SUMMER CYCLER PROGRAM 2017
IMPACT EVALUATION REPORT

January 26, 2017

Vectren Energy Delivery of Indiana
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Evansville, Indiana

The Cadmus Group LLC
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Executive Summary

Vectren Energy Delivery of Indiana operated the Summer Cycler Program to reduce residential and small commercial air-conditioning and water-heating electricity loads during summer peak hours. Vectren used radio communication equipment and control switches to turn off customer water heaters and to cycle air-conditioner compressors during load-control events.

In 2017, Vectren initiated eight demand response (DR) load-control events across seven event days. In six of the events, only participants in Vectren's treatment group and load research sample homes experienced load curtailments. The other two events coincided with Midcontinent Independent System Operator (MISO) demand response event periods, and because Vectren bids Summer Cycler demand response capacity into the MISO market, all Summer Cycler participants (including treatment and control group customers) experienced load curtailments during these two events. The last event day of the summer, September 22, 2017, included two events: one from 1:00 p.m. to 2:20 p.m., where only the treatment group and load research homes experienced load curtailment, and one from 3 p.m. to 4 p.m. where all Summer Cycler customers (treatment and control) experienced load curtailment because this hour coincided with MISO's DR event period. Table 1 presents a summary of each the 2017 Summer Cycler event day.

Table 1. Summer Cycler 2017 Direct Load Control Events

Event	Event Date	Event Day	Event Time	Average Outside Temperature (°F) During Event	Groups Cycled
1	7/11/2017	Tuesday	3:00 p.m. – 6:00 p.m.	88	Treatment group
2	7/12/2017	Wednesday	3:00 p.m. – 6:00 p.m.	91	Treatment group
3	7/20/2017	Thursday	3:00 p.m. – 6:00 p.m.	93	Treatment group
4	7/21/2017	Friday	1:00 p.m. – 3:00 p.m.	96	Treatment group
5	7/26/2017	Wednesday	3:00 p.m. – 6:00 p.m.	82	Treatment group
6	9/21/2017	Thursday	3:00 p.m. – 6:00 p.m.	87	Treatment and control groups
7	9/22/2017	Friday	1:00 p.m. – 2:20 p.m.	90	Treatment group
8	9/22/2017	Friday	3:00 p.m. – 4:00 p.m.	90	Treatment and control groups

This report provides estimates of Summer Cycler Program demand and energy savings from the residential sector during 2017. Specifically, the study estimates the following impacts:

- Average kW reduction, per air conditioner and per water heater, during event hours
- Program kW reductions during event hours
- Average and program kW impacts in hours after each event (rebound)
- Energy (kWh) savings on event days

Research Approach

To estimate Summer Cycler demand and energy savings, Cadmus employed an experimental research design that involved metering a representative sample of Summer Cycler Program air conditioners and water heaters. In this report, Cadmus refers to program air conditioners and water heaters with end-use loggers as "the logger analysis sample."

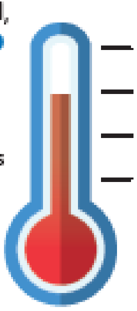
To estimate the air conditioning load control savings, Cadmus randomly assigned 50% of metered air conditioners to a treatment group and 50% to a control group. Air conditioners in the treatment group experienced load curtailments during events, while units in the control group did not. Cadmus estimated event-hour savings by comparing the energy demand of air conditioners in the treatment and control groups using difference-in-differences (D-in-D) regression analysis of the hourly energy-demand data.

To estimate savings from water-heating load control, Cadmus metered a representative sample of program water heaters and compared their electricity use during event and non-event hours. This approach is referred to as a "within-subject" research design. The design did not employ a control group to minimize the number of water-heater data loggers needed for the analysis. To collect the water-heater logger data, Vectren's logger installation contractor (Schneider Electric) had to enter customer homes, and gaining access proved difficult during previous Summer Cycler impact evaluations. The within-subject design minimized the costs of data collection and the burden on customers while still yielding an accurate estimate of savings. Cadmus estimated water-heating demand savings using regression analysis of the hourly water-heating demand data.

KEY IMPACT FINDINGS

The analysis of the logger sample resulted in the following findings about the Summer Cycler Program's impacts in 2017:

Vectren initiated events **between 3:00 p.m. and 6:00 p.m.**, when Vectren typically experiences peaks in system demand, and **between 1:00 p.m. and 3:00 p.m.**



Average event-hour temperatures ranged between **88°F** and **96°F.**

The installation contractor's deployment of the data loggers **improved** in 2017 compared to 2015—fewer loggers lacked data, and the loggers were set to the correct local time.

During events, the program achieved **0.52kW in average demand savings per air conditioner,** or approximately **31%** of average baseline demand.

The program achieved average energy savings of **0.45 kWh per air conditioner** and -0.03 kWh per water heater during each event, though the water heater estimates were not statistically significant (i.e., energy savings were not statistically different from zero).

Demand savings from air-conditioning load control were higher in 2017 than in 2015, primarily due to lower outdoor temperatures and space cooling demand during events in 2015 when the summer was mild.

Events occurred at significantly higher average temperatures in 2017 (88°F to 96°F) and 2012 (97°F) compared to 2015 (89°F to 91°F). The 2017 savings are similar to those found in 2012.

During events, the program produced **0.14 kW in average demand savings per water heater,** or approximately **50%** of average baseline demand

If Vectren cycled all Summer Cycler customers instead of just the treatment groups the Summer Cycler Program could have generated up to **20 MW in peak demand savings from residential air-conditioning** load control and **2 MW in peak demand savings from residential water-heating** load control during summer 2017 non-MISO events.

Two MISO load curtailment events occurred during summer 2017.

During these events, all Summer Cycler customers were cycled, which generated average savings of **0.35 kW per air conditioner** and **0.23 kW per water heater.**

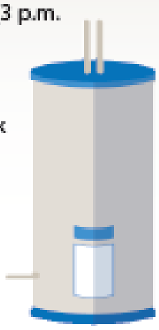
For all Summer Cycler customers and summer 2017 MISO event hours, these combined savings averaged **8,746 kW** from **air conditioners** and **1,707 kW** from **water heaters.**

CONCLUSIONS

Based on these findings, Cadmus offers the following conclusions:

The **Summer Cycler Program** continues to provide substantial demand reductions from air-conditioning direct load control (DLC) during high temperature events and MISO load curtailment events.

Vectren's per-unit demand reductions from water heaters are low because the typical Summer Cycler event window (3 p.m. to 6 p.m.) does not coincide with peak water-heating end use.



Summer Cycler's switch-based, 50% cycling demand response method for air conditioners produced **higher impacts** than those achieved by Honeywell thermostats (using 50% cycling) in the 2016 Vectren Smart Thermostat Pilot. However, the average temperature range during 2017 events (88°F to 96°F) was higher than 2016 events (79°F to 97°F). These differences may also be due to different customer characteristics between the two studies and not necessarily the cycling strategy or demand response technology.

RECOMMENDATIONS

According to Vectren program staff, in 2018, Vectren is planning to replace existing Summer Cycler switch devices with Wi-Fi-enabled thermostats capable of participating in demand response events. Additionally, to increase the demand response capacity from residential air conditioning, Vectren is expanding the number of air conditioners enrolled in the program by adding a bring-your-own-thermostat option for customers. Based on the findings and conclusions from the 2017 Summer Cycler evaluation, Cadmus recommends the following to increase the potential for demand savings in future cycling program evaluations:

- Continue to call demand response events from 3 pm. to 6 p.m. on days when outdoor temperatures exceed 95 degrees. These conditions provide impact estimates most comparable to those of system peaks.
- Maintain the existing water heater switches, if cost-effective. Although water-heating demand response achieved lower per-unit demand savings than air-conditioner cycling, the more than 11,000 water heaters enrolled in the program, along with the enrolled air conditioners, can provide over 1 MW of demand savings during peak periods.
- Until advanced metering infrastructure (AMI) data is available for Vectren's entire customer population, consider expanding the number of air conditioners and water heaters selected for metering for future impact studies. A larger sample size would increase the probability of detecting small demand savings, reduce sampling error, and increase the precision of the savings estimates.
- Consider evaluating both smart thermostat and switch-based demand response impacts in the same summer, using a randomized encouragement design, to allow a direct comparison between the demand savings and cost-effectiveness associated with each technology (i.e., the existing switches vs. their replacement with Wi-Fi-enabled thermostats).

Program Overview

Vectren initiates Summer Cycler Program events to reduce residential and small commercial air-conditioning and water-heating electric loads during summer peak hours. The program uses radio communication equipment and control switches that are installed on customer equipment to cycle air-conditioner compressors and turn off water heaters during load curtailment events. Vectren does not provide program participants with advance notification of events. Residential and small commercial customers qualify for the program, with customers receiving a bill credit as an incentive for participation.

Table 2 shows the number of residential customers and premises enrolled in the program. A single customer may be associated with more than one premise, and a premise may have more than one air conditioner or water heater. The program currently enrolls about 22,158 residential customers, covering approximately 22,126 premises. Some premises had multiple switches installed; as of June 2017, Vectren had installed load control switches on approximately 24,829 residential air conditioners and 6,482 residential water heaters.[1]

Table 2. Number of Residential Customers and Premises in the Summer Cycler Program for 2017

Load Control	Customers*	Premises*
Air Conditioning Only	16,648	16,627
Air Conditioning and Water Heating	5,510	5,499
Total	**22,158**	**22,126**

*Customer and premise counts as of July 29, 2017.

Table 3. Number of Residential Customers and Premises in the Summer Cycler Program for 2017

Equipment	Controlled Units*
Air Conditioning Only	24,829
Air Conditioning and Water Heating	6,482

* Controlled Units counts as of July 29, 2017.

Vectren can initiate load control events for multiple reasons, including the following:

- Balancing utility system supply and demand
- Alleviating transmission or distribution constraints
- Responding to load curtailment requests from the Midcontinent Independent System Operator Inc. (MISO), the regional electricity transmission grid authority

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[1] Vectren's program tracking database contains customers, premises, and switch counts, with the number of installed switches as of October 2017. Vectren is conducting a multiyear effort to inspect switches on all controlled units and to upgrade those that are not working properly. Vectren replaces broken or missing air-conditioner switches with an ADI version, which uses an adaptive algorithm to run the unit's compressor for one-half or one-third of the time that it ran in the hour before the event. These switches increase the likelihood that the program will realize the expected demand savings, especially for oversized air conditioners.

- Evaluation, measurement, and verification (EM&V) purposes

In 2017, Vectren initiated six load-control events for EM&V purposes, and two events to respond to MISO load-curtailment requests. During the six events, only participating homes with air-conditioning and water-heating units equipped with end-use loggers in the treatment group experienced load curtailment events. During the latter two MISO events, all Summer Cycler participants (including control group customers) experienced load curtailment events.

Summer Cycler Load Control Event Summary

In 2017, Vectren initiated eight events, as shown in Table 4. On September 22, 2017, Vectren cycled the treatment customers starting at 1:00 p.m. and ending at 2:20 p.m. (event 7). Later that afternoon, Vectren responded to a MISO load curtailment request by cycling all Summer Cycler participants (including control group customers) from 3:00 p.m. to 4:00 p.m. (event 8). During all events, Vectren cycled program air conditioners at 50% and shut off water heaters for the duration of the event. Vectren did not notify customers in advance of the events.

Table 4. Summer Cycler 2017 DLC Events

Event	Event Date	Event Day	Event Time	Average Outside Temperature (°F) During Event	Groups Cycled
1	7/11/2017	Tuesday	3:00 p.m. – 6:00 p.m.	88	Treatment group
2	7/12/2017	Wednesday	3:00 p.m. – 6:00 p.m.	91	Treatment group
3	7/20/2017	Thursday	3:00 p.m. – 6:00 p.m.	93	Treatment group
4	7/21/2017	Friday	1:00 p.m. – 3:00 p.m.	96	Treatment group
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Vectren saw higher event-day temperatures peaks in 2017 compared to previous evaluation years (specifically, 2015). During the summer of 2017, Vectren had the opportunity to test Summer Cycler load control, as well as MISO load curtailment events, under system peak conditions. Five of eight load control events occurred in the peak air conditioning months of July. Three more events occurred in late September. Four of the events had average hourly temperatures above 90˚F. The maximum temperature across all events was 96˚F. The maximum event hour temperature was 97˚F, which occurred during event 4.

Methodology

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

Research Design

Prior to summer 2017, Vectren installation contractor (Schneider Electric) installed end-use meters (loggers) on a random and representative sample of Summer Cycler Program residential air conditioners.[2] Cadmus employed a statistical power analysis to determine the minimum number of air conditioners that were required for metering to detect the expected demand savings with 90% probability.

Cadmus randomly assigned air conditioners in the logger analysis sample to a treatment group and a control group, first by dividing the logger analysis sample into low, medium, and high strata according to the home's energy use on non-event weekday afternoons in 2015 then by randomly assigning homes within each stratum to the treatment or control group. Stratifying the sample before the random assignment increased the likelihood that the resulting treatment and control groups would have balanced consumption.

During the summer, units in the treatment group and the load research homes[3] experienced curtailments during load control events; units in the control group did not experience such curtailments except during MISO events. Cadmus used the demand of control group units to establish a baseline for the treatment group and estimated the demand savings during non-MISO load control events as the difference between treatment and control group demand. To estimate air-conditioner demand savings during MISO events, during which all Summer Cycler customers were cycled, Cadmus calculated the

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[2] Vectren recruited Summer Cycler customers to the impact study. Customers who agreed to have loggers installed on their air conditioners and/or water heater received a monthly bill credit. Homes with two air conditioners or water heaters in the analysis sample had end-use meters installed on both units. Cadmus excluded homes with more than two air conditioners or water heaters; these homes made up a very small percentage of Vectren's residential Summer Cycler Program population.

At the beginning of the 2017 study, Vectren recruited additional homes for air conditioning and water heating load metering to account for attrition in the previous year's logger analysis sample. Cadmus used monthly customer bills to test for differences in energy use between Summer Cycler participants with metered units and those with unmetered units. Cadmus did not find any statistically significant differences and concluded the logger analysis sample was representative of the Summer Cycler Program population.

