluation methodology, including the study's research design, data collection, data preparation, and model specification and estimation. The appendices provide further details about the modeling process.

Research Design

During the summer cycling season (June to September 2018), load control events curtailed the energy demand of CACs in the test group (the control group did not experience any curtailments). To establish a baseline for the test group, Cadmus used the energy demand of control group CACs, which was valid because participants (customers) had been randomly assigned to test and control groups using the previous summer's consumption, to create balanced groups, and estimated the demand savings during load control events as the difference between test and control group demand.

Table 4 shows the number of participants assigned to the test and control groups from the 1,010 participants enrolled in the Smart Cycle Program at the beginning of the summer. Cadmus assigned approximately 75% (760 participants) to the test group and the remaining 25% (250 participants) to the control group.

Table 4. Analysis Sample Size— Participants in Test and Control Groups

Test	Control	Total
760	250	1,010

Data Collection and Preparation

Cadmus collected data from Vectren, Nest, and the National Oceanic and Atmospheric Administration (NOAA). Table 5 lists the type of data, the time period covered, and the source. A further description of the data collection can be found in the Appendix A. Demand Savings Estimation Detailed Methodology.

Table 5. 2018 Smart Cycle Data Collection

Data	Population	Period	Source
Customer Information System Data	Vectren Smart Cycle customers	From beginning of enrollment to end of summer 2018	Vectren
Event Dates and Hours	Vectren Smart Cycle customers	Summer 2018	Vectren
CAC Runtime and Other System Data	All CAC units of participants enrolled in the Smart Cycle Program	June 2018– September 2018	Nest
CAC System Nameplate Data	Vectren former Smart Thermostat Pilot customers	Time of thermostat installation	Schneider Electric and WES
	Vectren former Summer Cycler Program Customers	Time of thermostat installation	A+Derr
Weather	Evansville Regional Airport weather station	June 2018–September 2018	NOAA (retrieved by Cadmus)
AC Logger Data	Sample of program CACs	June 2018–September 2018	-A+Derr

Data Preparation

Cadmus verified that Vectren's customer database, CAC nameplate data, and Nest's runtime data were complete and that no significant data were missing. For each participant, Cadmus aggregated compressor and fan runtime data to hourly intervals and merged them with the hourly temperature and humidity data. Cadmus then merged nameplate data and the test or control group assignment onto the runtime data to form a panel dataset. A further description of the data preparation and data attrition can be found in Appendix A. Demand Savings Estimation Detailed Methodology.

Conversion of Runtime to kW

To estimate the load impacts, Cadmus used an engineering formula to convert runtime minutes per hour to kWh per hour for each CAC.[5] For full details of this calculation, refer to Appendix A. Demand Savings Estimation Detailed Methodology

Cadmus planned to verify the accuracy of the conversion using logger data, however, of the 30 loggers installed, only 11 were available in time for Cadmus' analysis. This sample size proved too small to be of use in Cadmus' planned calibration. In the future, Vectren will have access to automated metering infrastructure (AMI) data which, if used, would make the logger comparison unnecessary. Refer to Appendix A. Demand Savings Estimation Detailed Methodology for further detail of Cadmus' logger analysis and runtime-to-kW calibration.

Energy and Demand Savings Estimation Approach

Cadmus used panel regression to estimate average energy and demand impact per thermostat for the hours before, during, and after each event. Regression analysis is a means of modeling savings by comparing the consumption of test and control customers while controlling for exogenous factors such as weather. Refer to Appendix A. Demand Savings Estimation Detailed Methodology for further detail of Cadmus' specific regression analysis variables.

Market Effects Evaluation

To assess market effects, Cadmus asked Vectren staff, the installation technician, and customers questions about market transformation and current market practices. Their responses informed the development of program logic models and key performance indicators (KPIs) to track program performance over time. The main objectives of creating logic models are to develop an understanding of a program and define its underlying theory and assumptions. The logic model includes market actors, market barriers uncovered by the evaluation, current intervention strategies and activities, and the expected outcomes if current program intervention strategies are implemented.

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[5] Cutler, D., et al. *Improved Modeling of Residential Air Conditioners and Heat Pumps for Energy Calculations.* NREL Technical Report, NREL/TP-5500-56354. January 2013. http://www.nrel.gov/docs/fy13osti/56354.pdf

Process Evaluation Findings

The process evaluation of the Smart Cycle Program drew on the Vectren staff interview, the installation technician interview, and customer survey responses.

Program Implementation and Delivery

Program Context and Initiation

According to an interview with program staff, Vectren decided to launch the Smart Cycle Program after reviewing Cadmus' evaluation of the 2016 Vectren Smart Thermostat Pilot. The evaluation found that Nest thermostats produced larger demand reductions (1 kW per thermostat) compared to Honeywell thermostats (0.3 kW per thermostat) and the legacy Summer Cycler Program (0.5 kW per CAC in 2017). Vectren also noted that the switches used in the Summer Cycler Program lacked the two-way communication of smart thermostats, which made it difficult to verify if the switches were actually working during events. Based on these findings, Vectren rolled out the Smart Cycle Program, which relies on Nest thermostats to call load control events and began transferring participants over from the Smart Thermostat Pilot and Summer Cycler Program.

Marketing, Recruitment, and Enrollment

Participants from the 2016 Smart Thermostat Pilot already had a Nest thermostat, so they were automatically enrolled in the Smart Cycle Program. Vectren aims to replace 1,000 Summer Cycler switches with Nest thermostats per year over the next three years (2018–2020). Vectren nearly met this goal in 2018, replacing 975 switches with Nest thermostats.[6]

In March 2018, Vectren began promoting the direct installation of Nest thermostats at no additional cost to participants in the legacy Summer Cycler Program through email, direct mail (i.e., bill inserts), and outbound calls. Results from the customer surveys showed that respondents who had a Nest thermostat installed in 2018 most frequently heard about the Smart Cycle Program through email (41%, n=75). Twenty-five percent heard about the program through direct mail and only 5% through outbound calls.

All survey respondents (from both the Smart Thermostat Pilot and the Summer Cycler Program) were asked how they preferred to receive communication from Vectren about future programs and rebates. Of the 242 who responded, 83% said email, 23% said direct mail, and 20% said text message. Only 3% said they preferred phone calls.

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[6] This is the value reported in the DSM Scorecard. This value encompasses the full 2018 program year, not only those switches replaced with Nest thermostats prior to the start of the summer peak period.

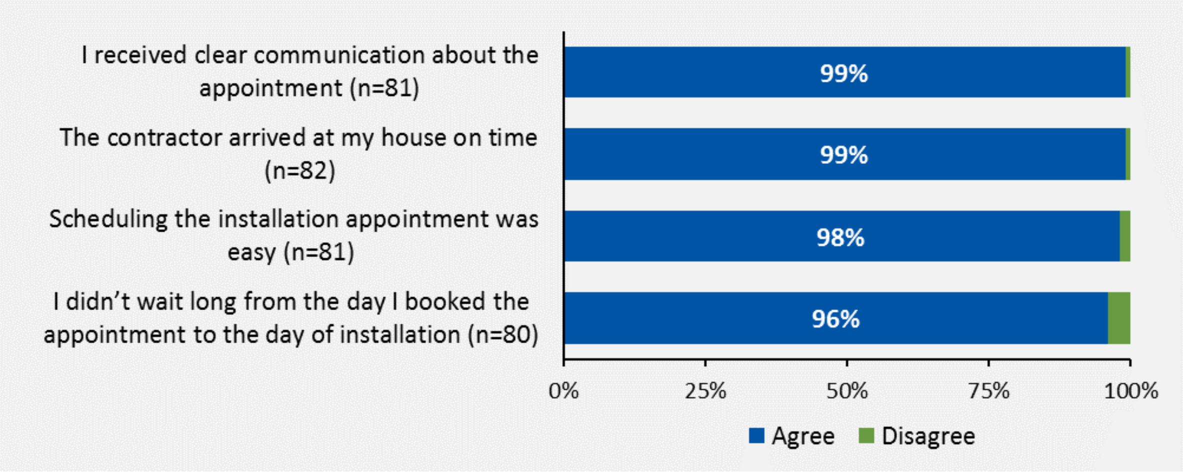
Installation Process

Vectren contracted with a local HVAC company, A+Derr, to schedule and perform the removal of the Summer Cycler load control switches and their replacement with Nest thermostats. Interested customers contacted A+Derr by phone or email to schedule an installation. While at the home, the technician completed a survey, which documented the customer's installation process and enrollment. According to A+Derr, customers typically scheduled the appointment two weeks out from the day they contacted A+Derr. The technician reported occasionally encountering two main challenges during the installation. One challenge was that a small number of homes did not have the necessary wires for the Nest thermostat, but the technician worked with Nest to resolve this issue. A second challenge was that a small number of homes did not have Wi-Fi, so the technician was unable to install the thermostat. Overall, the technician said the scheduling and installation process were easy.

While on site, the technician tested that the Nest thermostats worked properly by cycling through at least three load control test events and also made sure that the thermostat was calibrated to the customer's temperature preferences. Overall, the technician was very satisfied to work with Vectren on the Smart Cycle Program.

Cadmus asked respondents who received a Nest thermostat in 2018 about their experience with the installation process. Nearly all respondents (95%) said they were satisfied with the technician who installed their Nest thermostat (n=83). As shown in Figure 1, nearly all agreed that the installation appointment was clearly communicated (99%), the technician arrived on time (99%), scheduling the appointment with the technician was easy (98%), and the wait was not long (96%).

Figure 1. Agreement with Statements about the Installation



Customer Education

During the installation process, the technician educated customers on how to use the Nest thermostat and about load control events. The technician left behind printed information developed by Vectren, which explained how the Smart Cycle Program works, described what the Nest thermostat would do during load control events, and listed the call center phone number. Of 82 survey respondents, 70% said they received this leave-behind print material.

According to the technician, customers frequently asked if they could adjust the thermostat manually or if they always had to use the app to change the settings. The technician also reported that customers had concerns about Vectren taking complete control of their thermostat settings and about the data being shared by the Nest thermostat. The technician said most customers were familiar with load control events because they had previously participated in the Summer Cycler Program; most questions about the load control events were about how long events lasted and how often they would occur. Overall, the technician believed he had adequate information about the Nest thermostat and the Smart Cycle Program to answer customers' questions.

In the surveys, Cadmus asked direct install participants to rate how clearly the technician explained how the Smart Cycle Program worked and what the Nest thermostat would do during events. Most respondents said the technician's explanation was clear (86%, n=82). Six percent said the technician did not provide an explanation.

Cadmus also asked direct install participants to rate the clarity of the information about Vectren's program contained in the leave-behind material. Of 83 respondents, 95% said Vectren's program information was clear.

For the Smart Cycle Program participants who were transferred over from the Smart Thermostat Pilot, Vectren sent program information via email and direct mail, reminding them about the upcoming summer event season. Cadmus also asked these participants to rate the clarity of Vectren's program information. Of 156 respondents, 91% said Vectren's program information was clear.

Event Management

During the 2018 summer season (June to September), Vectren called 10 events. An hour prior to the start of the event, Nest sent an event notification to test group participants via the Nest smartphone app. About one hour before the event, Nest precooled (i.e., lowered) the home's interior temperature to reduce thermal discomfort and maximize the event load reduction. The length and magnitude of precooling were determined by Nest's software algorithm for each thermostat and varied depending on the home's thermal envelope and the customer's comfort preferences. During the event, Nest raised the thermostat setpoint by up to three degrees above its normal level.