[3] In prior evaluations, Cadmus used the load research homes' whole-home demand data to verify the savings estimates obtained from the logger analysis. These data were not available in 2017, so Cadmus did not conduct an analysis of the load research group homes for this report.

difference between the combined treatment and control group demand and the baseline, non-event demand predicted by the regression model.

To minimize data collection costs and inconveniences to Vectren customers, Cadmus employed a “within-subject” design to estimate demand savings from water heaters. Cadmus installed loggers on a representative sample (n=67) of program water heaters but did not install additional meters for a control group. Although this method resulted in less precision than the approach Cadmus employed for air conditioners, getting proper access to customers’ homes had proven difficult in prior evaluations, and this approach reduced the number of water-heating units required for metering. All metered units experienced load curtailments during events, and Cadmus compared their average demand during event and nonevent hours, while controlling for the effects of weather and the time of day on electricity demand. In this approach, each customer’s non-event days served as the baseline for that customer. This approach also meant that Cadmus estimated water heating demand impacts during MISO events in the same way as non-MISO events, as all metered water heaters were cycled in either case.

Table 5 shows the number of air conditioners and water heaters in the analysis sample and the number of air conditioners assigned to the treatment and control groups. A total of 171 air conditioners and 67 water heaters were metered. The study assigned approximately one-half of metered air conditioners to the treatment group and the other half to the control group. The sizes of the treatment and control groups are not identical as some loggers were damaged, missing, or inaccessible for data collection after the summer event season concluded.

Table 5. Analysis Sample Size—Air Conditioners and Water Heaters in Treatment and Control Groups*

Equipment	Treatment	Control	Total
Air Conditioning	84	87	171
Water Heaters	67	0	67
Total	**151**	**87**	**238**

*Vectren metered a larger number of air conditioners and water heaters, but the data of some units became corrupted or entry could not be gained to homes to retrieve the data.

Data Collection and Preparation

Cadmus collected five-minute interval energy-use data for 171 air conditioners and 67 water heaters, converting these interval data to average demand (kW) in each hour between June 15, 2017, and September 30, 2017. Cadmus estimated hourly demand by averaging available water-heater demand readings (i.e., water-heater loggers collected momentary amperage readings) or summing available air-conditioning energy-use readings (i.e., air-conditioner loggers collected kWh).

For each logger, Cadmus generated these plots to understand demand patterns and to identify missing or problematic data:

- Hourly kW vs. time (June 15, 2017, to September 30, 2017)
- Average hourly kW vs. the hour of the day (h = 1, 2, …, 24) for week and weekend days

- A histogram showing the distribution of hourly kW

Cadmus identified seven hourly air conditioner demand observations greater than 6 kW. Cadmus' research suggested that these readings were implausibly large for residential air conditioners (which generally did not exceed 4 kW) and were therefore likely to be bad data, so these observations were not included in the analysis sample. These excluded data constituted less than 0.01% of the observations in the analysis sample. Additionally, Cadmus completely excluded one logger from the analysis because the majority of its observations were greater than 6 kW.

During the logger data-cleaning effort, Cadmus verified that Vectren's installation contractor had set each logger's timestamp to Evansville, Indiana, summer local time, Greenwich Mean Time (GMT) -5, during deployment. Cadmus found that only one logger had been set to a time zone other than GMT -5. To correct this logger's timestamps, Cadmus extracted the timestamp specific to that logger (GMT -7) then shifted the date/time records forward two hours to ensure that all logger data were consistent.

Because air conditioners cycled on and off during events, it was not possible to identify the event period in any one air conditioner's logger's raw data; therefore, Cadmus confirmed that the average daily usage curve and average daily peak hours matched those of the previous evaluation (2015). Cadmus found that the summer 2017 average non-event air conditioner usage curve matched the curve observed in the 2015 impact evaluation, which confirmed that the installation contractor's logger deployment was effective and that Cadmus' logger data processing was accurate and comparable to previous evaluations.

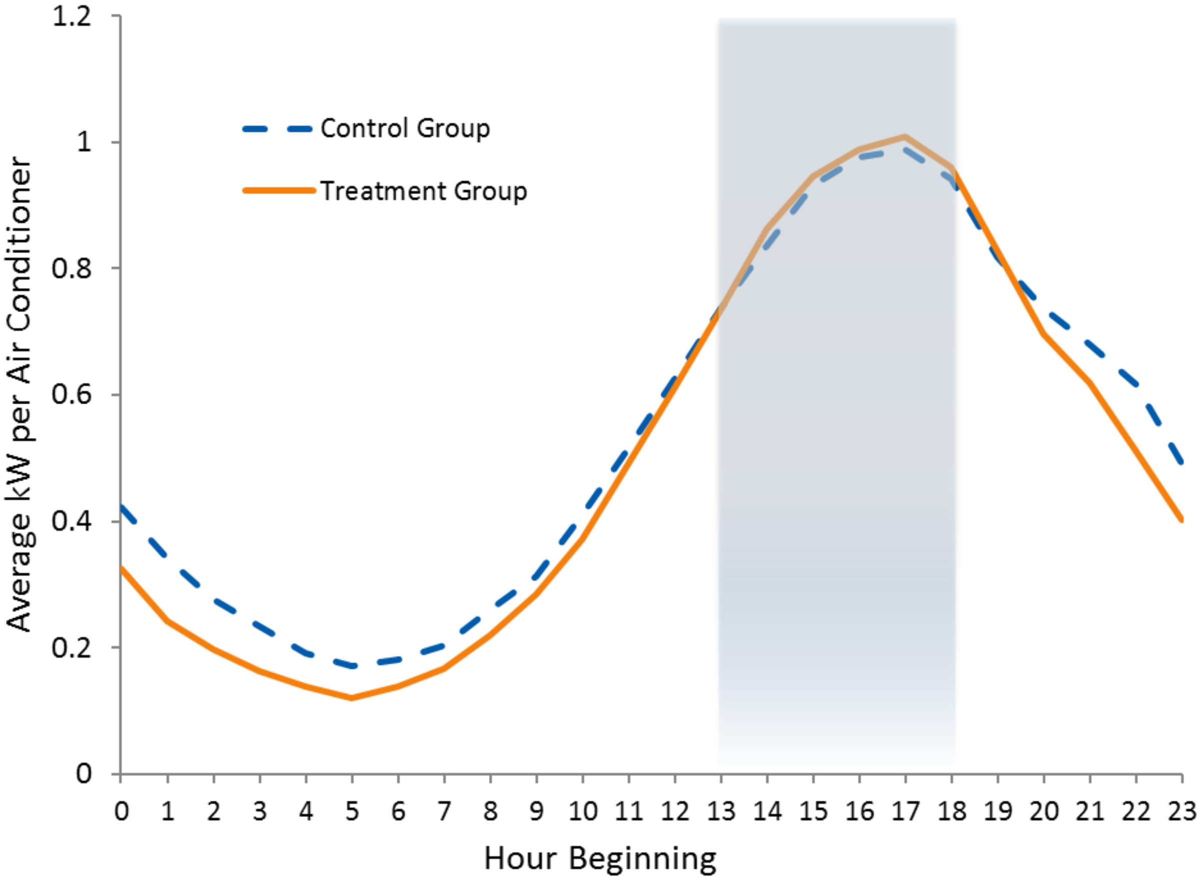
Unlike air conditioners, participating water heaters were completely switched off during events, so Cadmus could confirm water heater logger timestamp configuration by looking at the raw logger data during event days. Cadmus confirmed that the installation contractor had deployed the water heater loggers effectively.

Cadmus then merged the hourly demand data for air conditioners and water heaters with hourly weather from the Evansville, Indiana, regional airport. Weather data included temperature, humidity, and wind speed.

Air-Conditioning and Water-Heating Electricity-Use Patterns

Figure 1 displays electricity-use patterns for air conditioners in the treatment and control groups on non-event, non-holiday weekdays with average temperatures above 85°F between 3:00 p.m. and 6:00 p.m. The grey-shaded area indicates hours between 1:00 p.m. and 6:00 p.m.— the period during which Vectren called events in summer 2017. The demand curve in Figure 1 indicates the typical air-conditioning load for a Summer Cycler participant (treatment and control) on warm weekdays and shows that the random assignment of study air conditioners resulted in balanced treatment and control groups.

Figure 1. Air-Conditioner Demand (kW) on Non-Event Weekdays

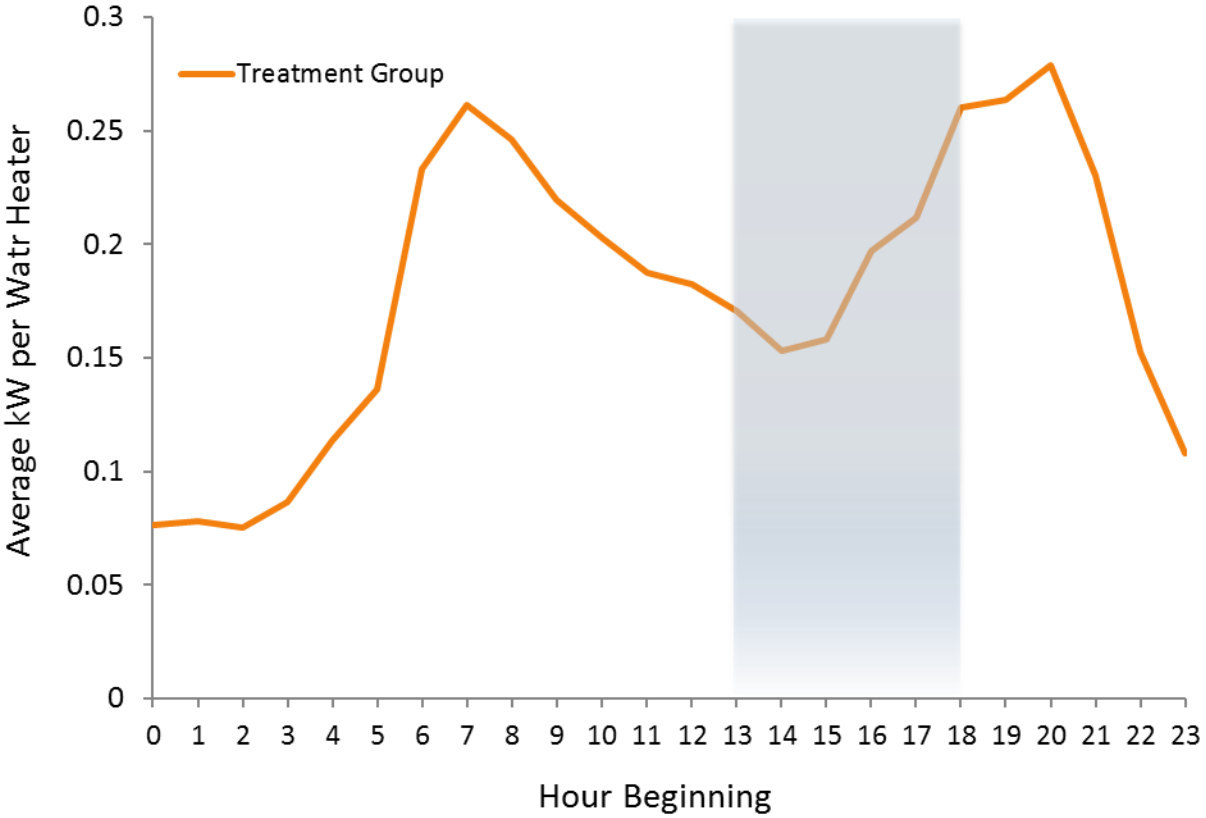


The average electricity demand per air conditioner increased over weekday afternoons and evenings, from approximately 0.6 kW at 12:00 p.m. to a peak of approximately 1 kW between 5:00 p.m. and 6:00 p.m. Demand decreased during the evening and was at its lowest during early morning hours.

The average demand of air conditioners in the treatment and control groups corresponded closely during daytime hours. Units in the treatment and control groups exhibited nearly identical average demand (differing by only 0.02 kW) during the event window, although units in the treatment group had slightly lower demand during early morning hours. These differences arose despite Cadmus' stratified random assignment of the logger analysis sample by peak energy use during the summer of 2015. The demand savings analysis accounted for these differences by estimating demand savings as a difference between treatment and control group air conditioners in the event hour/non-event hour.

Figure 2 shows the average demand per water heater in the logger analysis sample during warm, non-event weekdays. The evaluation did not employ a control group, so all sample water heaters experienced cycling.

Figure 2. Water Heater Demand (kW) on Non-Event Weekdays



Average electricity demand per water heater peaked twice during the day—first during morning hours and again during the evening. The Summer Cycler Program event window did not cover either peak, and during its event window, demand averaged 0.20 kW per water heater. After a period of high demand, such as multiple showers, a typical electric water heater demands between 4 kW and 5 kW to reheat the tank. Therefore, the small magnitude (less than 0.3 kW) of both peaks across the logger analysis group suggests that the timing of water heating demand during the day varied widely.

Detailed Impact Evaluation Findings

This section presents Cadmus' detailed findings from the 2017 Summer Cycler Program impact evaluation.

Savings Estimation Approach

Cadmus estimated demand savings from Vectren's Summer Cycler Program using kW data from the logger analysis sample for air conditioners in the treatment and control groups and for water heaters in the treatment group. The methodology included these elements *(Appendix D. Energy Savings Estimation Methodology* provides more details):

- Pooling logger electricity-demand data and estimating a model for each end use (air conditioning and water heating)
- Defining the analysis sample period as June 15, 2017, to September 31, 2017, and using data for all loggers and hours during this period
- Estimating savings from air-conditioning load control as a difference-in-differences (D-in-D) of demand per hour, which effectively compared the change in demand between event and non-event hours of treatment and control group units[4]
- Estimating savings from water-heating load control as a simple difference in energy demand between event and non-event hours, controlling for the hour of the day and weather
- Modeling 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. The air-conditioner models allowed the effects of hour of the day and cooling degree hours (CDH) to differ between treatment and control units.
- Using a Tobit regression to estimate the demand impacts accounted for the duty cycle of a typical air conditioner or water heater and the resulting non-normal distribution of electricity use for air conditioning and water heating, after controlling for the hour of the day, day of the week, and other factors[5]
- Estimating load impacts during the three hours of each event and the six hours after (+1, +2, …, +6) each event

Air-Conditioning Load Control Demand Savings

In the summer of 2017, Vectren initiated eight demand response load control events. Four of these events (events 1, 2, 3, and 5) cycled treatment and load research customers for three hours between 3 p.m. and 6 p.m. Event 4 cycled treatment and load research customers for two hours between 1 p.m.