Each event lasted two hours and occurred in the early afternoon (2 p.m. to 4 p.m.) or late afternoon (4 p.m. to 6 p.m.). Vectren reported receiving more customer complaints about late afternoon events than about early afternoon events, although, overall, complaints were not a significant issue.

Event Awareness and Participation

Cadmus asked test group participants (those who experienced load control events) if they noticed the events during the summer. Fifty-one percent of respondents said they noticed the events (n=156). These 79 respondents said they noticed, on average, 7.1 events.

Respondents (n=128) mostly noticed the events because of a message on the Nest thermostat display (59%), the event notification from the Nest app (44%), or a temperature change (37%).

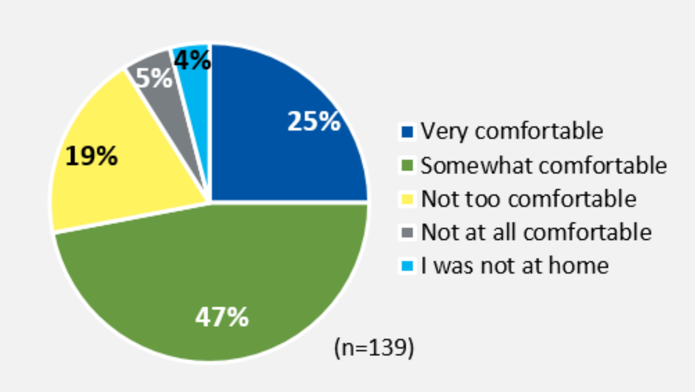
Overall, 94% of test group respondents said participating in the events was easy (n=154). Of the nine respondents who found it difficult to participate in the events, their top difficulties were these:[7]

- High temperatures and/or humidity (4 respondents)
- Having guests or visitors around (3 respondents)
- Poor air quality (2 respondents)
- Back-to-back or multiple events in a week (2 respondents)
- Health or medical reasons (2 respondents)

Comfort During Events

Overall, 72% of test group respondents said their home's interior temperature was comfortable during the events. As shown in Figure 2, 25% said the temperature was very comfortable and 47% said somewhat comfortable.

Figure 2. Comfort Level During Events



Cadmus reviewed the online program information and found that there was no penalty mentioned for overriding events. The program granted the $5 monthly bill credit to participants even if they overrode the events. The survey asked test group respondents if they changed the thermostat settings during any of the events (i.e., overrode the events). Thirty-seven percent said they changed the thermostat settings (Figure 3). Of these respondents, thermal discomfort was the reason cited most often (85%, n=46).

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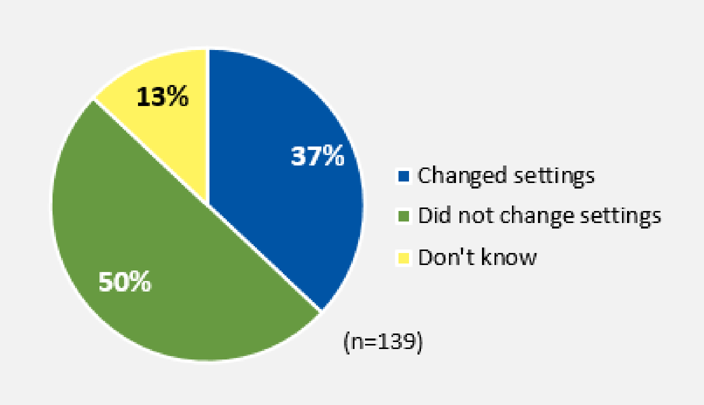
[7] Multiple responses allowed.

Figure 3. Changed Thermostat Settings During Events



Smart Thermostat Connectivity and Use

The survey asked test and control group respondents if their Nest thermostat was always connected online. Ninety-seven percent said their thermostat was always connected (n=233).

Eighty-nine percent of test and control group respondents said they used the Nest app to monitor and control their home's indoor temperature (n=237).

One of the main features of the Nest thermostat is its ability to learn from its user's preferences to automatically program and adjust the thermostat settings. In the first one to two months after the Nest thermostat was installed, 66% of test and control group respondents said they *frequently* or *sometimes* touched the device to adjust the settings (n=80). Now, after several months have passed, this percentage has dropped to only 44% (n=83). This significant decrease indicates that the Nest thermostat is helping to automate the indoor conditions of the home.[8]

Satisfaction

Cadmus asked test and control group respondents to rate their satisfaction with the smart thermostat, the bill credit, the program, and Vectren.

Satisfaction with Smart Thermostat

As shown in Figure 4, 97% of all survey respondents (test and control group combined) were satisfied with their Nest thermostat. There was no statistically significant difference between test and control group respondents' satisfaction.

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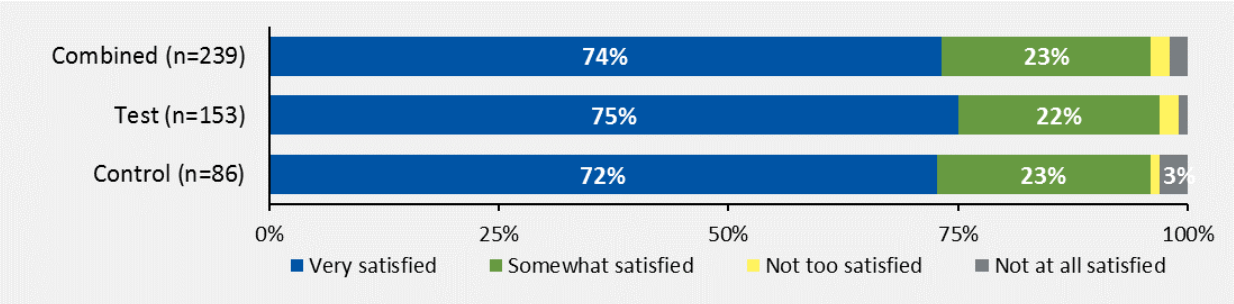
[8] Difference is statistically significant at the 90% level, (p≤.10).

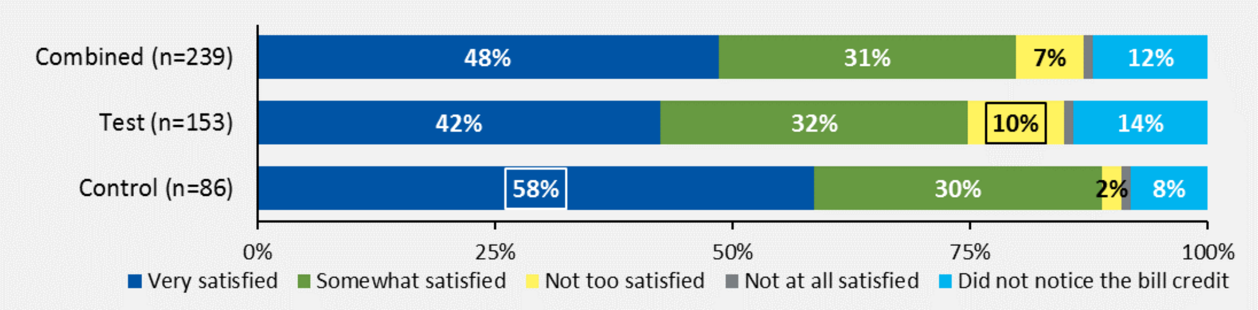
Figure 4. Satisfaction with Smart Thermostat



Satisfaction with Bill Credit

Figure 5 shows 79% of all survey respondents (test and control group combined) were satisfied with the monthly $5 bill credit. A small percentage of respondents (12%) did not notice the bill credit. Test and control group respondents differed in their satisfaction with the bill credit. A significantly larger percentage of control group respondents said they were *very satisfied* (58%) with the bill credit compared to test group respondents (42%). A significantly larger percentage of test group respondents said they were *not too satisfied* (10%) compared to control group respondents (2%). The higher satisfaction with the control group is not surprising because their thermostats were not controlled during events.

Figure 5. Satisfaction with Monthly Bill Credit

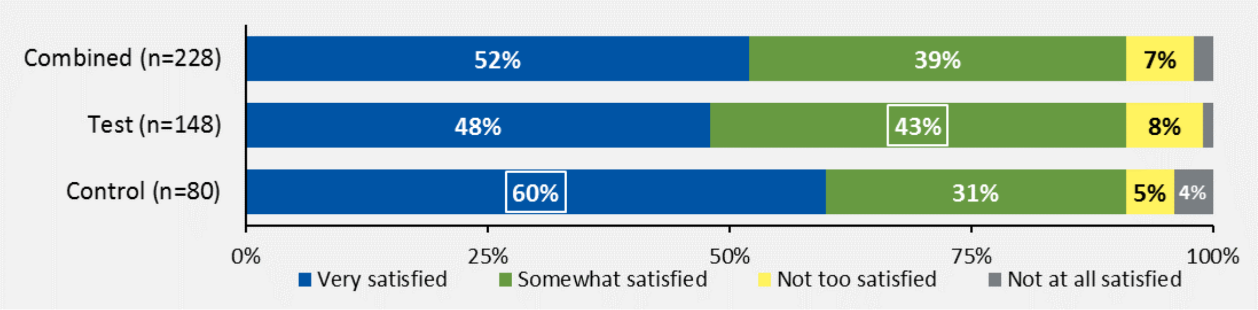


The boxed percentages indicate that the difference between test and control group is statistically significant at the 95% level, (p≤.05).

Satisfaction with Program

As shown in Figure 6, 85% of all survey respondents (test and control group combined) were satisfied with the program. Test and control group respondents differed in their program satisfaction. A significantly greater percentage of control group respondents were *very satisfied* (60%) than were test group respondents (48%). A significantly greater percentage of test group respondents were *somewhat satisfied* (43%) than were control group respondents (31%).

Figure 6. Satisfaction with Smart Cycle Program



The boxed percentages indicate that the difference between test and control group is statistically significant at the 90% level, (p≤.10).

Cadmus asked respondents who were less than satisfied with the program why they gave that rating. These were the test group respondents' top reasons for dissatisfaction:

- Low incentive amount (5 respondents)
- Problems using the thermostat (4 respondents)
- Feeling thermal discomfort (3 respondents)
- Lack of transparency regarding how the thermostat was changed (2 respondents)

Control group respondents were dissatisfied for similar reasons. Their top reasons were these:

- Problems using the thermostat (3 respondents)
- Feeling thermal discomfort (2 respondents)
- Lack of transparency regarding how the thermostat was changed (2 respondents)

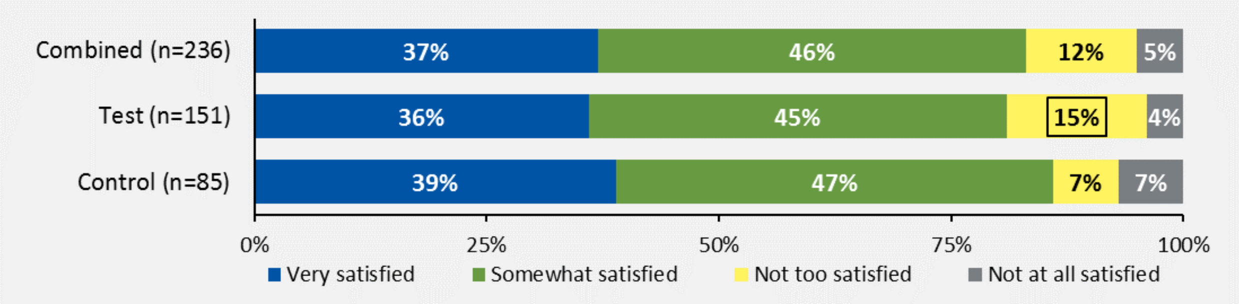
When asked how Vectren could improve the Smart Cycle Program, 36 respondents gave suggestions. The most frequently mentioned were to increase the incentive amount (53%), change the frequency or duration of events (19%), and provide clearer program information (11%). Specifically, respondents said they wanted clearer information on how the Nest thermostat worked and what energy-related benefits were derived from their participation.