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[4] The D-in-D analysis offered two benefits: it resulted in more precise savings estimates, and it controlled for non-program energy-use impacts correlated with events.

[5] See Appendix A. Demand Savings Estimation Methodology for details of the Tobit regression model.

and 3 p.m. Two events (events 6 and 8) were MISO events and cycled all customers (including treatment and control). Event 6 cycled all customers for three hours from 3 p.m. to 6 p.m. while event 8 cycled all customers for one hour between 3 p.m. and 4 p.m. Finally, event 7 cycled treatment and load research customers for an hour and 20 minutes from 1 p.m. to 2:20 p.m. Cadmus summarized this by combining events of the same event type (MISO or non-MISO) and the same event length. Additionally, the average MISO and non-MISO event effects are also presented.

Events 1, 2, 3, and 5 (3 p.m. to 6 p.m. Event Period)

Table 6 presents estimates of the average kW impact per air conditioner along the 3 p.m. to 6 p.m. events (events 1, 2, 3, and 5) and 90% confidence intervals for each of the three event hours, as well as for each of the first six hours after events. These events were non-MISO events during which only the customers in the treatment group and the load research samples experienced load curtailment. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each individual hour of each event (events 1, 2, 3 and 5).

Table 6 also presents the percentage demand savings (the estimated change in demand relative to the average demand of control units) and the achievable savings (savings Vectren would have achieved if it had curtailed the loads of all Summer Cycler air conditioners [treatment and control], not just those in the logger analysis and load research samples). Cadmus estimated achievable savings by multiplying the average load reduction per unit by the number of units in the program population (treatment and control).

Table 6. Estimates of Average Air-Conditioning DLC Impacts: 3 p.m. to 6 p.m. Events (Events 1, 2, 3, and 5)

Hour Beginning	Average Impact per Air Conditioner (kW)**	90% Confidence Intervals		Percentage Savings	Achievable Savings (kW)
		Lower Bound	Upper Bound		
Air Conditioning Load Control (N=84 treatment homes, 4 events)					
Event Hour 1 (3 p.m.)	-0.504*	-0.668	-0.341	29.8%	12,525
Event Hour 2 (4 p.m.)	-0.514*	-0.660	-0.367	30.4%	12,757
Event Hour 3 (5 p.m.)	-0.504*	-0.638	-0.369	29.9%	12,509
Post-Event Hour 1	0.106	-0.059	0.271	-6.8%	-2,629
Post-Event Hour 2	0.209*	0.042	0.376	-15.0%	-5,185
Post-Event Hour 3	0.151	-0.014	0.316	-12.4%	-3,757
Post-Event Hour 4	0.213*	0.052	0.374	-21.3%	-5,284
Post-Event Hour 5	0.159	-0.001	0.320	-18.3%	-3,951
Post-Event Hour 6	0.096	-0.038	0.229	-12.4%	-2,373

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

**The kW impacts are the average demand impacts across treatment-group air conditioners and events; they are based on Tobit regression analysis of unit hourly energy use.

The average demand reduction per air conditioner was 0.5 kW in the first event hour, 0.51 kW in the second event hour, and 0.5 kW in the third event hour. Overall, savings averaged 0.5 kW per air conditioner across the three event hours. The estimated average demand savings in each event hour was statistically different from zero at the 10% level.

Rebound of air conditioning loads for these events was modest. Estimated rebound impacts in four of the six post-event hours were not statistically significant, thus these increases in usage were not statistically different than 0.

The estimated average load reductions during event hours were depicted as deviations of metered kW from baseline kW during the event.

Figure 3 shows an average demand reduction of about 0.5 kW. The figure also shows a slight rebound of demand following the events. Metered kW and predicted kW were slightly greater than baseline kW between 6 p.m. to 11 p.m. Rebound disappeared and consumption returned to the baseline about six hours after the events ended.

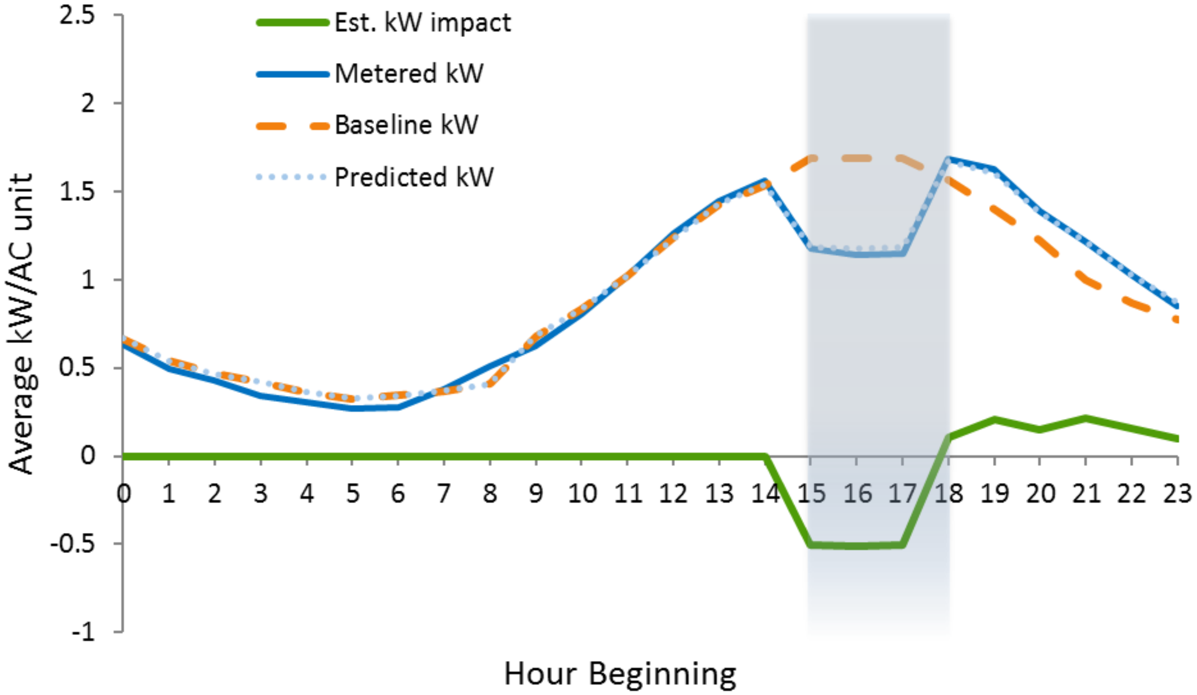
Figure 3 depicts the average impacts per air conditioner during 3 p.m. to 6 p.m. events and shows average metered kW, average model predicted kW, average baseline kW, and average estimated kW impacts. Cadmus defined each of these elements as follows:

- **Metered kW** represents demand per air conditioner unit, as recorded by the loggers.
- **Predicted kW** represents metered kW per unit, as predicted by the regression models. Only negligible differences occurred between metered kW and predicted kW during event and non-event hours, indicating, on average, the regression models predicted demand accurately.
- **Baseline kW** represents what the average demand predicted in the regression model would have been during the three 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 metered kW and baseline kW, as shown in the figure's green line (labeled with point estimates of the demand impacts).

The estimated average load reductions during event hours were depicted as deviations of metered kW from baseline kW during the event.

Figure 3 shows an average demand reduction of about 0.5 kW. The figure also shows a slight rebound of demand following the events. Metered kW and predicted kW were slightly greater than baseline kW between 6 p.m. to 11 p.m. Rebound disappeared and consumption returned to the baseline about six hours after the events ended.

Figure 3. Estimates of Air-Conditioning Load Control kW Impacts: Events 1, 2, 3, and 5



Event 4 (1 p.m. to 3p.m. Event Period)

Table 7 presents estimates of the average kW impact for event 4 (July 21, 2017, 1 p.m. to 3 p.m.) per air conditioner and 90% confidence intervals for each of the two event hours as well as for each of the first six hours after events. Unlike most summer 2017 events, this event occurred between 1 p.m. to 3 p.m. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each hour of event 4.

Table 7. Estimates of Average Air-Conditioning DLC Impacts: Event 4 (1 -3 p.m.)

Hour Beginning	Average Impact per	90% Confidence Intervals	Percentage	Achievable

		Lower Bound	Upper Bound		
Air Conditioning Load Control (N=80 treatment homes, 1 event)					
Event Hour 1 (1 p.m.)	-0.524*	-0.814	-0.234	29.4%	13,011
Event Hour 2 (2 p.m.)	-0.812*	-1.114	-0.509	39.1%	20,151
Post-Event Hour 1	-0.082	-0.399	0.235	4.0%	2,030
Post-Event Hour 2	0.054	-0.289	0.398	-2.6%	-1,352
Post-Event Hour 3	-0.022	-0.383	0.338	1.1%	557
Post-Event Hour 4	0.035	-0.331	0.400	-1.7%	-860
Post-Event Hour 5	-0.013	-0.359	0.333	0.7%	321
Post-Event Hour 6	0.027	-0.314	0.368	-1.7%	-672

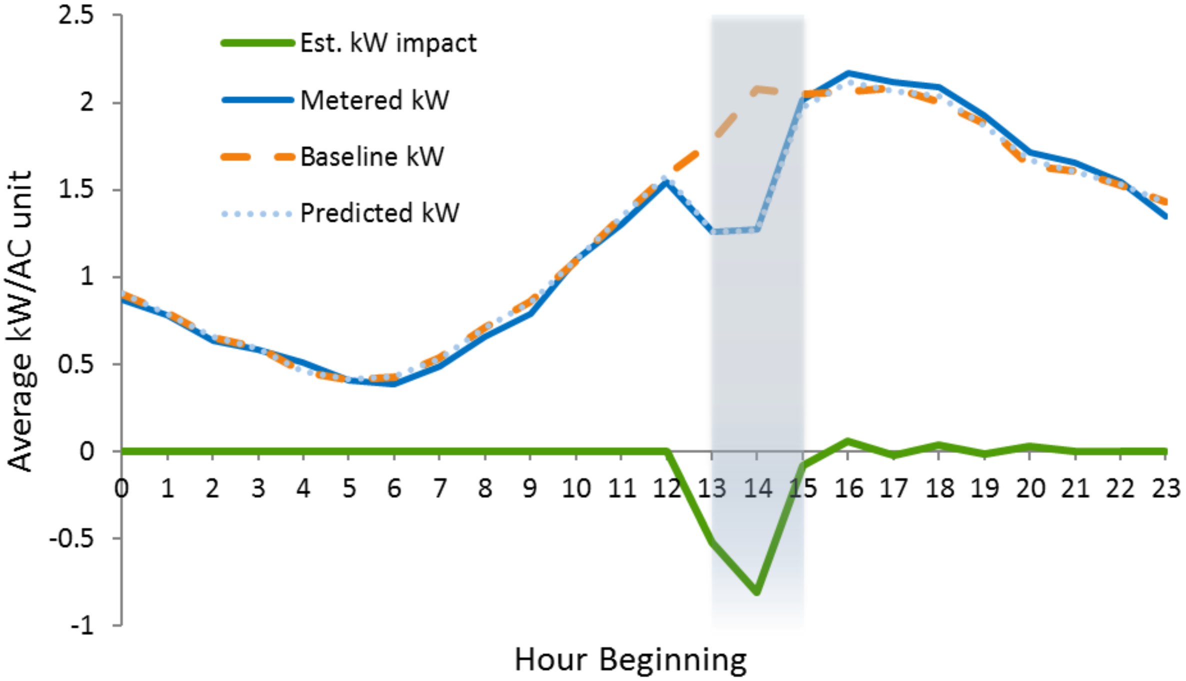
*This estimate is statistically significant at the 10% level.

**The kW impacts are the average demand impacts across treatment-group air conditioners and events; they are based on Tobit regression analysis of unit hourly energy use.

The average demand reduction per air conditioner was 0.52 kW in the first event hour and 0.81 kW in the second event hour. Overall, savings averaged 0.67 kW per air conditioner across the two event hours. The estimated average demand savings in each event hour was statistically different from zero at the 10% level. None of the post-event hour impact estimates were significant at the 10% confidence level. This event had the highest event hour average temperature among all summer 2017 events, which resulted in higher average savings than the other events.

Figure 4 shows the average demand reduction of about 0.7 kW. Rebound across all six post-event hours was minimal and not statistically significant. The absence of any major rebound after this event could be due to the extreme heat during and after this event. If the typical control group air conditioner was running at capacity (i.e., nonstop) throughout the afternoon, rebound after the event would not be observed among the control group as additional run time, and the effect of the event would be reflected only in higher interior temperatures. The flat shape of the metered kW shown in Figure 4 between 3 p.m. and 7 p.m. supports this theory in that the average kW per air conditioner did not increase later in the afternoon after the end of the event as it normally would have (as shown by the average non-event curves in Figure 1).

Figure 4. Estimates of Air-Conditioning Load Control kW Impacts: Event 4



Event 6 (MISO Event; 3 p.m. to 6 p.m. Event Period)

Table 8 presents estimates of the average kW impact for event 6 (September 21, 2017, 3 p.m. to 6 p.m.) per air conditioner and 90% confidence intervals for each of the two event hours as well as for each of the first six hours after events. This event was called in response to a MISO load curtailment request, and thus all Summer Cycler participants were cycled, not just the treatment customers as in previous events. Therefore, the Achieved Savings column represents the actual, estimated savings achieved by cycling all Summer Cycler customers during the event. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each hour of event 6.

Table 8. Estimates of Average Air-Conditioning DLC Impacts: Event 6 (MISO Event, 3 p.m. to 6 p.m.)