Overall, 92% said they were likely to recommend the Smart Cycle Program to a friend or neighbor (n=236). Specifically, 58% said they were *very likely* to recommend the program and 34% said they were *somewhat likely*.

Satisfaction with Vectren

As shown in Figure 7, 83% of all survey respondents (test and control group combined) were satisfied with Vectren (n=236). A significantly greater percentage of test group respondents were *not too satisfied* with Vectren (15%) than were control group respondents (7%).

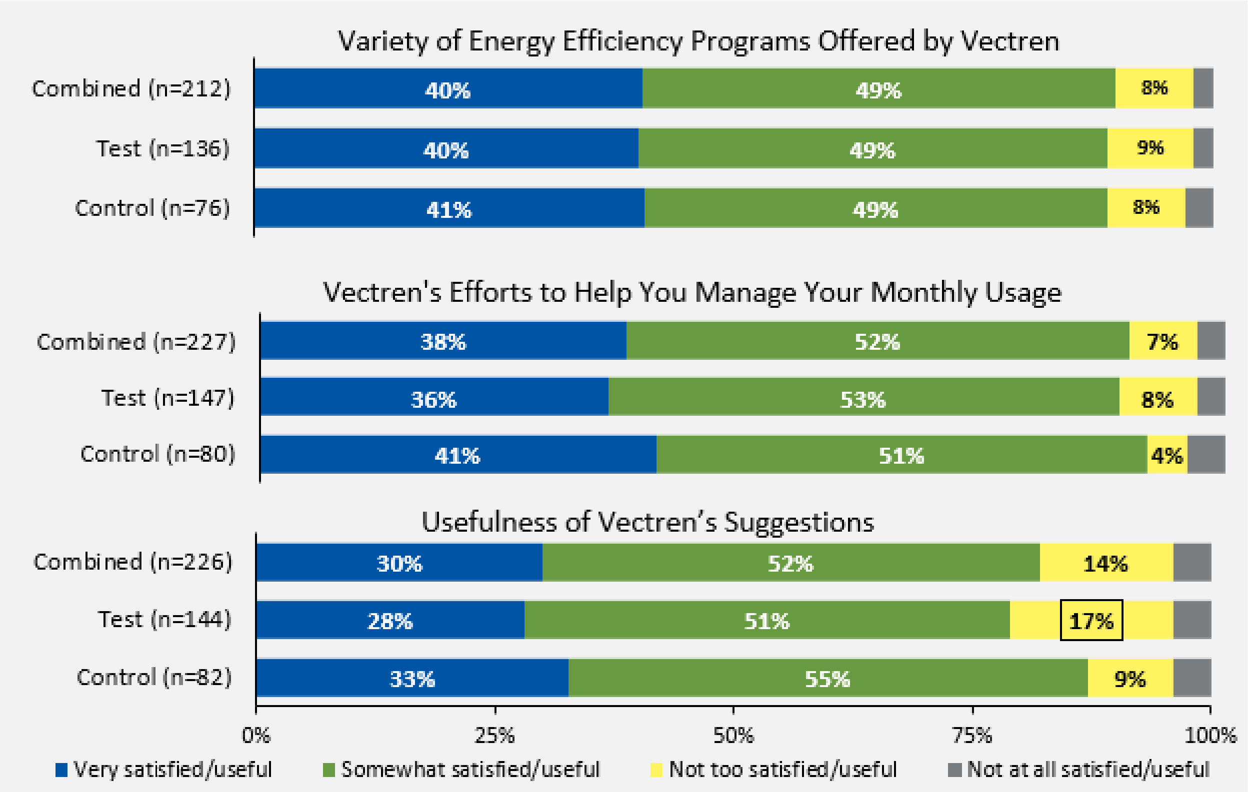
Figure 7. Satisfaction with Vectren



The boxed percentage indicates that the difference between test and control group is statistically significant at the 90% level, (p≤.10).

Finally, the survey asked respondents to rate Vectren based on the variety of energy efficiency programs it offers, its efforts to help manage monthly usage, and the usefulness of its suggestions to reduce energy usage—collectively known as the J.D. Power categories. Figure 8 shows the ratings for the three categories. The majority of respondents (test and control group combined) gave ratings of *very satisfied/useful* and *somewhat satisfied/useful* across all three categories (82% to 90%). More of these respondents gave *somewhat* ratings than gave *very* ratings.

Figure 8. J.D. Power Categories



The boxed percentage indicates that the difference between test and control group is statistically significant at the 90% level, (p≤.10).

Impact Evaluation Findings

The Smart Cycle impact evaluation was primarily based on panel regression. From June through September 2018, Vectren called 10 load control events, as listed in Table 6.

Table 6. 2018 Smart Cycle Program Load Control Events

Event Day	Date	Day of the Week	Time	Average Outside Temperature (°F) During Event
1	July 5, 2018	Thursday	2:00 p.m. - 4:00 p.m.	94
2	July 13, 2018	Friday	2:00 p.m. - 4:00 p.m.	91
3	August 3, 2018	Friday	2:00 p.m. - 4:00 p.m.	87
4	August 6, 2018	Monday	2:00 p.m. - 4:00 p.m.	89
5	August 9, 2018	Thursday	2:00 p.m. - 4:00 p.m.	82
6	August 13, 2018	Monday	2:00 p.m. - 4:00 p.m.	89
7	August 27 2018	Monday	4:00 p.m. - 6:00 p.m.	89
8	August 28, 2018	Tuesday	4:00 p.m. - 6:00 p.m.	91
9	September 4, 2018	Tuesday	2:00 p.m. - 4:00 p.m.	92
10	September 5, 2018	Wednesday	2:00 p.m. - 4:00 p.m.	90

Demand Savings

Demand impacts differed by event based on the time of day Vectren called the load control event.

2 p.m. to 4 p.m. Event Period

Table 7 presents estimates of the average kW impact per thermostat of the 2 p.m. to 4 p.m. events (event days 1–6 and 9–10) as well as for the hour before each event and the first six hours after events. Appendix B. Thermostat kW Impacts for Each Event Hour includes tables reporting average demand impacts for each individual hour of each event called during the 2 p.m. to 4 p.m. time period (event days 1–6 and 9–10 reported separately). The table also presents the percentage demand savings (estimated change in demand relative to the average demand of control units) and achievable program impact (if all enrolled customers were curtailed).

Table 7. Estimates of Average Smart Cycle Impacts: Events 1-6 and 9-10 (2-4 P.M.)

Hour Beginning	Average Impact per Thermostat (kW)	90% Confidence Intervals		Percentage Savings	Achievable Demand Reduction (kW)**
		Lower Bound	Upper Bound		
Thermostats (n=1,052 units, 8 events)					
Pre-Event Hour (1 p.m.)*	0.545	0.492	0.599	-45.6%	-878.80
Event Hour 1 (2 p.m.)*	-1.154	-1.213	-1.095	83.1%	1,859.27
Event Hour 2 (3 p.m.)*	-1.068	-1.125	-1.010	65.9%	1,720.41
Post-Event Hour 1 (4 p.m.)*	0.381	0.330	0.432	-22.0%	-613.95
Post-Event Hour 2 (5 p.m.)*	0.207	0.162	0.252	-11.7%	-332.90
Post-Event Hour 3 (6 p.m.)*	0.130	0.087	0.174	-7.8%	-209.72
Post-Event Hour 4 (7 p.m.)*	0.093	0.048	0.137	-6.1%	-149.15
Post-Event Hour 5 (8 p.m.)*	0.078	0.037	0.118	-5.4%	-125.18
Post-Event Hour 6 (9 p.m.)	0.031	-0.006	0.067	-2.3%	-49.42

*This estimate is statistically significant at the 10% level.

**1,611 thermostat devices. This represents the total number of thermostats enrolled in the Smart Cycle Program in 2018. This number was obtained by counting the total number of Nest IDs associated with each customer. If Vectren did not provide a Nest ID for a customer, Cadmus assumed one thermostat for that customer.

The average demand reduction per thermostat was 1.2 kW in the first event hour and 1.1 kW in the second event hour—an average savings of 1.1 kW per thermostat across the two event hours. The estimated average demand savings in each event hour was statistically different from zero at the 90% confidence level. The precooling impact was a 0.5 kW increase per thermostat; this result was statistically significant at the 90% confidence level. Rebound of air conditioning loads for these events was modest. Estimated rebound impacts decreased with each hour after the event and were no longer statistically significant at 90% confidence by the final hour (six hours post-event).

Figure 9 illustrates the average impacts per thermostat during 2 p.m. to 4 p.m. events, average metered kW (for test group customers), average model predicted kW, average baseline kW, and average estimated kW impacts. Cadmus defined each of these elements as follows:

- **Metered kW** represents energy demand per unit, converted from the runtime recorded by the thermostats.
- **Predicted kW** represents metered kW per unit, as predicted by the regression models.
- **Baseline kW** represents what the regression model predicted average energy demand would have been during the two event hours and six hours after each event had the event not been called. Baseline and predicted energy demand are equal except during the three event hours and six hours after each event.
- **Estimated kW impact** represents the differences in impacts between predicted kW and baseline kW.

Figure 9 shows the precooling effect and the rebound of energy demand following the events. Metered kW and predicted kW were greater than baseline kW between 4 p.m. and 9 p.m. Rebound subsided six hours after the events ended.

Figure 9. Estimates of Thermostat kW Impacts: Events 1–6 and 9–10 (2 p.m. to 4 p.m.)

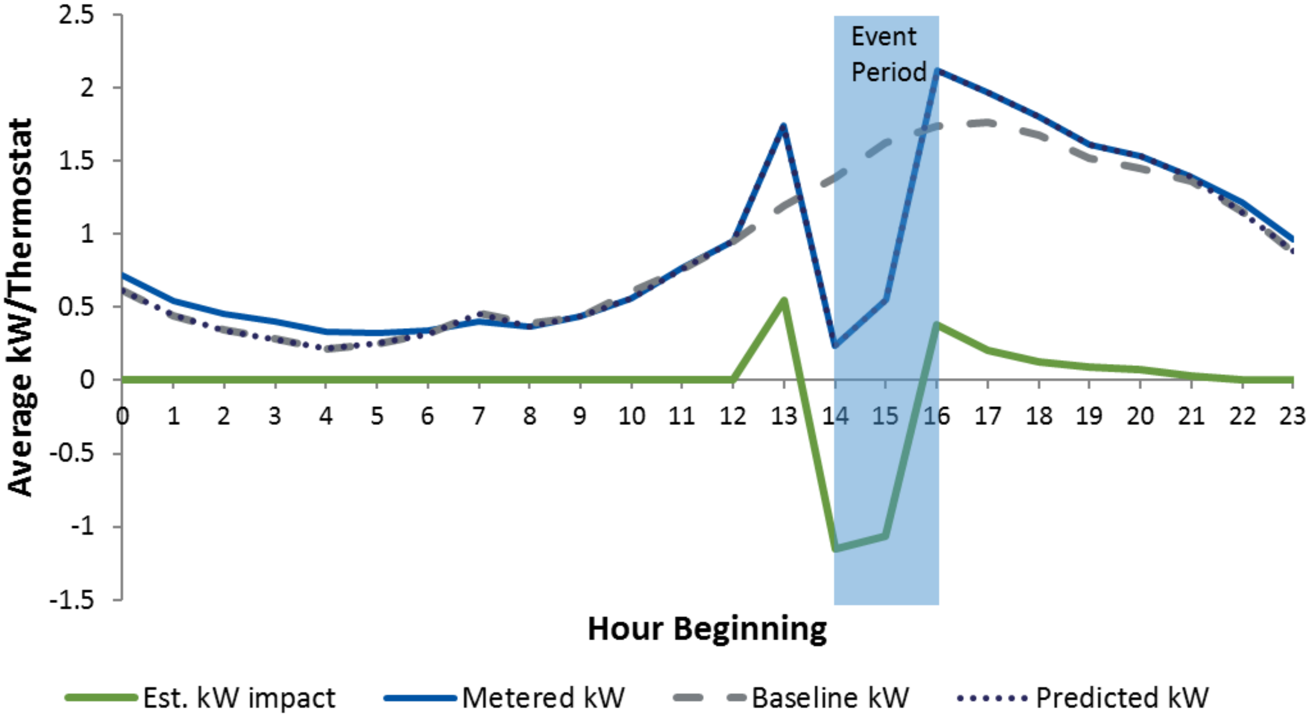


Table 8 presents the setpoint and interior temperature impacts for events 1–6 and 9–10. During non-event days the test and control customers had nearly identical indoor temperature and cooling setpoints. Cadmus compared the test customer's average cooling points and interior temperatures during the event hours to the control customers. Results showed a 1.8-degree increase in the cooling setpoint and 0.5-degree increase in interior temperatures for test group participants