Hour Beginning	Average Impact per	90% Confidence Intervals	Percentage	Achieved Savings

		Lower Bound	**Upper Bound**		
Air Conditioning Load Control (N=156 treatment homes, 1 events)					
Event Hour 1	-0.376*	-0.528	-0.225	25.7%	9,348
Event Hour 2	-0.469*	-0.601	-0.338	29.7%	11,656
Event Hour 3	-0.229*	-0.371	-0.087	17.8%	5,686
Post-Event Hour 1	0.312*	0.140	0.485	-28.7%	-7,754
Post-Event Hour 2	0.074	-0.095	0.244	-6.3%	-1,849
Post-Event Hour 3	0.188*	0.020	0.356	-22.2%	-4,662
Post-Event Hour 4	0.269*	0.111	0.426	-40.7%	-6,676
Post-Event Hour 5	0.190*	0.039	0.342	-32.1%	-4,725
Post-Event Hour 6	0.156*	0.008	0.304	-31.1%	-3,869

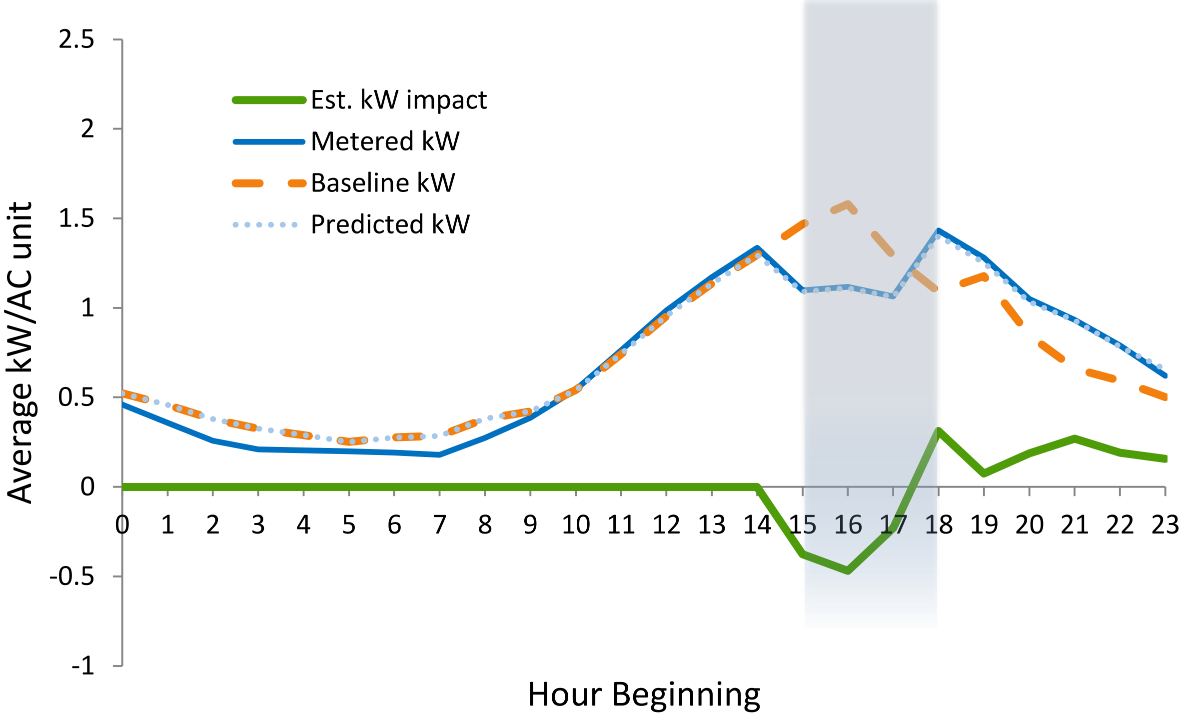
*This estimate is statistically significant at the 10% level.

**The kW impacts are the average demand impacts across treatment-group air conditioners and events; they are based on Tobit regression analysis of unit hourly energy use.

The average demand reduction per air conditioner was 0.38 kW in the first event hour, 0.47 kW in the second event hour, and 0.23 kW in the third event hour. Overall, savings averaged 0.36 kW per air conditioner across the three event hours. The estimated average demand savings in each event hour was statistically different from zero at the 10% level. Rebound of air conditioning loads for this event was significant for five of the six post-event hours and was of a similar magnitude to the demand reductions.

Figure 5 shows the average demand reduction of 0.4 kW associated with event 6. The figure also shows the rebound of demand following the events. The rebound effect disappeared after six hours.

Figure 5. Estimates of Air-Conditioning Load Control kW Impacts: Event 6



Events 7 and 8 (1 p.m. to 2:20 p.m. Event Period; MISO Event (3 p.m. to 4 p.m. Event Period)

Table 9 presents estimates of the average kW impact for event 7 (September 22, 2017) per air conditioner and 90% confidence intervals for each of the three event hours as well as for each of the first six hours after events. This event occurred between 1:00 p.m. and 2:20 p.m., then resumed from 3:00 p.m. and 4:00 p.m. From 1:00 p.m. to 2:20 p.m. only the treatment group was cycled. The second event hour impact (2 p.m. to 3 p.m.) is therefore the average of 20 minutes of cycling and 40 minutes of post-event rebound. MISO requested load curtailment from 3:00 p.m. to 4:00 p.m., so all Summer Cycler customers were cycled during the last hour of the event. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each hour of event 7.

Table 9. Estimates of Average Air-Conditioning DLC Impacts:
Events 7 and 8 (1 p.m. to 2:20 p.m.; 3 p.m. to 4 p.m.)

Hour Beginning	Average Impact per	90% Confidence Intervals	Percentage	Achieved Savings

		Lower Bound	Upper Bound		
Air Conditioning Load Control (N=156 treatment homes, 2 events)					
Event Hour 1	-0.193*	-0.332	-0.054	16.9%	4,792
Event Hour 2[+]	-0.054	-0.214	0.106	4.2%	1,337
Event Hour 3[++]	-0.340*	-0.481	-0.200	24.4%	8,447
Post-Event Hour 1	0.203*	0.037	0.368	-15.7%	-5,029
Post-Event Hour 2	0.189*	0.000	0.377	-14.8%	-4,688
Post-Event Hour 3	0.035	-0.131	0.201	-2.8%	-862
Post-Event Hour 4	0.376*	0.204	0.547	-52.7%	-9,324
Post-Event Hour 5	0.443*	0.299	0.586	-85.7%	-10,987
Post-Event Hour 6	0.299*	0.159	0.440	-61.6%	-7,431

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

**The kW impacts are the average demand impacts across treatment-group air conditioners and events; they are based on Tobit regression analysis of unit hourly energy use.

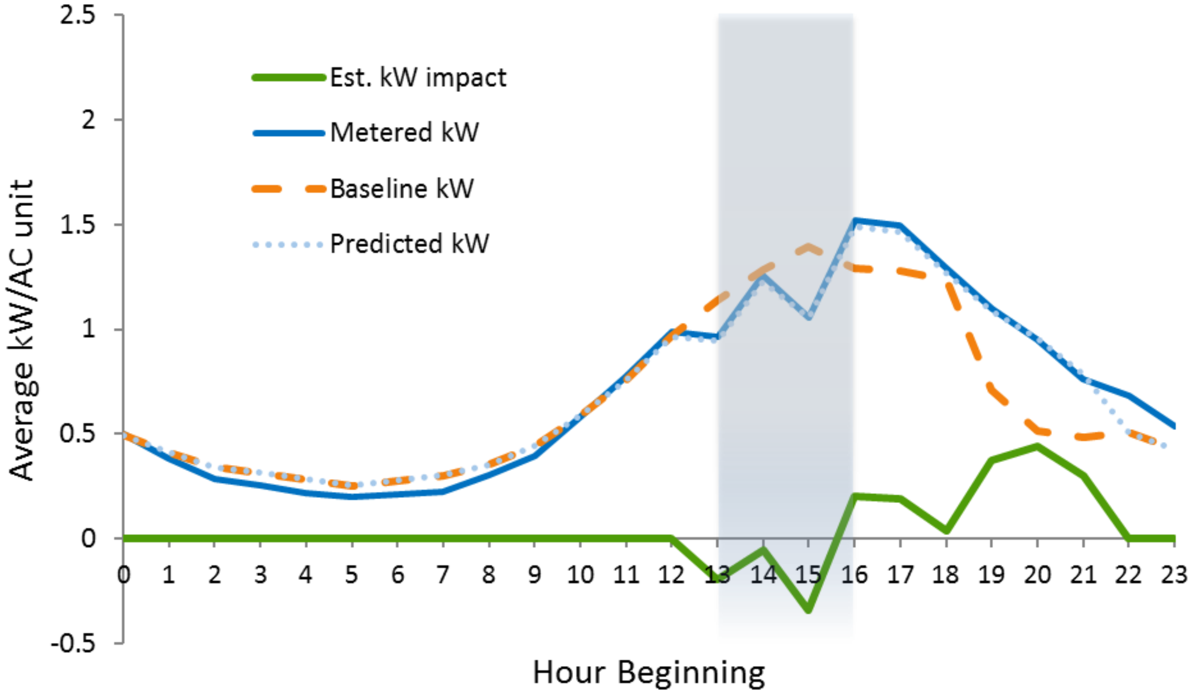
[+] Average of 20 minutes of cycling and 40 minutes of post-event rebound

[++] All Summer Cycler customers cycled due to MISO load reduction event.

The average demand reduction per air conditioner was 0.19 kW in the first event hour, 0.05 kW in the second event hour (which included only 20 minutes of cycling), and 0.34 kW in the third event hour (during which all Summer Cycler customers were cycled). Overall, savings averaged 0.20 kW per air conditioner across the three event hours. The estimated average demand savings in each event hour was statistically different from zero at the 10% level. Rebound of air conditioning loads for these events was significant and of a similar magnitude to the event impacts. Five of the six post-event hour rebound impact estimates were statistically different than 0.

Figure 6 shows the average demand reduction of about 0.20 kW associated with event 7 and the 0.34 kW associated with event 8. The figure shows the effects of the second event hour, which included only 20 minutes of cycling, as well as the slight rebound of energy demand following the events. Metered kW and predicted kW were slightly greater than baseline kW between 6:00 p.m. and 11:00 p.m. Rebound disappeared about six hours after the events ended.

Figure 6. Estimates of Air-Conditioning Load Control kW Impacts: Events 7 and 8



Combined Event Impacts for Air Conditioners

Non-MISO Events

Table 10 presents estimates of the average kW impact from all non-MISO event (1, 2, 3, 4, 5, and 7) hours per air conditioner and 90% confidence intervals for each of the three event hours as well as for each of the first six hours after events. Non-MISO events cycled only treatment and load research customers. The non-MISO events were not all during the same time of day or the same length of time. These event hours occurred between 1:00 p.m. and 2:00 p.m. and between 3:00 p.m. and 6:00 p.m. Cadmus combined all six events to create an average hour impact across all non-MISO events.

The first event hour includes events all six events. The second hour and all post-event hours include events 1 through 5, but not event 7, as event 7 had only one event hour that was then followed by a MISO event. The third event hour includes only events 1 through 3 and event 5; events 4 and 7 were both excluded as neither had a third event hour. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each hour of each of these events.

Table 10. Estimates of Average Air-Conditioning DLC Impacts: Non-MISO Events

Hour Beginning	Average Impact per	90% Confidence Intervals	Percentage	Achievable

		Lower Bound	Upper Bound		
Air Conditioning Load Control (N=156 treatment homes, 6 event)					
Event Hour 1+	-0.407*	-0.527	-0.287	26.5%	10,109
Event Hour 2++	-0.663*	-0.831	-0.495	35.2%	16,454
Event Hour 3+++	-0.504*	-0.638	-0.369	29.9%	12,509
Post-Event Hour 1++	0.012	-0.178	0.203	-0.7%	-299
Post-Event Hour 2++	0.132	-0.067	0.331	-7.6%	-3,268
Post-Event Hour 3++	0.064	-0.136	0.265	-3.9%	-1,600
Post-Event Hour 4++	0.124	-0.067	0.315	-8.3%	-3,072
Post-Event Hour 5++	0.073	-0.115	0.261	-5.3%	-1,815
Post-Event Hour 6++	0.061	-0.005	0.128	-5.1%	-1,522

+Average impact of events 1-5, and 7.

++Average impact of events 1-5.

+++Average impact of events 1-3, and 5.

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

**The kW impacts are the average demand impacts across treatment-group air conditioners and events; they are based on Tobit regression analysis of unit hourly energy use.

The average demand reduction per air conditioner was 0.41 kW in the first event hour, 0.66 kW in the second event hour, and 0.50 kW in the third event hour. Overall, savings averaged about 0.52 kW per air conditioner across the three event hours. The estimated average demand savings in each event hour was statistically different from zero at the 10% level. Rebound of air conditioning loads for these events was modest. None of the post-event hours were significant different than zero at the 10% confidence level.

MISO Events

Table 11 presents estimates of the average kW impact during all MISO event hours per air conditioner and 90% confidence intervals for each of the three event hours as well as for each of the first six hours after events. These events occurred between 3:00 p.m. and 6:00 p.m. These events cycled all Summer Cycler customers, not just treatment and load research customers. The first event hour and all post-event hours include events 6 and 8. The second and third event hour estimates include only event 6 as event 8 included only one hour of a MISO event. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each hour of each of these events.

Table 11. Estimates of Average Air-Conditioning DLC Impacts: MISO Events

Hour Beginning	Average Impact per	90% Confidence Intervals	Percentage	Achieved Savings

		Lower Bound	Upper Bound		
Air Conditioning Load Control (N=156 treatment homes, 2 events)					
Event Hour 1[+]	-0.358*	-0.461	-0.256	24.4%	8,897
Event Hour 2[++]	-0.469*	-0.601	-0.338	29.7%	11,656
Event Hour 3[++]	-0.229*	-0.371	-0.087	17.1%	5,686
Post-Event Hour 1[+]	0.257*	0.138	0.377	-21.6%	-6,391
Post-Event Hour 2[+]	0.132*	0.005	0.258	-10.7%	-3,269
Post-Event Hour 3[+]	0.111	-0.007	0.229	-10.7%	-2,762
Post-Event Hour 4[+]	0.322*	0.206	0.439	-46.9%	-8,000
Post-Event Hour 5[+]	0.316*	0.212	0.421	-57.1%	-7,856
Post-Event Hour 6[+]	0.228*	0.126	0.329	-46.1%	-5,650

[+] Average impact of events 6 and 8.