Table 8. Temperature Impacts: Events 1-6 and 9-10 (2-4 PM)

	Test (Degrees)	Control (Degrees)	Event Impact (Degrees)
Average Cooling Setpoint	78.7	76.9	1.8
Average Interior Temperature	77.1	76.6	0.5

4 p.m. to 6 p.m. Event Period

Table 9 presents estimates of the average kW impact per thermostat for the 4 p.m. to 6 p.m. events (event days 7 and 8) as well as for the hour before each event and each of the first six hours after events. Appendix B. Thermostat kW Impacts for Each Event Hour includes tables reporting average demand impacts for each hour of events 7 and 8 separately.

Table 9. Estimates of Average Thermostat Impacts: Events 7 and 8 (4 p.m. to 6 p.m.)

Hour Beginning	Average Impact per Thermostat (kW)**	90% Confidence Intervals		Percentage Savings	Achievable Demand Reduction (kW)**
		Lower Bound	Upper Bound		
Thermostats (n=1,052 units, 2 events)					
Pre-Event Hour 1 (3 p.m.)*	0.456	0.354	0.558	-24.8%	-734.57
Event Hour 1 (4 p.m.)*	-1.436	-1.533	-1.339	72.3%	2,313.73
Event Hour 2 (5 p.m.)*	-1.093	-1.178	-1.008	53.2%	1,761.01
Post-Event Hour 1 (6 p.m.)*	0.397	0.316	0.477	-20.1%	-638.95
Post-Event Hour 2 (7 p.m.)*	0.255	0.173	0.337	-14.5%	-411.13
Post-Event Hour 3 (8 p.m.)*	0.108	0.028	0.188	-6.4%	-174.30
Post-Event Hour 4 (9 p.m.)*	0.146	0.075	0.216	-9.8%	-234.43
Post-Event Hour 5 (10 p.m.)*	0.075	0.003	0.147	-5.8%	-121.26
Post-Event Hour 6 (11 p.m.)*	0.091	0.027	0.154	-8.8%	-145.80

*This estimate is statistically significant at the 10% level

**1,611 thermostats , representing the total number of thermostats enrolled in the Smart Cycle Program in 2018. This number was obtained by counting the total number of Nest IDs associated with each customer. If Vectren did not provide a Nest ID for a customer, Cadmus assumed one thermostat for that customer.

During 4 p.m. to 6 p.m. events, the average demand reduction per thermostat was 1.4 kW in the first event hour and 1.1 kW in the second event hour. Overall, savings averaged 1.3 kW per thermostat across the two event hours. The estimated average demand savings in each event hour was statistically different from zero at the 90% confidence level. The precooling impact was 0.5 kW increase per thermostat and was statistically significant at the 90% confidence level. All of the post-event hour impact estimates were significant at the 90% confidence level, though like events 1–6 and 9–10, were relatively small after the first two post-event hours. These events had an average event temperature of 90 degrees, while the other eight events (from 2 p.m. to 4 p.m.) had an average event temperature of 89 degrees, which could account for the difference in kW reduction.

Figure 10 shows the precooling effect and the rebound of energy demand following the events. Metered kW and predicted kW were greater than baseline kW between 6 p.m. to 11 p.m. Rebound subsided about six hours after the events ended.

Figure 10. Estimates of Thermostat kW Impacts: Events 7 and 8 (4 p.m. to 6 p.m.)

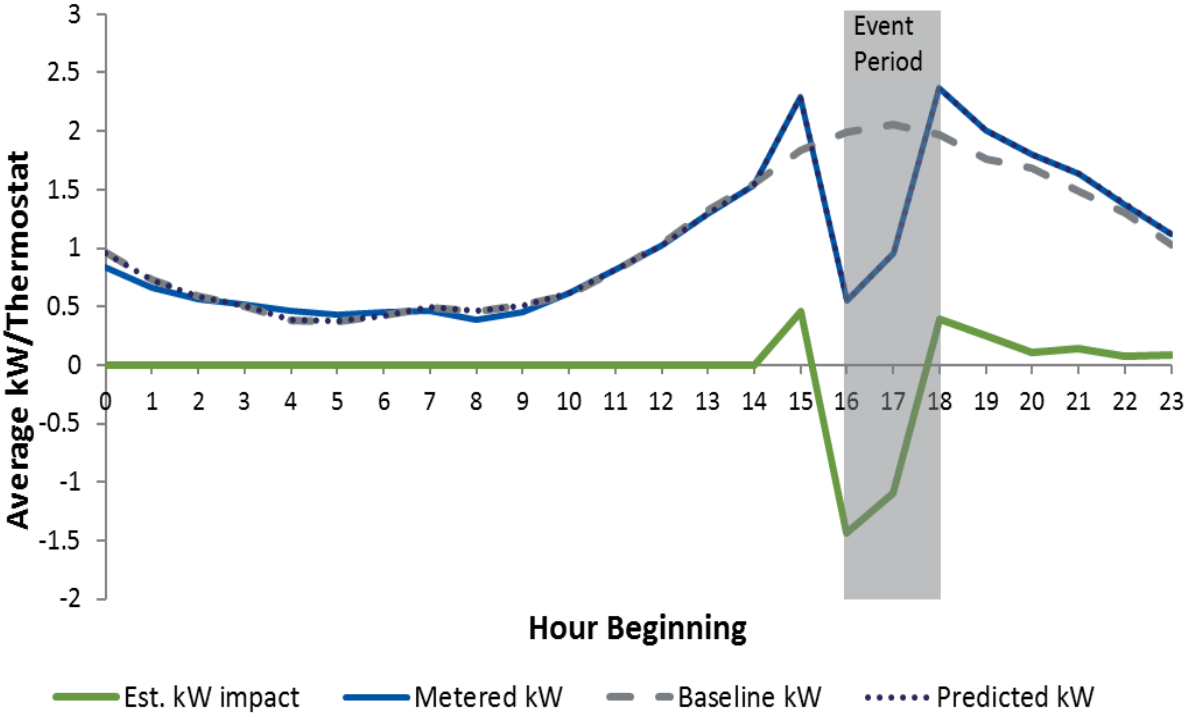


Table 10 presents the setpoint and interior temperature impacts for events 7 and 8. During non-event days the test and control customers had nearly identical indoor temperature and cooling setpoints. Cadmus compared the test customers' average cooling points and interior temperatures during the event hours to the control customers'. Cadmus saw a 1.8-degree increase in the cooling setpoint and 0.9-degree increase in interior temperatures for test group customers who experience the curtailment.

Table 10. Temperature Impacts: Events 7 and 8 (4 p.m. to 6 p.m.)

	Test (Degrees)	Control (Degrees)	Event Impact (Degrees)
Average Cooling Setpoint	77.8	76.0	1.8
Average Interior Temperature	77.6	76.7	0.9

Average Demand Savings During System Peak Hours

Vectren timed the load control events to test the Smart Cycle Program under conditions when loads would normally peak. Outside temperature during 2018 event hours averaged between 87 degrees Fahrenheit (^{o}F) and 94^{o}F.

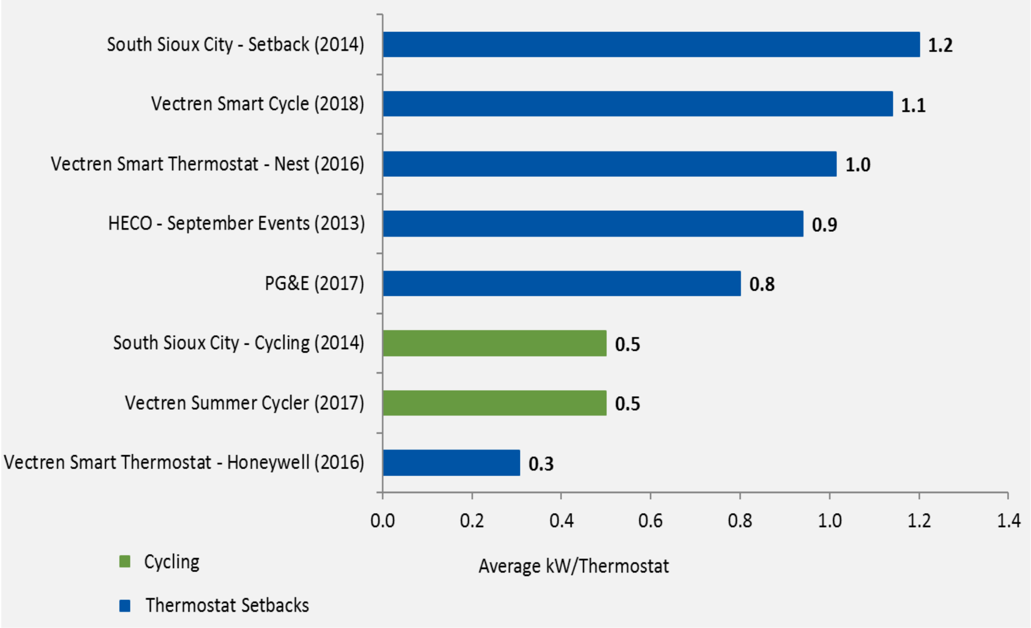
The average 2018 Smart Cycle Program demand reduction was 1.1 kW. The 2018 savings were just higher than those achieved in the 2016 Smart Thermostat Pilot by Nest thermostats (by 0.1 kW), possibly due to higher event-hour temperatures in 2018. The 2018 evaluation had an average event-hour temperature of 90^{o}F, while the 2016 average event-hour temperature was 88^{o}F. Table 11 shows historical program performance for Vectren's three load control programs: Smart Cycle (2018), Summer Cycler (2012-2017), and the Smart Thermostat Pilot (2016).

Table 11. Vectren Historical Load Control Program Performance

Vectren Program Name	Program Year	Average kW/Thermostat
Smart Cycle	2018	1.1
Summer Cycler	2017	0.5
Smart Thermostat Pilot- Nest	2016	1.0
Smart Thermostat Pilot- Honeywell	2016	0.3
Summer Cycler	2015	0.2
Summer Cycler	2014	0.2
Summer Cycler	2013	0.3
Summer Cycler	2012	0.5

As shown in Figure 11, Cadmus compared the 2018 Smart Cycle Program demand savings per thermostat to those achieved by other residential air-conditioning direct load control (DLC) programs, including Vectren's 2017 Summer Cycler Program and the 2016 Smart Thermostat Pilot. Other utilities' DLC programs achieved a range of demand savings. The Smart Cycle Program achieved higher savings than the comparison programs. However, caution should be exercised when comparing demand savings of different utility programs, as savings depend on many factors, including outdoor temperature, event initiation time and duration, load control technologies, cycling strategies (which are identified in the Figure 11), customer peak demand, and appliance efficiencies, that varied among utilities.

Figure 11. Comparison Residential Air Conditioning DLC Evaluated Demand Savings



Note: Years indicate program year.

Sources: Public evaluation studies for National Grid (2016-2017), Consumers Energy (2017), Public Service Company of New Mexico (2017), Pacific Gas & Electric (2017), and Vectren (2016-2018)

Total Program Demand Savings

Cadmus estimated the total achievable kW impacts , across all 10 events. To estimate total program demand impacts, Cadmus multiplied the average kW impact per thermostat (across all 10 events) by the total number of thermostats enrolled as test group customers in the Smart Cycle Program at the beginning of the season (n=801).

During event hours, the program produced total achievable demand savings from air conditioning load control of approximately 858 kW to 973 kW, as shown in Table 12. Precooling resulted in load increase of approximately 422 kW. Electricity demand also rebounded in the first hour after the event ended, resulting in an increased load of approximately 314 kW.

Table 12. Estimates of Smart Cycle Program Total kW Impacts

Hour	Achieved Impact (kW)	90% Confidence Intervals	
		Lower Bound	Upper Bound
Thermostats (n=801)**			
Pre-event hour 1*	422.44	381.85	463.02
Event hour 2*	-972.53	-1,017.86	-927.20
Event hour 3*	-857.69	-900.25	-815.13
Post-event Hour 1*	314.02	278.31	349.72
Post-event Hour 2*	174.73	141.79	207.67
Post-event Hour 3*	100.12	67.83	132.40
Post-event Hour 4*	82.07	50.45	113.70
Post-event Hour 5*	60.36	32.03	88.69
Post-event Hour 6*	33.38	7.16	59.60

*Estimate was statistically significant at the 10% level.

**Number of thermostats analyzed in the test group

Expected MISO Event Impacts

Based on the evaluation findings, Cadmus estimated the expected average demand reduction per thermostat for each month during a MISO event. To do this, Cadmus estimated demand reductions as a function of weather. Cadmus downloaded weather data for the last 10 years to estimate the expected temperature during a MISO event. As MISO events are most likely called on days experiencing higher outside temperatures, Cadmus took the average temperature for each month between 2 p.m. and 6 p.m. (MISO peak period) and then removed any observation below the average. Using this data, Cadmus recalculated the average temperature between 2 p.m. and 6 p.m. for each month. Cadmus used the expected temperature per month during a MISO event (2 p.m. and 6 p.m.) to estimate expected impact per month. Table 13 presents the expected impacts per thermostat per month for a MISO event.

Table 13. Estimated MISO Event Impacts per Month

Month	Expected Temperature During MISO Event (2 p.m.-6 p.m.)	Expected Average Impact per Thermostat (kW)
June	89°F	-1.113
July	90°F	-1.161
August	89°F	-1.119
September	85°F	-0.984

Energy Savings

In addition to demand impacts, Cadmus evaluated the energy savings resulting from the load control events. Energy savings from load control events depended on the relative magnitudes of event-hour demand savings, Nest precooling energy consumption, and the post-event rebound in energy demand.

Cadmus aggregated the hour interval kW to daily kWh for each thermostat then estimated a regression using the aggravated daily kWh. Appendix C. Event Day Energy Savings Estimation Detailed Methodology describes the regression model specification and estimation procedures. Table 14 shows average event-day energy savings of 0.88 kWh per thermostat and for the program's test groups overall. The estimate was statistically significant at 90% confidence.

Table 14. Average Energy Savings per Event

Energy Savings Per Thermostat (kWh)	90% Confidence Limits		Overall Achievable Group Savings (kWh)
	Lower Bound	Upper Bound	
0.88*	0.51	1.26	1,421

*Estimate was statistically significant at the 10% level.

Market Effects Evaluation Findings

After reviewing program materials and interviewing program stakeholders, Cadmus developed a logic model and key performance indicators (KPIs) for the Smart Cycle Program. The logic model reflects these key program components:

- Existing program design and administration
- Market barriers discovered through evaluation activities
- Current intervention strategies and activities
- Expected outcomes from implementing current intervention strategies

Logic Model

Figure 12 shows the Smart Cycle Program's logic model, which documents key program components across the three market actors (customers, installation technicians, and demand response vendor).

Program Performance

Cadmus measured 2018 Smart Cycle Program performance against KPIs listed in Table 15. Vectren should continue to track program performance against these KPIs in future program years; 2018 program performance may serve as a baseline for KPI tracking in the future.

Table 15. Smart Cycle KPI and 2018 Performance

KPI		2018
Number of customers enrolled in the program and randomized by the start of the summer event season		1,010 participants
Average kW Savings Per Thermostat		1.1 kW
Customer satisfaction with the technician		95% satisfied (n=83)
Customer's installation experience ratings	*Scheduling the installation appointment was easy*	98% agreed with statement (n=81)
	Did not wait long for the day of installation after booking the appointment	96% agreed with statement (n=80)
	Received clear communication about the appointment	99% agreed with statement (n=81)
	The contractor arrived on time	99% agreed with statement (n=82)
Clarity of the technicians' explanation of the program and events		86% said it was clear (n=82)
Clarity of Vectren's explanation of the program and events		91% said it was clear (n=238)
Percentage of customers who reported receiving leave-behind material from technician		70% (n=82)
Percentage of smart thermostats reported being online		97% said always online (n=233)
Smart thermostat satisfaction		97% satisfied (n=239)
Incentive satisfaction		79% satisfied (n=239)
Program satisfaction		85% satisfied (n=228)

Figure 12. Logic Model of Smart Cycle Program

SMART CYCLE PROGRAM

Market Actor	Market Barriers	Intervention Strategies / Activities	Outcomes	Key Indicators
End-Use Customer Residential Customer	• Lack of education about smart thermostat technology • Lack of understanding of demand response benefits • Negative experience with installation process • Concerns about thermal comfort • Concerns about data privacy and utility control of thermostat • Smart thermostat setting overrides during events	• Information (email, bill insert, web content) provided about smart thermostats and demand response • Installation process documented • Customer installation experience issues identified and resolved • User education provided during installation process • Data privacy and control clarifications provided during installation process • Leave-behind program information and call center phone number provided • Monthly bill credit during the summer for program enrollment • Event notifications sent in advance via Nest app	• Increased customer understanding of smart thermostats and demand response • Improved customer perception of smart thermostats • Customer satisfaction with smart thermostats • Ongoing participation in events • Customer satisfaction with the program • Peak load reduction	• Smart thermostat and demand response clarity of information ratings • Number of customers enrolled in the program • Smart thermostat satisfaction ratings • Program satisfaction ratings • Incentive satisfaction ratings • Total MW reduced during events
Trade Allies Installation Technicians	• Customer homes do not meet device requirements (Wi-Fi, compatible AC system, wiring) • Lack of information about the program and demand response to answer customer questions • Faulty installation of smart thermostats	• Customers completed pre-qualification survey to identify AC system • Technicians completed survey to document the installation process • Provided support on technical issues that arose during the installation process • Provided information and leave-behind materials for technicians to educate customers • Ran test events to confirm successful installation of smart thermostat	• Properly installed and functioning smart thermostats • Positive customer experience of the installation • Increased customer understanding of smart thermostats and demand response	• Number of thermostats installed through program • Technician satisfaction ratings • Installation experience ratings • Percentage of customers who reported receiving leave-behind materials from technicians
Demand Response Vendor Nest	• Smart thermostats offline when events are called	• Monitored online connectivity of participants' smart thermostats	• Ability to implement events and manage peak load	• Percentage of smart thermostats that were online during events

Conclusions and Recommendations

Based on the detailed evaluation findings, Cadmus came to the following conclusions and recommendations.

Conclusion: The Smart Cycle Program achieved savings similar to the 2016 Smart Thermostat Pilot and higher demand reduction impacts than the legacy Summer Cycler Program.

Across all 10 events during summer 2018, the program achieved an average event-hour savings of 1.1 kW, with an average of 1.1 kW for event days 1–6 and 9–10, and 1.3 kW for events 7 and 8. These savings were similar to the 2016 pilot savings of 1.0 kW. Vectren was successful in curtailing demand, achieving statistically significant savings across all events. These savings were more than twice as high as the per-unit savings typically achieved in the Summer Cycler Program. The Smart Cycle Program setback technology is more effective than the Summer Cycler Program's methodology.

Conclusion: Email, direct mail, and text messaging, rather than phone calls, may be the most effective recruitment channels.

Vectren aims to replace 1,000 Summer Cycler switches with Nest thermostats per year over the next three years (2018–2020). Vectren nearly met its switch-out goal in 2018 and replaced 975 switches with Nest thermostats.

Vectren promoted the direct installation of Nest thermostats at no additional cost to Summer Cycler participants through email, direct mail, and outbound calls. Summer Cycler respondents most frequently heard about the Smart Cycle Program from email (41%) and direct mail (25%). Only 5% heard from outbound calls. Overall, Summer Cycler and Smart Thermostat Pilot respondents preferred to receive communication from Vectren about programs and rebates through email (83%), direct mail (23%), and text message (20%); very few preferred phone calls (3%).

- **Recommendation: Increase email and direct mail marketing efforts to recruit Summer Cycler customers into the Smart Cycle Program.** Even though customers preferred text messages, at this time Vectren is only able to use text messages for communicating service disruptions or emergencies to customers. If corporate restrictions change in the future, consider using text messages as a way to communicate with customers about program offerings.

Conclusion: From scheduling the appointment to educating the customer, the smart thermostat installation technician delivered a positive customer experience throughout.

Respondents who received a Nest thermostat in 2018 had a positive experience with the installation process and were satisfied with the technician (95%). Most respondents agreed that the installation appointment was clearly communicated (99%), the technician arrived on time (99%), scheduling the appointment was easy (98%), and the wait was not long (96%). Most respondents said the technician clearly explained how the program worked and what the Nest thermostat would do during events (86%).

Conclusion: Customers tended to notice the events more from the Nest thermostat display and event notifications from the app rather than through a temperature change.

About half (51%) of test group respondents said they noticed the events. On average, respondents noticed 7.1 events out of the 10 events called. Respondents mostly noticed the events because of a message on the Nest thermostat display (59%) and the event notification from the Nest app (44%). Only a third of respondents (37%) noticed the events because of a temperature change.

Conclusion: Despite customers saying their home's interior temperature was comfortable during events, a sizeable proportion reported overriding the events.

Overall, 72% of test group respondents said their home's interior temperature was comfortable during the events. However, more than one-third (37%) of test group respondents said they changed the thermostat settings during events (i.e., overriding the events), most often because of discomfort.

Cadmus reviewed the online program information and found no mention of a penalty for overriding events. The program granted the $5 monthly bill credit to participants even if they overrode the events.