[++] Average impact of event 6

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

**The kW impacts are the average demand impacts across treatment-group air conditioners and events; they are based on Tobit regression analysis of unit hourly energy use.

The average demand reduction per air conditioner was 0.36 kW in the first event hour, 0.47 kW in the second event hour, and 0.23 kW in the third event hour. Overall, savings averaged about 0.38 kW per air conditioner across the three event hours. The estimated average demand savings in each event hour was statistically different from zero at the 10% level. Rebound of air conditioning loads for these events was modest. Five of the post-event hours were significant at the 10% confidence level. Events 6 and 7 had the lowest average hourly event temperatures.

Overall Event Impacts for Air Conditioners

Vectren’s system typically experiences peak loads on summer weekdays between 3:00 p.m. and 6:00 p.m., when the outside temperature exceeds 95°F. Summer 2017 was relatively warm, with the outside temperature during event hours averaging between 82ºF and 96ºF. The average savings during summer 2017 was 0.52 kW for non-MISO events and 0.38 kW for MISO events. Event 4 achieved the highest savings since the outdoor temperature on event 4 were greater than all other events.

Air-Conditioning Load Control Percentage of Control Group Load

In 2017, the Summer Cycler Program non-MISO events achieved average demand savings per controlled air conditioner of about 0.52 kW. Expressing these demand savings as a percentage of average baseline air conditioning load yields a realization rate of approximately 31%, instead of 50% as specified by the cycling strategy

Water-Heating Load Control Demand Savings

Events 1, 2, 3, and 5 (3 p.m. to 6 p.m. Event Period)

Table 12 presents estimates of the average kW impact per water heater among the 3 p.m. to 6 p.m. events (events 1, 2, 3, and 5) and 90% confidence intervals for each of the three event hours, as well as for each of the first six hours after events. An additional table listing average water heater demand impacts for each hour of events 1, 2, 3, and 5 is included in *Appendix C. Water Heater kW Impacts by Event Hour*.

Table 12. Estimates of Water-Heating DLC Impacts*: Events 1, 2, 3, and 5

Hour Beginning	Impact per Water Heater (kW)**	90% Confidence Intervals		Percentage Savings	Achievable Savings (kW)
		Lower Bound	Upper Bound		
Water-Heating Load Control (N=67 treatment homes, 4 events)					
Event Hour 1	-0.127*	-0.188	-0.067	52.3%	826
Event Hour 2	-0.053	-0.121	0.015	22.5%	345
Event Hour 3	-0.062	-0.137	0.012	24.4%	405
Post-Event Hour 1	0.207*	0.086	0.327	-105.3%	-1,340
Post-Event Hour 2	0.001	-0.107	0.109	-0.4%	-7
Post-Event Hour 3	-0.040	-0.129	0.050	13.5%	258
Post-Event Hour 4	0.000	-0.073	0.074	-0.2%	-2
Post-Event Hour 5	0.053	-0.038	0.144	-34.4%	-343
Post-Event Hour 6	0.027	-0.027	0.080	-21.2%	-174

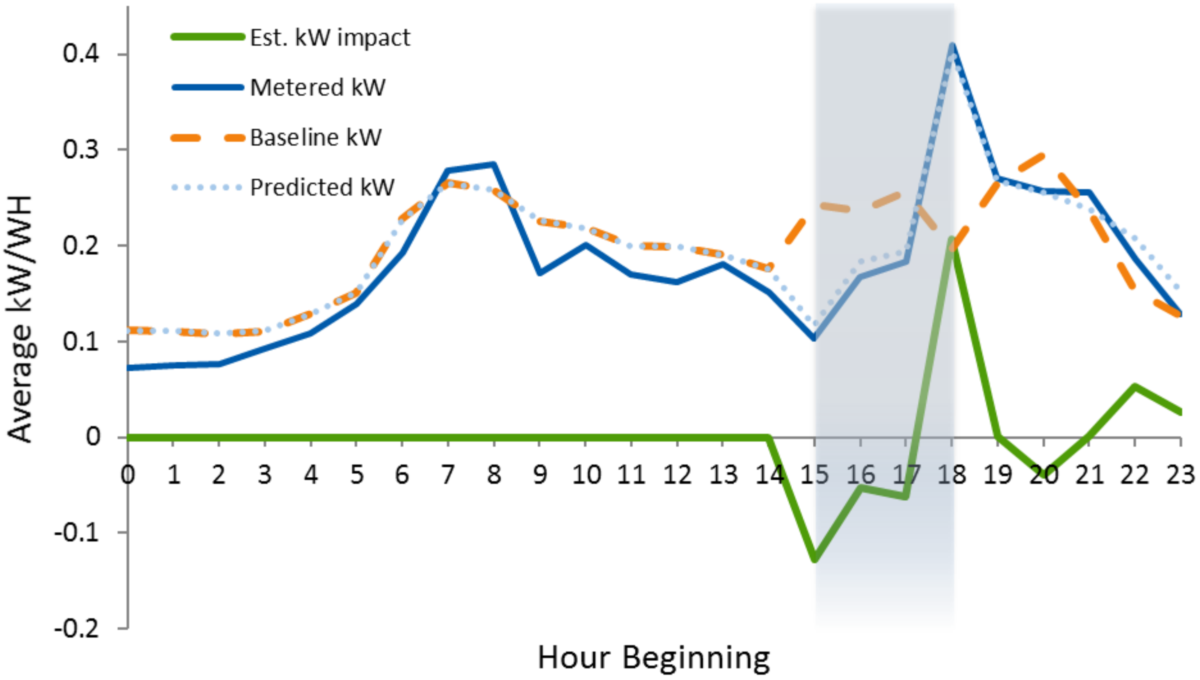
*These estimates were statistically significant at the 10% level.

**The kW impacts and the average demand impacts across water heaters and events in the treatment group were based on Tobit regression of unit hourly energy use.

The average demand reduction per water heater was 0.13 kW in the first event hour, 0.05 kW in the second event hour, and 0.06 kW in the third event hour. Demand savings averaged 0.08 kW across all event hours. The demand reductions were statistically different from zero at the 10% significance level in only the first event hours and in the first hour after the event.

Figure 7 presents savings during events 1, 2, 3, and 5 from water-heating direct load control (DLC) events, showing average metered kW, average model-predicted kW, average baseline kW, and estimated average kW impacts, as defined previously in the air-conditioning impact analysis. Again, load reduction during the event and rebound afterward appeared as deviations between metered kW and baseline kW. Rebound was statistically significant and was larger in magnitude than the demand savings impacts during the event hours. However, rebound occurred only during the first hour after the event, as the estimated additional demand of 0.21 kW represents only three minutes of additional run time relative to the baseline for a water heater with a 4-kilowatt heating element.

Figure 7. Estimates of Water-Heating Load Control kW Impacts (3:00 p.m. to 6:00 p.m.): Events 1, 2, 3, and 5



Event 4 (1-3p.m. Event Period)

Table 13 presents estimates for event 4 (July 21, 2017, 1 p.m. to 3 p.m.) of the average kW impacts per controlled water heater for the first and second event hours as well as for each of the first six post-event hours. An additional table listing average demand impacts for each hour of event 4 is included in *Appendix C. Water Heater kW Impacts by Event Hour.*

Table 13. Estimates of Water-Heating DLC Impacts*: Event 4 (1-3 p.m.)

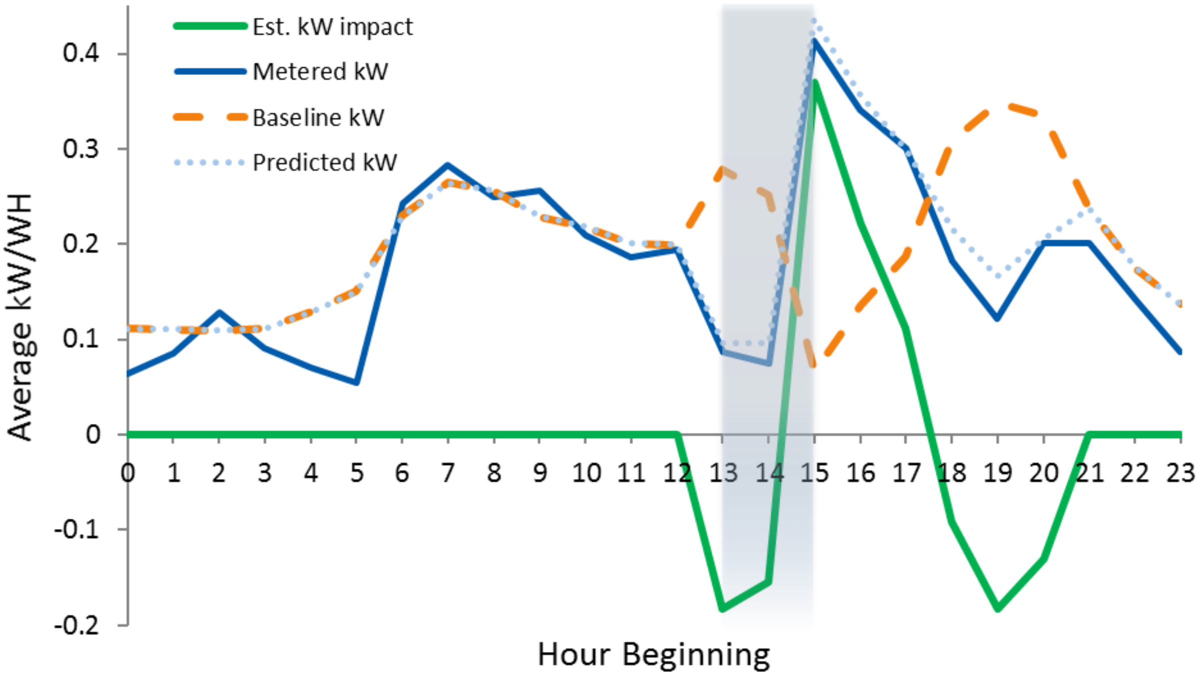
Hour Beginning	Impact per Water Heater (kW)**	90% Confidence Intervals		Percentage Savings	Achievable Savings (kW)
		Lower Bound	Upper Bound		
Water-Heating Load Control (N=67 treatment homes, 1 event)					
Event Hour 1	-0.182*	-0.304	-0.061	65.4%	1,183
Event Hour 2	-0.155	-0.330	0.021	61.5%	1,002
Post-Event Hour 1	0.370*	0.132	0.608	-556.5%	-2,398
Post-Event Hour 2	0.222	-0.082	0.526	-163.8%	-1,438
Post-Event Hour 3	0.111	-0.112	0.335	-59.5%	-722
Post-Event Hour 4	-0.091	-0.271	0.088	29.7%	591
Post-Event Hour 5	-0.183	-0.529	0.164	52.5%	1,186
Post-Event Hour 6	-0.130	-0.394	0.134	38.9%	846

*These estimates were statistically significant at the 10% level.

**The kW impacts and the average demand impacts across water heaters and events in the treatment group were based on Tobit regression of unit hourly energy use.

The average demand reduction per water heater was 0.18 kW in the first event hour and 0.16 kW in the second event hour. Demand savings averaged 0.17 kW across event hours. The demand reductions were statistically different from zero at the 10% significance level in event hour one and in the first hour after the event. Figure 8 presents savings during event 4 from water-heating DLC events.

Figure 8. Estimates of Water-Heating Load Control kW Impacts (1:00 p.m. to 3:00 p.m.): Event 4



Event 6 (MISO Event; 3 p.m. to 6 p.m. Event Period)

Table 14 presents estimates for event 6 (September 21, 2017, 3 p.m. to 6 p.m.) of the average kW impacts per controlled water heater for the first and second event hours as well as for each of the first six post-event hours. An additional table listing average demand impacts for each hour of event 6 is included in *Appendix C. Water Heater kW Impacts by Event Hour*.

Table 14. Estimates of Water-Heating DLC Impacts*: Events 6

Hour Beginning	Impact per Water Heater (kW)**	90% Confidence Intervals		Percentage Savings	Achieved Savings (kW)
		Lower Bound	Upper Bound		
Water-Heating Load Control (N=12 treatment homes, 1 event)					
Event Hour 1	-0.270	-0.653	0.113	82.1%	1,752
Event Hour 2	-0.273	-0.731	0.185	77.2%	1,771
Event Hour 3	-0.244	-0.641	0.153	69.9%	1,582
Post-Event Hour 1	1.077	-0.349	2.502	-4493.7%	-6,979
Post-Event Hour 2	0.348	-0.352	1.048	-227.9%	-2,258
Post-Event Hour 3	-0.036	-0.414	0.343	12.2%	232
Post-Event Hour 4	0.366	-0.381	1.113	-305.4%	-2,370
Post-Event Hour 5	0.071	-0.187	0.329	-48.3%	-460
Post-Event Hour 6	0.103	-0.174	0.380	-105.0%	-666

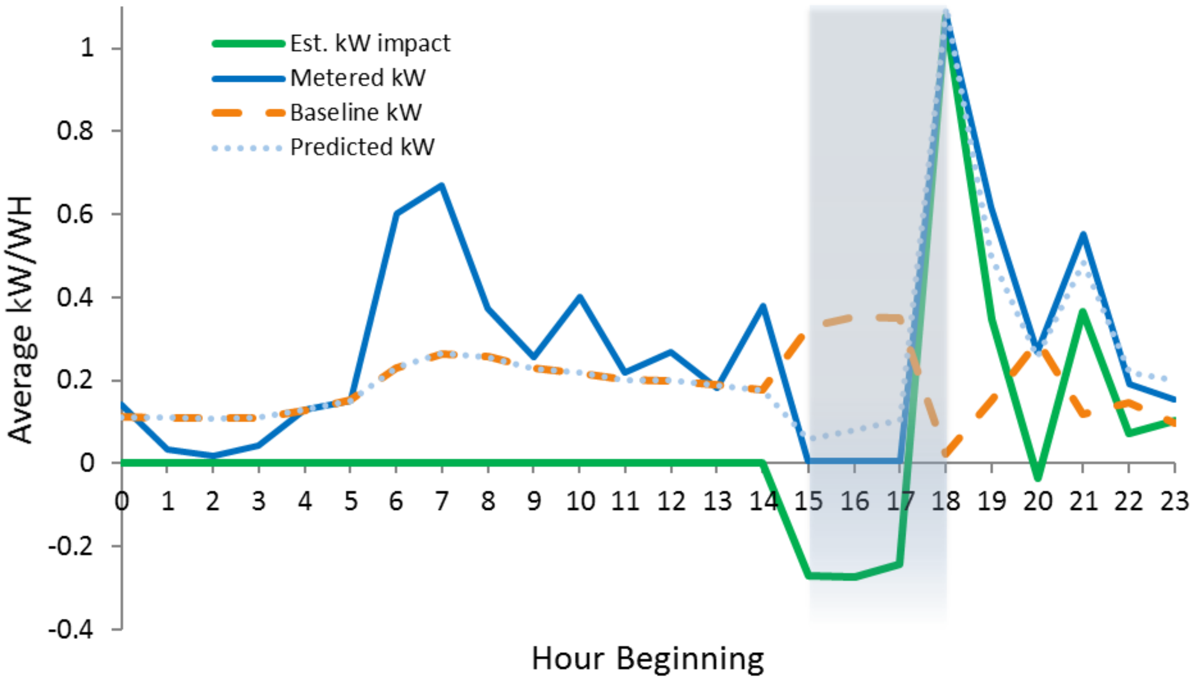
*These estimates were statistically significant at the 10% level.