- **Recommendation: Communicate to customers the expected level of program participation to reduce the occurrence of overriding of events.** Before the next summer event season commences, clearly communicate to customers the number of events or hours that is expected from them (personal theme) and/or would help meet community energy goals (community theme).
- **Recommendation: Consider changing the incentive structure whereby customers who override too many events do not receive the bill credit.** Other utilities that Cadmus has evaluated (Consumers Energy and Portland General Electric) stipulate in their demand response program requirements that customers must participate in a minimum number of events or event hours to receive the incentive.

Conclusion: Having their thermostats controlled did not affect customer satisfaction with Vectren; however, customers were more satisfied with the program and the bill credit when their thermostats were not controlled.

The majority of participant respondents (83%) were satisfied with Vectren. The percentage of *very satisfied* and *somewhat satisfied* did not differ between test and control group respondents.

The majority of participant respondents (79%) were satisfied with the monthly $5 bill credit. Not surprisingly, more control group respondents were *very satisfied* (58%) than test group respondents (42%). Participants in the control group never experienced an event because their thermostats were not controlled. Overall, 85% of participant respondents were satisfied with the program. Similar to the pattern observed with the bill credit, more control group respondents were *very satisfied* (60%) compared to test group respondents (48%).

Appendix A. Demand Savings Estimation Detailed Methodology

A.1 Demand Reduction Analysis

Cadmus estimated the demand impacts of the Smart Cycle Program, which ran load control events during summer 2018. The study involved 1,010 participating customers, randomly assigned to a test group (760) or a control group (250), whose energy use was monitored by Nest thermostats. Cadmus collected and analyzed the runtime data of central air conditioners (CACs) by referring to the unit's nameplate data then converting runtime to kW and estimating the savings by comparing the kWh/hour during load control events of the test and control group participants.

A.1.1 Develop Logger Analysis Sample

To verify the accuracy of Cadmus' conversion of thermostat runtime to kW, Cadmus and Vectren arranged installation of loggers in a subsample of 30 test group homes. To ensure that the logger analysis sample was representative, Cadmus stratified participants by summer energy consumption and established a recruitment quota for each stratum. Vectren recruited customers for logger metering from a randomly ordered list of customers provided by Cadmus. Because customers were randomly assigned to test and control groups, all loggers could be installed in test group homes.

The loggers were intended to record energy consumption of CACs at five-minute intervals. However, the majority of the loggers were not available in time for the evaluation nor did all of the available loggers have useable data. The final sample had only 11 loggers, too small a sample for Cadmus to calibrate the runtime-to-kW process. This was also the case in the previous 2016 Smart Thermostat Pilot.

A.1.2 Data Collection

Cadmus collected several types of data for the impact evaluation. Table A-1 lists the major categories, period, and sources of these data.

Table A-1. 2018 Smart Cycle Data Collection

Data	Population	Period	Source
Customer Information System Data	Vectren Smart Cycle customers	From beginning of enrollment to end of summer 2018	Vectren
Event dates and hours	Vectren Smart Cycle customers	Summer 2018	Vectren
CAC runtime and other system data	All CAC units of participants enrolled in the Smart Cycle Program	June 2018– September 2018	Nest
CAC system nameplate data	Vectren former Smart Thermostat Pilot customers*	Time of thermostat installation	Schneider Electric and WES
	Vectren former Summer Cycler Program Customers**	Time of thermostat installation	A+Derr
Weather	Evansville Regional Airport weather station	June 2018–September 2018	NOAA (collected by Cadmus)
AC Logger Data	Sample of program CACs	June 2018–September 2018	A+Derr

Vectren's database included each participant's enrollment date, thermostat installation date, zip code location, assignment to test or control group, and number of thermostats/controlled CACs. The event data included the event date, the beginning and end times of the events, and beginning and end times of any precooling periods.

Cadmus requested runtime and other system data, which included unit-level compressor and fan runtimes for all program CACs from Nest. To make the conversion from unit runtime per hour to kWh per hour, Cadmus required data about the capacity and efficiency of program CACs. Vectren provided these data when possible and, for these units, Cadmus set the SEER/EER and tonnages to the averages for CACs as defined in the 2015 Indiana TRM.[9]

Finally, Cadmus collected hourly temperature and humidity data from the National Oceanic and Atmospheric Administration (NOAA) Quality Controlled Local Climatological Data (QCLCD) database. All homes in the pilot were in the Evansville, Indiana, area, so Cadmus collected weather data from the Evansville Regional Airport weather station.

A.1.3 Data Preparation

Cadmus verified that the database, runtime, and CAC nameplate data were complete and that there were no significant portions of missing data. For each customer, Cadmus aggregated compressor and fan runtime data to hour intervals and merged them with hourly temperature and humidity data from Evansville Regional Airport then merged the customer data to form a panel dataset.

Cadmus analyzed each dataset and performed any necessary cleaning. Nest data required minimal cleaning, as they were already aggregated to 15-minute intervals. Nevertheless, Cadmus found the following items in the analysis:

- **Markets for missing data.** Some rows contained markers for missing data due to connectivity problems. These rows were marked with a “Lost At” indicator and a timestamp. Cadmus marked the time from the last valid record before the “Lost At” indicator, through the time of next valid record after the indicator, as missing data.
- **Timestamps.** Some timestamps were associated with multiple rows with conflicting system status information. For example, in some instances two rows were associated with one timestamp, with one row containing a “Fan On” message and the other containing “Fan Off.” In these cases, Cadmus defaulted to the record that contained different information from the immediate previous valid record, with the rationale that a new record should be created only when the status of the attribute changed. Thus, the record that contained the same information as the previous record was likely due to error and was removed.
- **Unexplained gaps in the thermostat data.** Periods of multiple hours or days, with no “Lost At” indicator, resulted in long durations during which Cadmus had to assume that the thermostat had not changed status. This meant that some thermostats appeared to be “stuck” on or off. If

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[9] Cadmus, Opinion Dynamics, Integral Analytics, and Building Metrics. *Indiana Technical Reference Manual, Version 2.2.* Prepared for Indiana Demand Side Management Coordination Committee and EM&V Subcommittee. July 28, 2015.

the user turned the thermostat off manually, hours or days of compressor inactivity were valid data. Long periods of compressor runtime were less plausible, but not impossible. Given the challenge presented by these cases, Cadmus could not determine if the data were missing or valid, so these data remained in the analysis dataset.

Cadmus also cleaned the CAC system nameplate data. Some energy efficiency ratings (EERs) and tonnages were missing or contained typos. In these cases, Cadmus set the SEER/EER and tonnages to the averages for CACs as defined in the 2015 Indiana TRM.[10]

To be included in the analysis, each thermostat had to be present in the thermostat data and Vectren's database. Any device that was not present, with valid data, in both datasets was excluded from the analysis. Cadmus also removed individual hourly observations from the analysis if one observation met any of these criteria:

- The fan runtime was less than the compressor runtime (the compressor never runs when the fan is not running, so these observations were likely the result of missing data).
- Runtime for fan or compressor was missing at any point during the hour.
- The timestamp was missing.
- The thermostat was set to heating instead of cooling or off.

Sample Disposition and Equivalency Checks

Table A-2 shows that 882 Nest customers were included in the evaluation after removing non-valid and missing data.

Table A-2. Data Attrition

Data Processing Step	Nest Thermostats
Total customers randomly assigned to Control or Test groups	1,010
Customers remaining after removing non-valid and missing data	**882**

Figure A-1 shows the average, non-event day demand of the Nest thermostats after the runtime-to-kW conversion process. The test group's demand was at most 0.06 higher than the control group's demand in some hours. However, the demand of the two groups was nearly equal during the event period (2 p.m. to 4 p.m.) when the majority of the events occurred (eight of the 10 events). The match was less close during the event period of (4 p.m. to 6 p.m.) but still within 4% of the usage.

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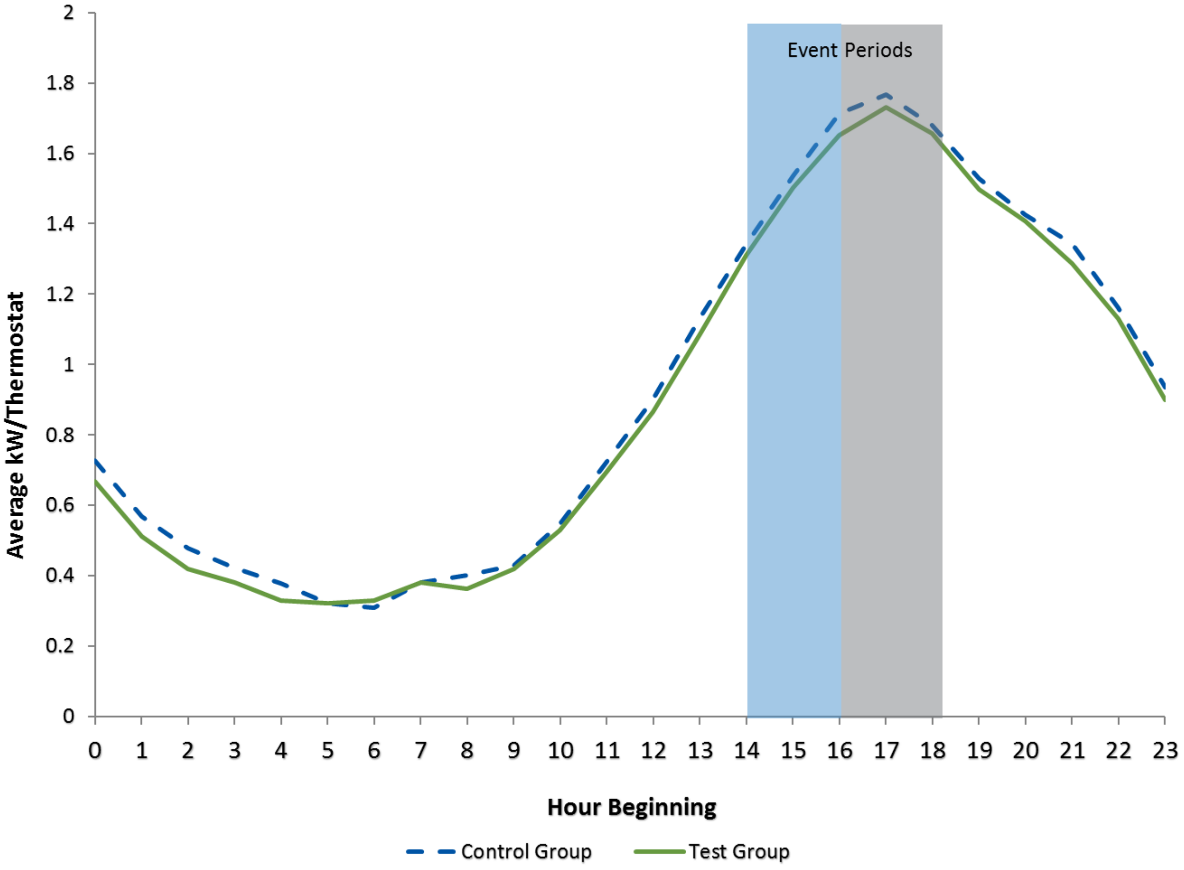
[10] Cadmus, Opinion Dynamics, Integral Analytics, and Building Metrics. *Indiana Technical Reference Manual, Version 2.2.* Prepared for Indiana Demand Side Management Coordination Committee and EM&V Subcommittee. July 28, 2015.

Figure A-1. Nest Average Nonevent-Day Demand



Conversion of Runtime to kW

To estimate the load impacts, Cadmus converted runtime per hour to kWh per hour for each CAC. The formula estimates the instantaneous kW for the unit, including power for the unit's condenser and evaporator fans and compressor, as a function of unit size (tonnage), efficiency, and indoor wet-bulb and outdoor dry-bulb temperatures. Cadmus assumed an indoor wet-bulb temperature of 67 degrees Fahrenheit (F°), the Air Conditioning, Heating, and Refrigeration Institute (AHRI) standard, as indoor wet-bulb temperatures were not available in the thermostat data. Cadmus used outdoor dry-bulb temperatures collected from the Evansville Regional Airport weather dataset, as the thermostats did not collect home-specific outdoor temperatures.

Cadmus used a standard engineering formula to make the conversion.[11] The formula estimates the instantaneous kW for the unit, including power for the unit's condenser and evaporator fans and compressor, as a function of unit size (tonnage), efficiency, and indoor wet-bulb and outdoor dry-bulb temperatures:

$$Instantaneous\ System\ kW = \frac{(Tons * 12{,}000 * CAP * \frac{3.413}{EER} * EIR)}{3413}$$

Where:

Tons = Tonnage of CAC (collected from nameplate data during thermostat installation)

12,000 = Conversion factor to convert tons to Btu

EER = EER of CAC unit (collected from nameplate data during thermostat installation)

$$CAP = a_{CAP} + (b_{CAP} * EWB) + (c_{CAP} * EWB^2) + (d_{CAP} * ODB) + (e_{CAP} * ODB^2) + (f_{CAP} * EWB * ODB)$$

$$EIR = a_{EIR} + (b_{EIR} * EWB) + (c_{EIR} * EWB^2) + (d_{EIR} * ODB) + (e_{EIR} * ODB^2) + (f_{EIR} * EWB * ODB)$$

In the CAP (total capacity) and EIR (energy input ratio) equations above, terms "*a*" through "*f*" are standardized performance curve coefficients obtained from the Cutler study.[12] Terms ODB and EWB are the outdoor dry-bulb and indoor wet-bulb temperatures, respectively. Cadmus assumed an indoor wet-bulb temperature of 67°F, the AHRI standard, as indoor wet-bulb temperatures were not available in the thermostat data. Cadmus used outdoor dry-bulb temperatures collected from the Evansville Regional Airport weather dataset, as the thermostats do not collect home-specific outdoor temperatures.

For each hour, Cadmus multiplied the CAC runtime by the instantaneous kW to estimate the unit's kWh/hour.

A.1.4 Randomize Test and Control Design

Cadmus randomly assigned participants (customers) in the Smart Cycle Program into test and control groups, first by dividing the participating customers' analysis sample into five strata (low, mid-low, medium, mid-high, and high) according to the home's energy use on non-event weekday afternoons in 2017 then by randomly assigning homes within each stratum to the test or control group. Stratifying the sample before the random assignment increased the likelihood that the test and control groups would

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[11] Cutler, D., et al. *Improved Modeling of Residential Air Conditioners and Heat Pumps for Energy Calculations.* NREL Technical Report, NREL/TP-5500-56354. January 2013. http://www.nrel.gov/docs/fy13osti/56354.pdf

[12] Ibid.

have balanced consumption. Of the 1,010 participating customers, approximately 75% (760) were assigned to the test group and 25% (250) to the control group.

During summer 2018, thermostats in the test group experienced curtailments during load control events; thermostats in the control group did not experience such curtailments. Cadmus used the energy demand of control group CACs to establish a baseline for the test group and estimated the demand savings during load control events as the difference between test and control group demand. Electricity use of CACs in the control group constituted a valid baseline because these units had been randomly assigned to test and control groups.

A.1.5 Savings Estimation

Cadmus estimated the average runtime impact per thermostat for hours before, during, and after each event. For the pre-event hours, Cadmus estimated the demand impacts of precooling by the Nest thermostat that could lead to higher-than-normal runtime. For event hours, Cadmus estimated the demand impacts of thermostat setback. It is expected that demand would be significantly less than the baseline during event hours. For post-event hours, Cadmus estimated the rebound in demand (above-average use) as the unit returned the home to the programmed thermostat temperature setpoint.

Cadmus estimated the average kW impact per hour per thermostat using panel regression. The dependent variable was average kW per hour and the independent variables included indicators for hour of the day, an indicator for weekday, and cooling degrees as stand-alone and interaction variables. The regression also included separate indicator variables for the six hours before events, all event hours, and six hours after each event. Baseline kW was established by the randomized control group, using their average kWh during the same event hours.

Cadmus estimated the models using ordinary least squares (OLS) with standard errors clustered on households.[13] Cadmus' methodology included these elements:

- Defining the analysis sample period as June 15, 2018, to September 15, 2018, excluding holidays, and using all valid thermostat data for hours during this period.

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[13] Cadmus had initially planned to specify the panel regression as a Tobit model. During many summer hours, CACs do not run and demand is zero in these hours. Cadmus found that across all Smart Cycle Program participants about half of Nest demand observations were zeroes. The Tobit accounts for this non-normal distribution of CAC energy demand. Although the Tobit model predicted non-event demand with good accuracy, Cadmus observed that heteroscedastic errors during event hours were producing severely biased estimates of event impacts. The Tobit model is highly sensitive to violations of its assumption of constant variance of the error term and produces unreliable and biased estimates if this assumption is broken. For this reason, Cadmus used OLS instead of Tobit to estimate the models.

- Estimating savings from thermostat load control as a difference-in-differences of energy demand per hour, which effectively compared the change in energy demand between event and non-event hours of test and control group units.[14]
- Modeling energy demand per hour as a function of these variables—hour of the day, day of the week, weather, and indicators for hours during and after events. These models allowed the effects of hour of the day and cooling degree hours (CDH) to differ between test and control units, as well as between weekdays and weekends.
- Using an OLS regression, with standard errors clustered on households, to estimate the demand impacts accounted for the duty cycle of a typical CAC after controlling for the hour of the day, day of the week, and other factors.
- Estimating demand impacts for event hours as the difference between the model predicted kW/hour and the baseline average kW/hour.

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[14] The difference-in-differences analysis offered two benefits. First, it resulted in more precise savings estimates. Second, it controlled for non-program energy-use impacts correlated with events.

Appendix B. Thermostat kW Impacts for Each Event Hour

Table B-1 shows estimates of the demand impacts during each event hour and each of the six post-event hours. Cadmus defined the elements in this table as the following:

- **Metered kW** represents energy demand per unit, converted from the runtime recorded by the thermostats.
- **Predicted kW** represents metered kW per unit, as predicted by the regression models.
- **Baseline kW** represents what the regression model predicted average energy demand would have been during the two event hours and six hours after each event had the event not been called. Baseline and predicted energy demand are equal, except during the three event hours and six hours after each event.
- **Estimated kW impact** represents the differences in impacts between predicted kW and baseline kW.

Table B-1. Nest Thermostat kW Impacts for Each Event Hour

Event Day	Date	Hour Beginning	Hour Type	Outside Temp. (°F)	Estimated Impact per A/C Unit (kW)	Average Metered kW	Predicted kW	Baseline kW
1	5-Jul-18	8	Pre-Event Hour 6	91	-0.030	0.730	0.730	0.760
1	5-Jul-18	9	Pre-Event Hour 5	93	0.036	0.858	0.858	0.821
1	5-Jul-18	10	Pre-Event Hour 4	93	-0.132	0.957	0.955	1.086
1	5-Jul-18	11	Pre-Event Hour 3	93	-0.084	1.221	1.222	1.306
1	5-Jul-18	12	Pre-Event Hour 2	94	-0.039	1.530	1.529	1.569
1	5-Jul-18	13	Pre-Event Hour 1	94	0.307	2.186	2.185	1.878
1	5-Jul-18	14	Event Hour 1	95	-1.487	0.387	0.386	1.873
1	5-Jul-18	15	Event Hour 2	93	-1.076	0.885	0.884	1.961
1	5-Jul-18	16	Post-Event Hour 1	92	0.403	2.520	2.519	2.116
1	5-Jul-18	17	Post-Event Hour 2	89	0.264	2.385	2.384	2.121
1	5-Jul-18	18	Post-Event Hour 3	86	0.145	2.199	2.198	2.053
1	5-Jul-18	19	Post-Event Hour 4	81	0.115	1.988	1.987	1.871
1	5-Jul-18	20	Post-Event Hour 5	80	0.094	1.833	1.834	1.740
1	5-Jul-18	21	Post-Event Hour 6	79	-0.021	1.680	1.681	1.702
2	13-Jul-18	8	Pre-Event Hour 6	81	-0.028	0.301	0.300	0.329
2	13-Jul-18	9	Pre-Event Hour 5	83	0.048	0.387	0.387	0.339
2	13-Jul-18	10	Pre-Event Hour 4	86	-0.017	0.491	0.491	0.508
2	13-Jul-18	11	Pre-Event Hour 3	87	-0.023	0.649	0.649	0.672
2	13-Jul-18	12	Pre-Event Hour 2	89	0.012	0.832	0.833	0.821
2	13-Jul-18	13	Pre-Event Hour 1	90	0.587	1.684	1.683	1.096
2	13-Jul-18	14	Event Hour 1	91	-1.165	0.240	0.240	1.405
2	13-Jul-18	15	Event Hour 2	91	-1.035	0.544	0.545	1.580
2	13-Jul-18	16	Post-Event Hour 1	89	0.351	2.076	2.075	1.724
2	13-Jul-18	17	Post-Event Hour 2	86	0.140	1.953	1.953	1.813