**The kW impacts and the average demand impacts across water heaters and events in the treatment group were based on Tobit regression of unit hourly energy use.

The average demand reduction per water heater was 0.27 kW in the first event hour, 0.27 kW in the second event hour, and 0.24 in the third event hour. Demand savings averaged 0.26 kW across all event hours. The demand reductions were statistically different from zero at the 10% significance level in all three event hours and in the first hour after the event. It should be noted that due to the late date of this event, many loggers did have data for these events. Therefore, these results are not statistically significant.

Figure 9 presents savings during event 6 from water-heating DLC events, showing average metered kW, average model-predicted kW, average baseline kW, and estimated average kW impacts, with these variables defined in the air-conditioning impact analysis. Again, load reduction during the event and rebound afterward appeared as deviations between metered kW and baseline kW.

Figure 9. Estimates of Water-Heating Load Control kW Impacts (3:00 p.m. to 6:00 p.m.): Event 6



Events 7 and 8 (1-2:20 p.m. Event Period; MISO Event 3 p.m. to 4 p.m. Event Period)

Table 15 presents estimates for events 7 and 8 (September 22, 2017, 1 p.m. to 4 p.m.) of the average kW impacts per controlled water heater for the first and second event hours as well as for each of the first six post-event hours. An additional table listing average demand impacts for each hour of events 7 and 8 is included in *Appendix C. Water Heater kW Impacts by Event Hour*.

Table 15. Estimates of Water-Heating DLC Impacts*: Events 7 and 8

Hour Beginning	Impact per Water Heater (kW)**	90% Confidence Intervals		Percentage Savings	Achieved Savings (kW)
		Lower Bound	Upper Bound		
Water-Heating Load Control (N=12 treatment homes, 2 events)					
Event Hour 1	-0.192	-0.532	0.148	67.5%	1,245
Event Hour 2	0.251	-0.369	0.870	-277.4%	-1,625
Event Hour 3	-0.276	-0.818	0.266	82.8%	1,787
Post-Event Hour 1	0.352	-0.121	0.824	-353.5%	-2,279
Post-Event Hour 2	-0.061	-0.484	0.361	24.0%	398
Post-Event Hour 3	-0.002	-0.291	0.287	0.8%	13
Post-Event Hour 4	0.026	-0.319	0.371	-10.1%	-168
Post-Event Hour 5	-0.099	-0.444	0.246	30.8%	640
Post-Event Hour 6	0.017	-0.240	0.275	-7.5%	-112

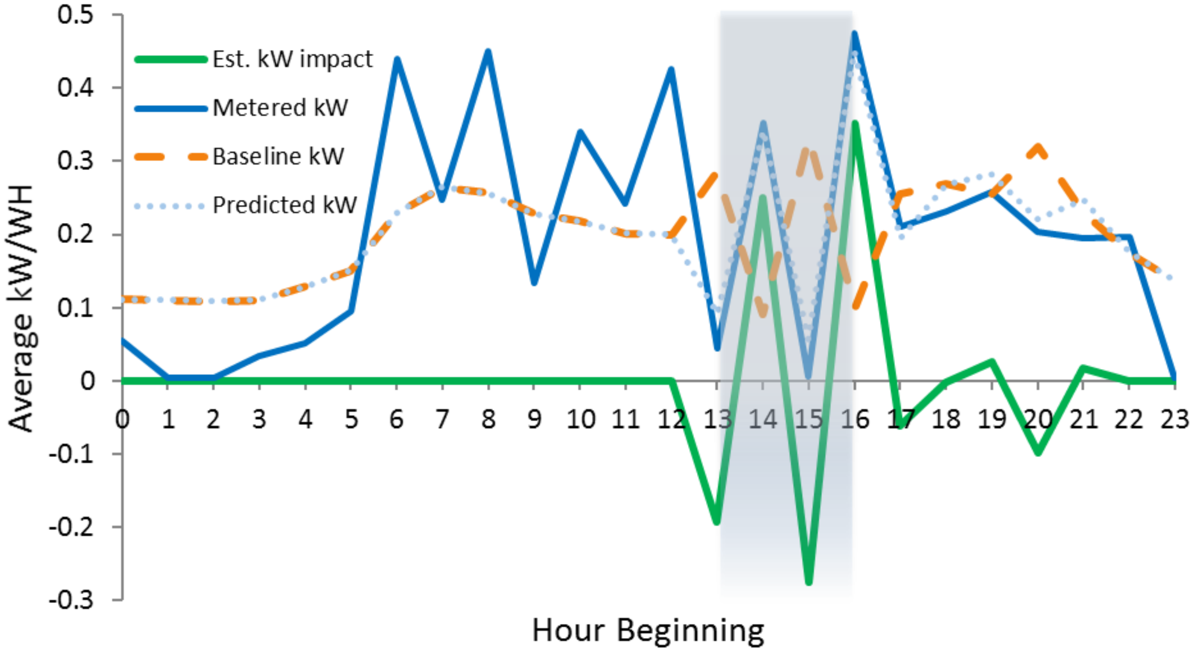
*These estimates were statistically significant at the 10% level.

**The kW impacts and the average demand impacts across water heaters and events in the treatment group were based on Tobit regression of unit hourly energy use.

The average demand reduction per water heater was 0.19 kW in the first event hour, -0.25 kW in the second event hour (which was a partial event), and 0.28 kW in the third event hour. Overall, savings averaged about 0.07 kW per air conditioner across the three event hours. It should be noted that due to the late date of this event, many loggers did have data for these events. Therefore, these results are not statistically significant.

Figure 10 presents savings during events 7 and 8 from water-heating DLC events, showing average metered kW, average model-predicted kW, average baseline kW, and estimated average kW impacts, with these variables defined in the air-conditioning impact analysis. Again, load reduction during the event and rebound afterward appeared as deviations between metered kW and baseline kW.

Figure 10. Estimates of Water-Heating Load Control kW Impacts (1:00 p.m. to 4:00 p.m.): Event 7



Combined Event Impacts for Water Heaters

Non-MISO Events

Table 16 presents estimates of the average kW impact from all non-MISO event (events 1, 2, 3, 4, 5, and 7) hours per air conditioner and 90% confidence intervals for each of the three event hours as well as for each of the first six hours after events. The non-MISO events were not all during the same time of day or the same length of time. These event hours occurred between 1:00 p.m. and 2:00 p.m. and 3:00 p.m. and 6:00 p.m. Cadmus combined all six events to create an average hour impact across all non-MISO events.

The first event hour includes events all six events. The second hour and all post-event hours include events 1 through 5, but not event 7 as event 7 only had one event hour that was then followed by a MISO event. The third event hour includes only events 1 through 3 and event 5; events 4 and 7 were both excluded as neither had a third event hour. *Appendix B. Air Conditioner kW Impacts for Each Event Hour* includes tables reporting average demand impacts for each hour of each of these events.

Table 16. Estimates of Water-Heating DLC Impacts*: Non-MISO Events

Hour Beginning	Impact per Water Heater (kW)**	90% Confidence Intervals		Percentage Savings	Achieved Savings (kW)
		Lower Bound	Upper Bound		
Water-Heating Load Control (N=81 treatment homes, 6 events)					
Event Hour 1[+]	-0.167*	-0.289	-0.045	62.2%	1,084
Event Hour 2[++]	-0.104*	-0.198	-0.010	42.6%	673
Event Hour 3[+++]	-0.062	-0.137	0.012	24.4%	405
Post-Event Hour 1[++]	0.288*	0.155	0.422	-219.5%	-1,869
Post-Event Hour 2[++]	0.111	-0.050	0.273	-55.5%	-722
Post-Event Hour 3[++]	0.036	-0.084	0.156	-14.8%	-232
Post-Event Hour 4[++]	-0.045	-0.142	0.052	16.7%	294
Post-Event Hour 5[++]	-0.065	-0.244	0.114	25.9%	421
Post-Event Hour 6[++]	-0.052	-0.186	0.083	22.5%	336

[+] Average impact of events 1-5, and 7.

[++] Average impact of events 1-5.

[+++] Average impact of events 1-3, and 5.

*These estimates were statistically significant at the 10% level.

**The kW impacts and the average demand impacts across water heaters and events in the treatment group were based on Tobit regression of unit hourly energy use.

The average demand reduction per water heater was 0.17 kW in the first event hour, 0.10 kW in the second event hour, and 0.06 kW in the third event hour. Overall, savings averaged about 0.11 kW per air conditioner across the three event hours. The first two event hours are statistically different than zero.

MISO Events

Table 17 presents estimates for all MISO event hours of the average kW impacts per controlled water heater for the first, second, and third event hours as well as for each of the first six post-event hours. The first event hour and all post-event hours include events 6 and 8. The second and third event hours include only event 6. An additional table listing average demand impacts for each hour of events 6 and 8 is included in *Appendix C. Water Heater kW Impacts by Event Hour.*

Table 17. Estimates of Water-Heating DLC Impacts*: MISO Events

Hour Beginning	Impact per Water Heater (kW)**	90% Confidence Intervals		Percentage Savings	Achieved Savings (kW)
		Lower Bound	Upper Bound		
Water-Heating Load Control (n=12 treatment homes, 2 events)					
Event Hour 1++	-0.273	-0.605	0.059	82.4%	1,769
Event Hour 2++	-0.273	-0.731	0.185	77.2%	1,771
Event Hour 3+	-0.244	-0.641	0.153	69.9%	1,582
Post-Event Hour 1+	0.714	-0.037	1.465	-1157.4%	-4,629
Post-Event Hour 2+	0.143	-0.265	0.552	-70.3%	-930
Post-Event Hour 3+	-0.019	-0.257	0.219	6.7%	123
Post-Event Hour 4+	0.196	-0.216	0.607	-104.2%	-1,269
Post-Event Hour 5+	-0.014	-0.229	0.202	5.9%	90
Post-Event Hour 6+	0.060	-0.129	0.249	-36.5%	-389

+Average impact of events 6 and 8.

++Average impact of event 6

*These estimates were statistically significant at the 10% level.

**The kW impacts and the average demand impacts across water heaters and events in the treatment group were based on Tobit regression of unit hourly energy use.

The average demand reduction per water heater was 0.27 kW in the first event hour, 0.27 kW in the second event hour, and 0.24 kW in the third event hour. Overall, savings averaged about 0.26 kW per air conditioner across the three event hours. It should be noted that because these events occurred toward the end of September (September 21 and 22), many water heater loggers lacked data for these events. This resulted in a smaller sample of logger data available to estimate the impacts of these events, which meant that the results were not statistically significant.

Overall Event Impacts for Water Heaters

The average savings during summer 2017 was 0.11 kW for non-MISO events and 0.23 kW for MISO events. Event 6 achieved the highest savings; however, savings were not statistically different than 0. Events 4 had the highest statistically significant individual hour savings of 0.18 kW.

Water-Heating Load Control Percentage of Control Group Load

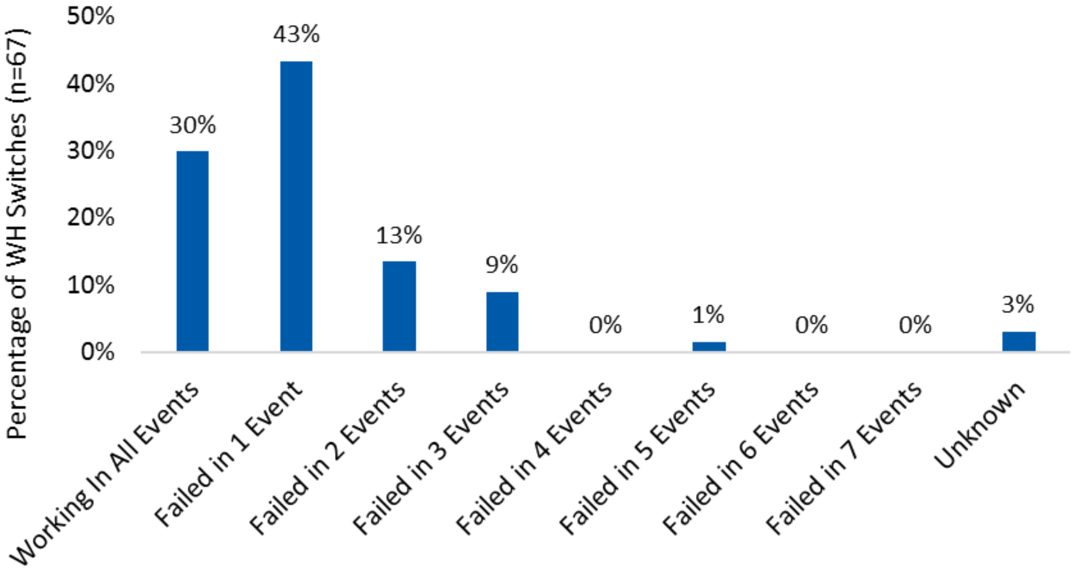
In 2017, the Summer Cycler Program achieved average demand savings of approximately 0.12 kW per controlled water heater for non-MISO events. To determine the savings realization rate, Cadmus calculated the load reduction per water heater as a percentage of the average baseline water-heating load. The average baseline demand was 0.27 kW, indicating that the Summer Cycler Program achieved a realization rate of approximately 45%.