Event Day	Date	Hour Beginning	Hour Type	Outside Temp. (°F)	Estimated Impact per A/C Unit (kW)	Average Metered kW	Predicted kW	Baseline kW
2	13-Jul-18	18	Post-Event Hour 3	85	0.096	1.801	1.801	1.705
2	13-Jul-18	19	Post-Event Hour 4	78	0.209	1.590	1.590	1.381
2	13-Jul-18	20	Post-Event Hour 5	77	0.126	1.435	1.437	1.311
2	13-Jul-18	21	Post-Event Hour 6	74	0.023	1.264	1.263	1.240
3	3-Aug-18	8	Pre-Event Hour 6	81	0.038	0.253	0.253	0.216
3	3-Aug-18	9	Pre-Event Hour 5	82	0.010	0.284	0.284	0.274
3	3-Aug-18	10	Pre-Event Hour 4	83	-0.014	0.407	0.408	0.422
3	3-Aug-18	11	Pre-Event Hour 3	86	0.013	0.548	0.546	0.533
3	3-Aug-18	12	Pre-Event Hour 2	87	-0.002	0.677	0.678	0.680
3	3-Aug-18	13	Pre-Event Hour 1	88	0.550	1.492	1.492	0.942
3	3-Aug-18	14	Event Hour 1	87	-1.066	0.209	0.209	1.276
3	3-Aug-18	15	Event Hour 2	88	-0.992	0.490	0.490	1.482
3	3-Aug-18	16	Post-Event Hour 1	88	0.352	2.014	2.015	1.662
3	3-Aug-18	17	Post-Event Hour 2	86	0.143	1.928	1.929	1.786
3	3-Aug-18	18	Post-Event Hour 3	84	0.071	1.747	1.748	1.677
3	3-Aug-18	19	Post-Event Hour 4	81	0.043	1.537	1.537	1.495
3	3-Aug-18	20	Post-Event Hour 5	79	0.109	1.432	1.433	1.324
3	3-Aug-18	21	Post-Event Hour 6	78	0.036	1.329	1.330	1.294
4	6-Aug-18	8	Pre-Event Hour 6	83	-0.024	0.414	0.414	0.438
4	6-Aug-18	9	Pre-Event Hour 5	86	-0.014	0.510	0.510	0.525
4	6-Aug-18	10	Pre-Event Hour 4	87	-0.099	0.587	0.587	0.686
4	6-Aug-18	11	Pre-Event Hour 3	89	0.001	0.897	0.897	0.896
4	6-Aug-18	12	Pre-Event Hour 2	90	-0.006	1.153	1.153	1.159
4	6-Aug-18	13	Pre-Event Hour 1	91	0.500	1.920	1.920	1.420
4	6-Aug-18	14	Event Hour 1	89	-1.240	0.263	0.263	1.502
4	6-Aug-18	15	Event Hour 2	89	-1.103	0.633	0.633	1.736
4	6-Aug-18	16	Post-Event Hour 1	89	0.544	2.347	2.347	1.802
4	6-Aug-18	17	Post-Event Hour 2	88	0.388	2.206	2.207	1.818
4	6-Aug-18	18	Post-Event Hour 3	86	0.210	2.003	2.004	1.794
4	6-Aug-18	19	Post-Event Hour 4	82	0.122	1.821	1.823	1.701
4	6-Aug-18	20	Post-Event Hour 5	82	0.126	1.804	1.804	1.678
4	6-Aug-18	21	Post-Event Hour 6	81	0.030	1.644	1.645	1.615
5	9-Aug-18	8	Pre-Event Hour 6	80	-0.024	0.291	0.291	0.315
5	9-Aug-18	9	Pre-Event Hour 5	83	0.001	0.343	0.342	0.341
5	9-Aug-18	10	Pre-Event Hour 4	83	-0.003	0.419	0.419	0.421
5	9-Aug-18	11	Pre-Event Hour 3	82	0.065	0.515	0.515	0.450
5	9-Aug-18	12	Pre-Event Hour 2	83	-0.022	0.575	0.575	0.597
5	9-Aug-18	13	Pre-Event Hour 1	82	0.674	1.265	1.265	0.591
5	9-Aug-18	14	Event Hour 1	82	-0.631	0.110	0.109	0.740
5	9-Aug-18	15	Event Hour 2	82	-0.902	0.212	0.214	1.115
5	9-Aug-18	16	Post-Event Hour 1	81	0.378	1.476	1.475	1.097

Event Day	Date	Hour Beginning	Hour Type	Outside Temp. (°F)	Estimated Impact per A/C Unit (kW)	Average Metered kW	Predicted kW	Baseline kW
5	9-Aug-18	17	Post-Event Hour 2	80	0.217	1.352	1.353	1.135
5	9-Aug-18	18	Post-Event Hour 3	78	0.176	1.220	1.219	1.043
5	9-Aug-18	19	Post-Event Hour 4	74	0.060	1.127	1.128	1.068
5	9-Aug-18	20	Post-Event Hour 5	70	-0.009	1.050	1.050	1.059
5	9-Aug-18	21	Post-Event Hour 6	71	-0.011	0.952	0.953	0.964
6	13-Aug-18	8	Pre-Event Hour 6	82	-0.046	0.206	0.206	0.252
6	13-Aug-18	9	Pre-Event Hour 5	86	0.016	0.219	0.219	0.202
6	13-Aug-18	10	Pre-Event Hour 4	88	-0.040	0.342	0.341	0.381
6	13-Aug-18	11	Pre-Event Hour 3	88	0.036	0.519	0.520	0.484
6	13-Aug-18	12	Pre-Event Hour 2	89	0.106	0.749	0.747	0.641
6	13-Aug-18	13	Pre-Event Hour 1	90	0.591	1.555	1.555	0.964
6	13-Aug-18	14	Event Hour 1	90	-1.057	0.155	0.154	1.212
6	13-Aug-18	15	Event Hour 2	89	-1.079	0.427	0.427	1.506
6	13-Aug-18	16	Post-Event Hour 1	88	0.397	2.008	2.007	1.610
6	13-Aug-18	17	Post-Event Hour 2	84	0.284	1.824	1.824	1.540
6	13-Aug-18	18	Post-Event Hour 3	83	0.156	1.628	1.628	1.472
6	13-Aug-18	19	Post-Event Hour 4	77	0.121	1.429	1.430	1.310
6	13-Aug-18	20	Post-Event Hour 5	76	0.095	1.376	1.377	1.282
6	13-Aug-18	21	Post-Event Hour 6	76	0.031	1.260	1.260	1.230
7	27-Aug-18	10	Pre-Event Hour 6	91	-0.029	0.600	0.601	0.630
7	27-Aug-18	11	Pre-Event Hour 5	92	-0.087	0.795	0.794	0.882
7	27-Aug-18	12	Pre-Event Hour 4	93	-0.079	1.004	1.003	1.082
7	27-Aug-18	13	Pre-Event Hour 3	92	-0.025	1.227	1.227	1.252
7	27-Aug-18	14	Pre-Event Hour 2	93	-0.099	1.472	1.471	1.570
7	27-Aug-18	15	Pre-Event Hour 1	92	0.526	2.244	2.244	1.717
7	27-Aug-18	16	Event Hour 1	90	-1.325	0.534	0.534	1.859
7	27-Aug-18	17	Event Hour 2	88	-1.056	0.939	0.939	1.995
7	27-Aug-18	18	Post-Event Hour 1	86	0.420	2.314	2.314	1.894
7	27-Aug-18	19	Post-Event Hour 2	84	0.267	1.982	1.982	1.715
7	27-Aug-18	20	Post-Event Hour 3	82	0.165	1.763	1.764	1.599
7	27-Aug-18	21	Post-Event Hour 4	81	0.172	1.591	1.592	1.420
7	27-Aug-18	22	Post-Event Hour 5	80	0.085	1.353	1.353	1.268
7	27-Aug-18	23	Post-Event Hour 6	78	0.048	1.047	1.047	0.999
8	28-Aug-18	10	Pre-Event Hour 6	91	0.058	0.624	0.624	0.566
8	28-Aug-18	11	Pre-Event Hour 5	91	0.087	0.830	0.828	0.740
8	28-Aug-18	12	Pre-Event Hour 4	92	0.037	1.041	1.040	1.003
8	28-Aug-18	13	Pre-Event Hour 3	95	-0.049	1.358	1.358	1.406
8	28-Aug-18	14	Pre-Event Hour 2	94	0.061	1.603	1.603	1.542
8	28-Aug-18	15	Pre-Event Hour 1	95	0.383	2.348	2.348	1.965
8	28-Aug-18	16	Event Hour 1	93	-1.545	0.574	0.573	2.118
8	28-Aug-18	17	Event Hour 2	90	-1.127	0.985	0.985	2.112

Event Day	Date	Hour Beginning	Hour Type	Outside Temp. (°F)	Estimated Impact per A/C Unit (kW)	Average Metered kW	Predicted kW	Baseline kW
8	28-Aug-18	18	Post-Event Hour 1	88	0.372	2.415	2.415	2.044
8	28-Aug-18	19	Post-Event Hour 2	83	0.243	2.041	2.042	1.799
8	28-Aug-18	20	Post-Event Hour 3	82	0.051	1.828	1.828	1.777
8	28-Aug-18	21	Post-Event Hour 4	80	0.118	1.672	1.673	1.555
8	28-Aug-18	22	Post-Event Hour 5	78	0.044	1.402	1.403	1.360
8	28-Aug-18	23	Post-Event Hour 6	77	0.132	1.189	1.190	1.058
9	4-Sep-18	8	Pre-Event Hour 6	87	-0.035	0.365	0.364	0.399
9	4-Sep-18	9	Pre-Event Hour 5	90	-0.095	0.392	0.392	0.487
9	4-Sep-18	10	Pre-Event Hour 4	91	-0.125	0.572	0.572	0.698
9	4-Sep-18	11	Pre-Event Hour 3	91	-0.054	0.810	0.807	0.861
9	4-Sep-18	12	Pre-Event Hour 2	92	-0.030	1.048	1.048	1.078
9	4-Sep-18	13	Pre-Event Hour 1	93	0.633	1.926	1.925	1.293
9	4-Sep-18	14	Event Hour 1	93	-1.339	0.257	0.257	1.596
9	4-Sep-18	15	Event Hour 2	91	-1.209	0.660	0.659	1.868
9	4-Sep-18	16	Post-Event Hour 1	92	0.287	2.313	2.313	2.027
9	4-Sep-18	17	Post-Event Hour 2	87	0.126	2.132	2.132	2.006
9	4-Sep-18	18	Post-Event Hour 3	86	0.123	2.003	2.002	1.879
9	4-Sep-18	19	Post-Event Hour 4	79	0.008	1.737	1.738	1.729
9	4-Sep-18	20	Post-Event Hour 5	80	0.096	1.709	1.709	1.614
9	4-Sep-18	21	Post-Event Hour 6	79	0.039	1.547	1.548	1.508
10	5-Sep-18	8	Pre-Event Hour 6	86	-0.011	0.403	0.403	0.414
10	5-Sep-18	9	Pre-Event Hour 5	88	0.020	0.481	0.482	0.462
10	5-Sep-18	10	Pre-Event Hour 4	90	-0.010	0.687	0.685	0.695
10	5-Sep-18	11	Pre-Event Hour 3	92	0.097	0.965	0.964	0.867
10	5-Sep-18	12	Pre-Event Hour 2	92	0.063	1.087	1.087	1.023
10	5-Sep-18	13	Pre-Event Hour 1	92	0.505	1.891	1.891	1.387
10	5-Sep-18	14	Event Hour 1	92	-1.277	0.272	0.270	1.547
10	5-Sep-18	15	Event Hour 2	89	-1.146	0.577	0.576	1.722
10	5-Sep-18	16	Post-Event Hour 1	88	0.329	2.166	2.166	1.837
10	5-Sep-18	17	Post-Event Hour 2	85	0.091	1.953	1.954	1.862
10	5-Sep-18	18	Post-Event Hour 3	84	0.060	1.843	1.844	1.784
10	5-Sep-18	19	Post-Event Hour 4	79	0.062	1.628	1.628	1.565
10	5-Sep-18	20	Post-Event Hour 5	81	0.002	1.587	1.589	1.586
10	5-Sep-18	21	Post-Event Hour 6	80	0.148	1.471	1.472	1.324

Appendix C. Event Day Energy Savings Estimation Detailed Methodology

Cadmus estimated energy savings from load control events by aggregating hour-interval kWh to daily kWh for each thermostat and estimating the following regression of daily electricity (kWh) use of CACs:

$$kWh_{id} = \alpha_i + \tau_d + \beta Test_i * Event_d + \varepsilon_{id}$$

Where:

kWh_{id} = Daily electricity use of CAC ‘i,’ i=1, 2, …, N, on day ‘d’, d=1, 2, …, D of the estimation period.

α_i = Unobservable, time-invariant electricity use for CAC ‘i.’ These effects are controlled for with CAC fixed effects (i.e., the regression includes a separate dummy variable for each CAC).

τ_d = Day of the analysis sample fixed effect. This variable captures effects specific to a day, such as weather on CAC electricity use.

$Test_i$ = Indicator variable for whether CAC i is in the test group. $Test_i$ equals 1 if CAC i is in the test group and equals 0 if it is in the control group.

$Event_d$ = Indicator variable for an event day. This variable equals 1 if day ‘d’ is an event day and equals 0 otherwise.

β = Average impact of an event day on daily electricity use of CACs.

Cadmus estimated the model by ordinary least squares and clustered the standard errors on CACs to account for unobserved correlation in an CAC’s energy use over time.

Energy savings are indicated by β, and, if events reduced energy use, $\beta<0$.