Cadmus expected to find a realization rate closer to 100% because the water heaters in the treatment group were switched off for the duration of each event and therefore no energy should have been used during this time of day. By analyzing loads for individual water heaters, Cadmus determined that nearly half of the water heater switches did not function correctly during at least one event. Water heaters should have been completely switched off from 3:00 p.m. to 6:00 p.m. for events 1, 2, 3, 5, and 6, from

1:00 p.m. to 3:00 p.m. for event 4, and from 1:00 p.m. to 2:20 p.m. and from 3:00 p.m. to 4:00 p.m. for events 7 and 8. However, 47% of the units were on during at least one event hour. The functionality of the water heater switches across the six events in summer 2017 was not consistent, and the switch problems were not associated specifically with any one of the six events. Cadmus also investigated the distribution of water heater switch failures by zip code, but there was no clear pattern—almost all zip codes contained switches that worked as expected and switches that failed. This issue was also present, though less prevalent, in the 2015 evaluation.

Cadmus categorized each of the 67 switches associated with the water heater loggers by the number of events during which the switch failed to fully control the water heater. Cadmus used data from three "middle" hours of events—the 4:00 p.m. hour of event days 1, 2, 3, 5, and 6, data from the 2:00 p.m. hour of event 4, and data from the 1:00 p.m. hour for event 7. During this middle hour of the event period, the switch should have turned off the water heater for the whole hour. As shown in Figure 11, only 30% of the switches performed as expected in all of these events. The rest of the switches failed during at least one or more events. However, no switches failed during six or more events, suggesting that the switch problems are intermittent, not permanent. Cadmus classified a few switches (3%) as "Unknown" when the non-event-day usage of the water heater was so low that it was not possible to determine if the switch had functioned correctly or not.

Figure 11. Water Heater Switch Failures



Cadmus was not able to perform a similar functionality analysis for the air conditioner switches. Because the air conditioner switches cycle their connected load instead of switching off completely for the duration of the event, it is impossible to differentiate normal air conditioner on/off cycles from switch-controlled cycling. However, given that the air conditioner cycling achieved a realization rate of only 32% of average baseline demand in 2017, instead of 50% as specified by the cycling strategy, it is possible that the air conditioner switches also fail intermittently.

Benchmarking

As shown in Figure 12 and Figure 13, Cadmus compared the Summer Cycler Program demand savings per air conditioner and per water heater in 2017 to those achieved by the program in 2012, 2013, 2014, and 2015, to the 2016 Vectren Smart Thermostat Pilot, and to those of several other utilities that operate similar residential water-heating and air-conditioning DLC programs.

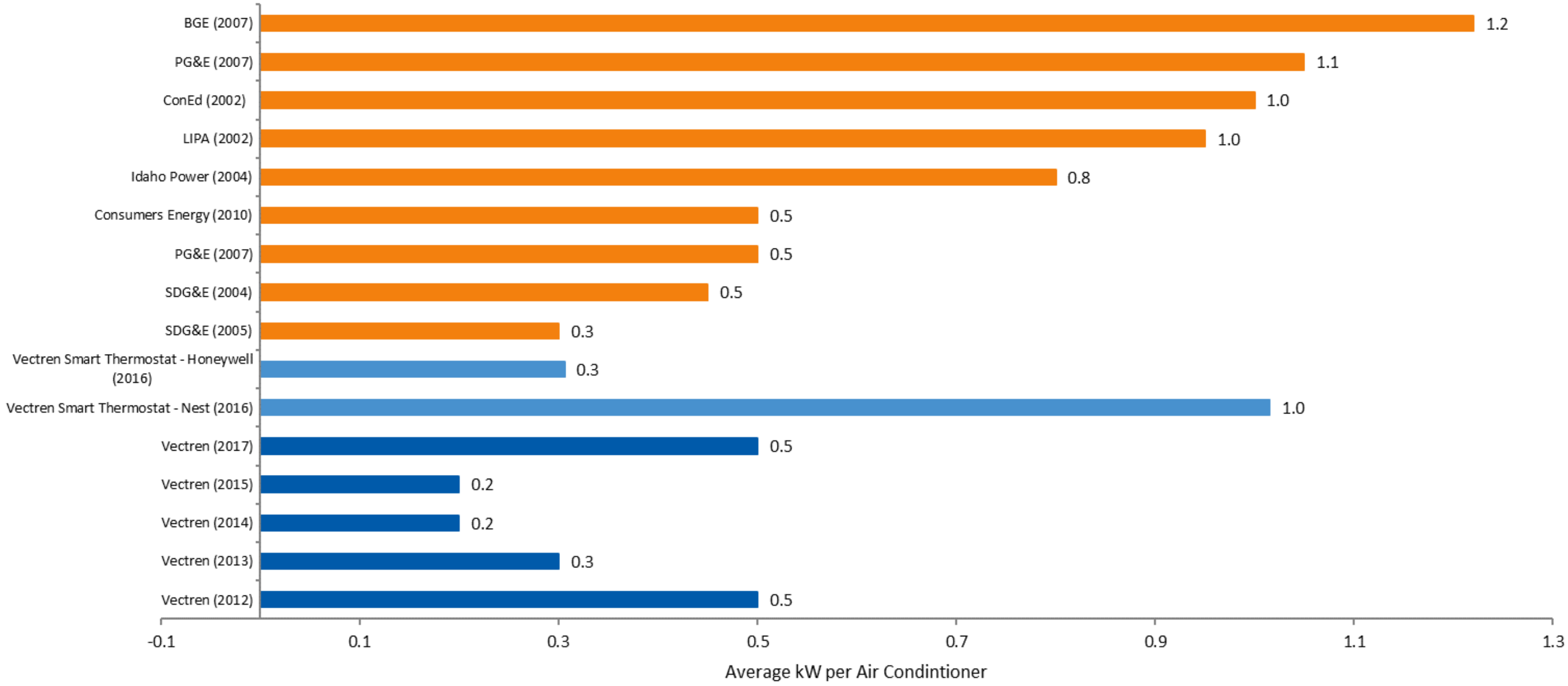
In 2017, Vectren's Summer Cycler Program achieved average demand savings of 0.52 kW per air conditioner, similar to the 2012 evaluation of the program as well to similar residential DLC programs such as the PG&E 2007 evaluation and the Consumers Energy 2010 evaluation.

As Figure 12 and Figure 13 show, other utilities' DLC programs achieved a range of demand savings, and most achieved average savings of 0.5 kW per air conditioner or higher. Compared to these programs, the Summer Cycler Program achieved relatively consistent demand savings. The 2017 Summer Cycler also achieved savings of 0.5 kW were higher than the Honeywell thermostats that were enrolled in Vectren's 2016 Smart Thermostat Pilot, which achieved 0.31 kW per air conditioner.

The 2017 Summer Cycler also achieved average demand savings of approximately 0.12 kW per water heater, which is in line with the 2014 and 2015 Summer Cycler savings and just less and not statistically different than the 0.2 kW achieved in 2012 and 2013. The Summer Cycler Program also achieved relatively low savings from water-heating DLC, mainly because Vectren customers had low water-heating loads overall and because of the intermittent failures of almost half of the switches during events.

Caution should be exercised when comparing demand savings of different utility programs, as savings depend on factors that include outdoor temperature, event initiation time and duration, load control technologies, cycling strategies, customer peak demand, and appliance efficiencies, all of which may vary among utilities.

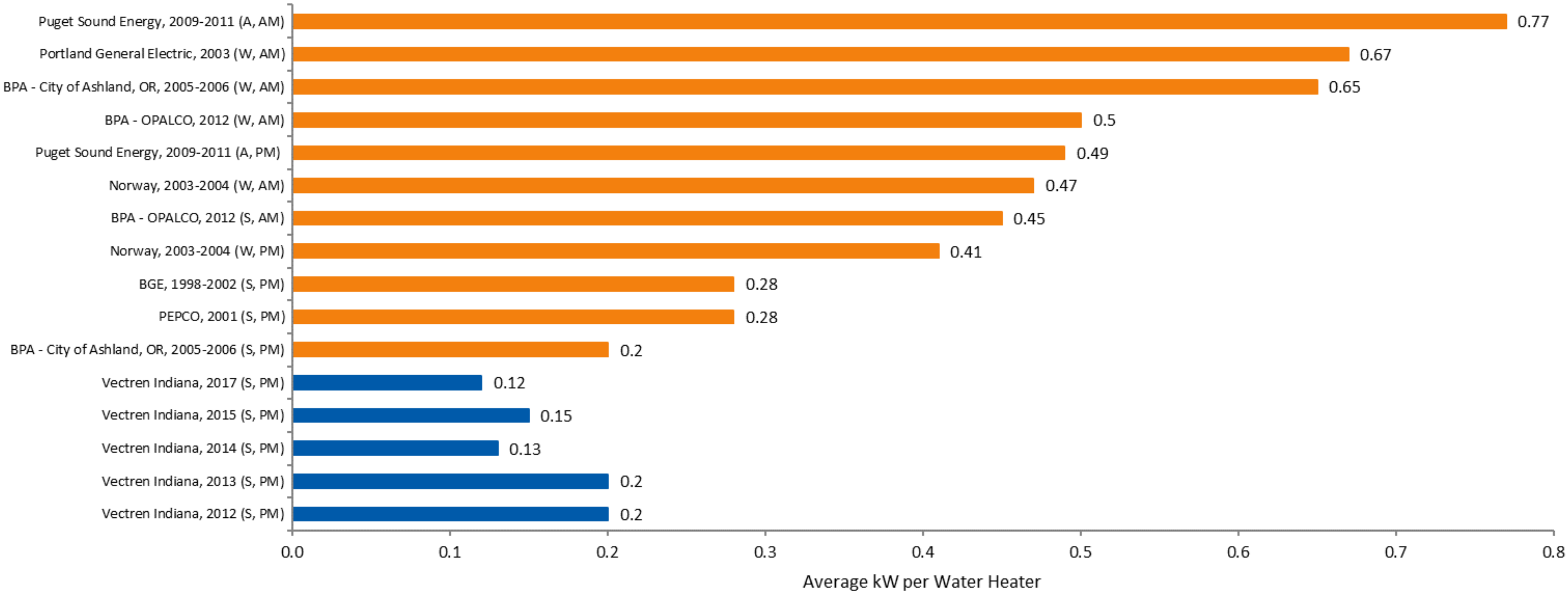
Figure 12. Comparison of Vectren and Other Utilities' Residential Air-Conditioning DLC Evaluated Demand Savings



Note: Years indicate program year.

Sources: Cadmus evaluation studies for Consumers Energy (2010), Vectren (2012-2016), and Newsham and Bowker (2010).

Figure 13. Comparison of Vectren and Other Utilities' Residential Water-Heating DLC Evaluated Demand Savings



Note: Years indicate program year.

Note: Years indicate program year. Information in parentheses indicates the season of DLC events (S=summer, W=winter, and A=Year-round) and if events were called in the morning (a.m.) or afternoon (p.m.).

Sources: Cadmus evaluation studies for BPA (2011), Vectren (2012-2015), Pacific Gas & Electric (2004), RLW Analytics (2007), and Navigant (2012).

Total Demand Savings in End-Use Logger Sample

Cadmus estimated the total kW impacts from air-conditioning DLC, water-heating DLC, and for both end uses in the end-use logger sample, as shown in Table 18.[6] To estimate total impacts, Cadmus multiplied the average kW impact per controlled unit by the total number of controlled units in the end-use logger analysis sample. Slightly larger estimates of demand savings would have resulted if savings could have been counted from the small number of units with loggers that did not provide valid data.

During event hours, the Summer Cycler Program produced demand savings from air conditioning and water heating load control of approximately 45 kW to 62 kW. Electricity demand rebounded in the first hour after the event ended, resulting in an increased load of approximately 20 kW.

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[6] Previous tables had shown the achievable (or, in the case of MISO events, achieved) savings from all customers enrolled in the Summer Cycler program. Table 18 shows instead the total kW impacts among customers in the end-use logger sample treatment groups.

Table 18. Estimates of Summer Cycler Program Non-MISO Total kW Impacts in End-Use Logger Analysis Sample

Hour	Impact (kW)	90% Confidence Intervals	
		Lower Bound	Upper Bound
Air Conditioners (n=84)			
Event hour 1	-34.2*	-44.3	-24.1
Event hour 2	-55.7*	-69.8	-41.6
Event hour 3	-42.3*	-53.6	-31.0
Post-event Hour 1	1.0	-15.0	17.0
Post-event Hour 2	11.1	-5.6	27.8
Post-event Hour 3	5.4	-11.4	22.3
Post-event Hour 4	10.4	-5.6	26.4
Post-event Hour 5	6.1	-9.7	22.0
Post-event Hour 6	5.2	-0.4	10.7
Water Heaters (n=67)			
Event Hour 1	-11.2*	-19.4	-3.0
Event Hour 2	-7.0*	-13.3	-0.6
Event Hour 3	-4.2	-9.2	0.8
Post-Event Hour 1	19.3*	0.7	37.9
Post-Event Hour 2	7.5	-8.8	23.7
Post-Event Hour 3	2.4	-12.1	16.9
Post-Event Hour 4	-3.0	-13.0	6.9
Post-Event Hour 5	-4.4	-16.3	7.6
Post-Event Hour 6	-3.5	-15.2	8.2
Total Logger Analysis Sample			
Event Hour 1	-45.4*	-58.4	-32.4
Event Hour 2	-62.6*	-78.1	-47.2
Event Hour 3	-46.5*	-58.9	-34.1
Post-Event Hour 1	20.3*	2.9	37.8
Post-Event Hour 2	18.5	-0.8	37.9
Post-Event Hour 3	7.8	-10.7	26.3
Post-Event Hour 4	7.3	-10.6	25.3
Post-Event Hour 5	1.8	-18.2	21.8
Post-Event Hour 6	1.7	-16.1	19.5

*Estimate was statistically significant at the 10% level.

Energy Savings

Energy savings from DLC events depended on the relative magnitude of event-hour demand savings and the post-event rebound in energy demand. Cadmus estimated energy savings from air-conditioning load control by aggregating the hour interval kWh to daily kWh for each unit and then estimating a regression of air-conditioner daily kWh. Cadmus also performed a similar regression analysis of daily water-heating kWh to estimate energy savings from water-heating load control. Appendix D. Energy Savings Estimation Methodology describes the regression model specification and estimation procedures.

Table 19 shows average event-day energy savings per air conditioner, per water heater, and for the overall program.

Table 19. Average Energy Savings per Event

Season	Energy Savings Per Unit (kWh)*	90% Confidence Limits		Logger Analysis Sample (kWh)
Air Conditioning	0.45	0.16	1.06	37.6
Water Heating	-0.03	-0.33	0.27	-2.1
Total	**0.42**	**N/A**		**35.5**

*Cadmus based the energy-savings estimates on regression analysis of the daily electricity use of air conditioners and water heaters.

On average, the Summer Cycler Program resulted in modest energy savings of 0.45 kWh per air conditioner per event day, and a small increase in consumption of 0.03 kWh per water heater per event day. The air conditioner estimate is statistically different from zero at the 10% significance level, but the water heater estimate is not. Overall, the program saved about 35.5 kWh per event.

Conclusions and Recommendations

Based on the key evaluation findings Cadmus came to the following conclusions and recommendations about the 2017 Summer Cycler program.

Key Impact Findings

The analysis of the logger sample resulted in the following findings about the Summer Cycler Program's impacts in 2017:

- Vectren initiated events between 3:00 p.m. and 6:00 p.m., when Vectren typically experiences peaks in system demand, and between 1:00 p.m. and 3:00 p.m. Average event-hour temperatures ranged between 88˚F and 96˚F. Hours with higher temperatures, as well as the MISO demand response event hours, provided Vectren with the opportunity to test the impacts of the program during typical peak conditions.
- The installation contractor's deployment of the data loggers improved in 2017 compared to 2015—fewer loggers lacked data, and the loggers were set to the correct local time.
- During events, the program achieved 0.52kW in average demand savings per air conditioner, or approximately 31% of average baseline energy demand.
- Demand savings from air-conditioning load control were higher in 2017 than in 2015, primarily due to lower outdoor temperatures and space cooling energy demand during events in 2015 when the summer was mild. The 2017 savings are similar to those found in 2012. Events occurred at significantly higher average temperatures in 2017 (88˚F to 96˚F) and 2012 (97˚F) compared to 2015 (89˚F to 91˚F).
- During events, the program produced 0.14 kW in average demand savings per water heater, or approximately 50% of average baseline energy use during event hours. In 2015, the program yielded average demand savings of 0.18 kW per water heater and achieved saving of about 0.20 kW in 2012.
- Low unit-demand savings from the water-heating load control resulted from low average baseline energy use during event hours. Also, based on analysis of individual water heater loads, most load control switches on water heaters appear to have malfunctioned during at least one event, resulting in decreased demand savings.
- Two MISO load curtailment events occurred during summer 2017. During these events, all Summer Cycler customers were cycled, which generated average savings of 0.35 kW per air conditioner and 0.23 kW per water heater. For all Summer Cycler customers and summer 2017 MISO event hours, these savings averaged 8,746 kW from air conditioners and 1,707 kW from water heaters.
- Based on current program enrollments, Cadmus predicts that had Vectren cycled all Summer Cycler customers instead of just the treatment groups (for example, if these events had coincided with a MISO load curtailment event) the Summer Cycler Program could have generated up to 13 MW in peak demand savings from residential air-conditioning load control

and 1 MW in peak demand savings from residential water-heating load control during summer 2017 non-MISO events.

- The program achieved average energy savings of 0.45 kWh per air conditioner and -0.03 kWh per water heater during each event, though the water heater estimates were not statistically significant (i.e., energy savings were not statistically different from zero).

Conclusions

Based on these findings, Cadmus offers the following conclusions:

- The Summer Cycler Program continues to provide substantial demand reductions from air-conditioning direct load control (DLC) during high temperature events and MISO load curtailment events.
- Vectren's per-unit demand reductions from water heaters are low because the typical Summer Cycler event window (3 p.m. .to 6 p.m.) does not coincide with peak water-heating end use.
- Summer Cycler's switch-based, 50% cycling demand response method for air conditioners produced higher impacts than those achieved by Honeywell thermostats (using 50% cycling) in the 2016 Vectren Smart Thermostat Pilot. However, the average temperature range during 2017 events (88˚F to 96˚F) was higher than 2016 events (79˚F to 97°F). These differences may also be due to different customer characteristics between the two studies and not necessarily the cycling strategy or demand response technology.

Recommendations

According to Vectren program staff, in 2018, Vectren is planning to replace existing Summer Cycler switch devices with Wi-Fi-enabled thermostats capable of participating in demand response events. Additionally, to increase the demand response capacity from residential air conditioning, Vectren is expanding the number of air conditioners enrolled in the program by adding a bring-your-own-thermostat option for customers. Based on the findings and conclusions from the 2017 Summer Cycler evaluation, Cadmus recommends the following to increase the potential for demand savings in future cycling program evaluations:

- Continue to call demand response events from 3 pm. to 6 p.m. on days when outdoor temperatures exceed 95 degrees. These conditions provide impact estimates most comparable to those of system peaks.
- Maintain the existing water heater switches, if cost-effective. Although water-heating demand response achieved lower per-unit demand savings than air-conditioner cycling, the more than 6,000 water heaters enrolled in the program, along with the enrolled air conditioners, can provide over 1 MW of demand savings during peak periods.
- Until advanced metering infrastructure (AMI) data is available for Vectren's entire customer population, consider expanding the number of air conditioners and water heaters selected for metering for future impact studies. A larger sample size would increase the probability of

detecting small demand savings, reduce sampling error, and increase the precision of the savings estimates.

- Consider evaluating both smart thermostat and switch-based demand response impacts in the same summer, using a randomized encouragement design, to allow a direct comparison between the demand savings and cost-effectiveness associated with each technology (i.e., the existing switches vs. their replacement with Wi-Fi-enabled thermostats).

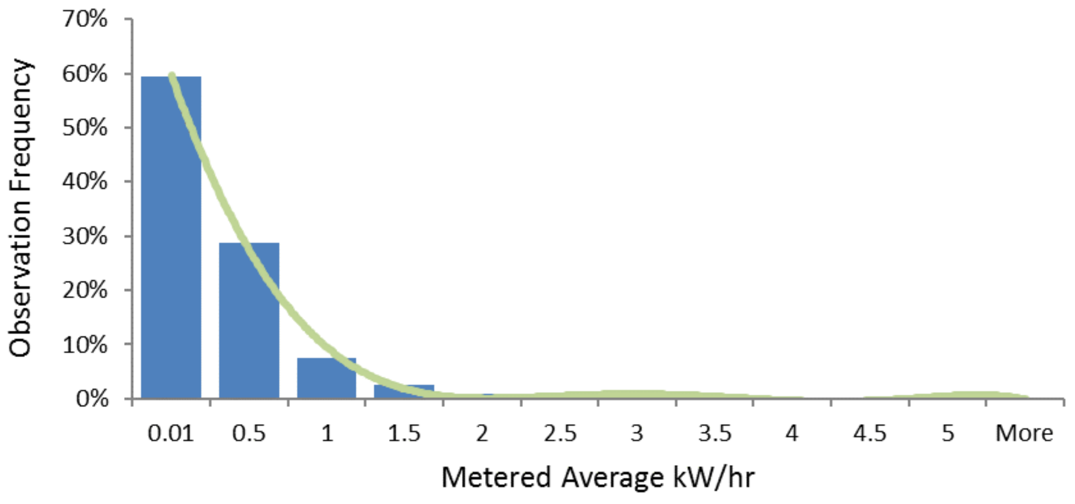
Appendix A. Demand Savings Estimation Methodology

This appendix describes the econometric modeling of electricity use for air conditioning and water heating. For both, Cadmus applied a Tobit regression model to account for the non-normal distribution of electricity use. This discussion focuses on estimating water-heating impacts, and it also applies to air conditioning.

To inform the econometric modeling, Cadmus created an engineering model of the duty cycle for a residential tank water heater.[7] In many homes, residential water heaters remain in stand-by modes rather than in active modes for most of the day, so, for many hours, units exhibit metered energy demand equal or close to zero.

Figure A-1 illustrates this phenomenon for water heaters in the analysis sample, showing a histogram of average demand between 3:00 p.m. to 6:00 p.m. on non-holiday, non-event weekdays (see Figure 2, in the main report). In a large percentage of hours, water heaters exhibited electricity use of approximately zero average kW. The non-normal distribution of water heating violates the normality assumptions of the classical regression model. Applying ordinary least squares to the data would result in biased savings estimates.[8]

Figure A-1. Distribution of Electricity for Domestic Hot Water Hourly Average kW



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[7] The average duty cycle at time ‘t’ can be defined as average load at ‘t’ divided by the connected load at ‘t’; this can be considered as the percentage of time that the appliance remained on during the measurement period. Powers, J.T., S.D. Braithwait, and B.A. Smith. “Generalizing Direct Load Control Program Analysis: Implementation of the Duty Cycle Approach.” *IEEE Transactions on Power Systems.* Volume: 4, Issue: 1. 1989. Pg. 293–299.

[8] Greene, William. *Econometric Analysis*. 1997. Pg. 959–974.

A Tobit model provided the appropriate econometric model to fit the end-use data and to estimate demand savings.[9] In the equation shown below, kW_t^* represents a simple index of the home occupant's demand for water heat in hour 't,' which may take on a positive or negative value, and where demand is a function of a vector **X,** containing the following variables and variable interactions: month of the year, day of the week, hour of the day, and cooling degree hours (CDH) (for air conditioning only):

$$kW_t^* = \mathbf{X_t'\beta} + \theta e_t + \varepsilon_t$$

Although the index of electricity demand for water heat (kW*) may take on any real value, metered demand always remains greater than or equal to zero.

Also, electricity demand for water heating is a function of whether an event is called in hour 't.'

Where:

e_t = 1 if an event is called and

e_t = 0, otherwise.

The coefficient θ reflects the event's impact on demand. (For simplicity, Cadmus included just one variable to indicate an event. When estimating the model, separate variables represented each event and post-event hour.)

When the index kW* is less than zero, the analysis does not observe kW_t^*; it observes only $kW_t = 0$. Water heating demand can then be expressed as a censored regression model, capturing the non-normal distribution of the demand data:

Where:

kW_t = kW_t^* if $kW^* \geq 0$

kW_t = 0 if $kW^* < 0$

Assuming normal distribution of ε_t with constant variance, the Tobit model's maximum likelihood estimation yields a consistent estimate of the model's parameters.

Cadmus estimated electricity savings in an event hour as the difference between expected kW in the hour, $E[kW_t|X_{t,}\ e_t=1]$, and baseline kW, the expected kW, conditional on the event not occurring, denoted as $E[kW_t|X_{t,}\ e_t=0]$:

$$E[kW_t|X_{t,}\ e_t=1] - E[kW_t|X_{t,}\ e_t=0] = \Phi((\mathbf{X_t'\beta} + \theta)/\sigma))*(\mathbf{X_t'\beta} + \theta + \sigma\lambda_1) - \Phi((\mathbf{X_t'\beta})/\sigma))*(\mathbf{X_t'\beta} + \sigma\lambda_2)$$

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[9] The Tobit model has been widely used in econometrics to study vacation expenditures, the number of hours worked by women in the labor force, household expenditures on various goods, and many additional applications in which one observes the probability mass at zero (Greene 1997, pg. 959).

Where:

Φ = the cumulative distribution function of the standard normal distribution

ϕ = the probability density function of the standard normal distribution

σ = the standard error of the regression

λ_1 = $\phi(\mathbf{X_t}'\beta+\theta)/\Phi(\mathbf{X_t}'\beta+\theta)$

λ_2 = $\phi(\mathbf{X_t}'\beta)/\Phi(\mathbf{X_t}'\beta)$

Cadmus estimated the Tobit model by pooling data from the water heater loggers and then using model coefficients to estimate demand savings during each event and in the six hours after each event. The analysis estimated the standard errors and confidence intervals for the demand impacts using bootstrap estimations (i.e., 200 samples drawn with replacements).

Appendix B. Air Conditioner 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. The *Air-Conditioning Load Control Demand Savings* section of this report defines metered, predicted, and baseline kW.

Table B-1. Air Conditioner kW Impacts for Each Event Hour

Event	Date	Hour Beginning	Hour Type	Outside temperature (degrees F)	Est. impact per AC unit (kW)	Average Metered (kW)	Predicted (kW)	Baseline (kW)
1	11-Jul-17	15	Event Hour 1	89	-0.425	0.930	0.965	1.390
1	11-Jul-17	16	Event Hour 2	88	-0.532	0.948	0.982	1.514
1	11-Jul-17	17	Event Hour 3	87	-0.598	1.026	1.050	1.647
1	11-Jul-17	18	Post-Event Hour 1	86	0.092	1.597	1.586	1.494
1	11-Jul-17	19	Post-Event Hour 2	81	0.223	1.541	1.524	1.301
1	11-Jul-17	20	Post-Event Hour 3	77	0.164	1.254	1.268	1.104
1	11-Jul-17	21	Post-Event Hour 4	76	0.139	1.109	1.133	0.994
1	11-Jul-17	22	Post-Event Hour 5	78	0.137	0.873	0.888	0.751
1	11-Jul-17	23	Post-Event Hour 6	74	-0.003	0.645	0.702	0.706
2	12-Jul-17	15	Event Hour 1	92	-0.520	1.191	1.191	1.711
2	12-Jul-17	16	Event Hour 2	92	-0.503	1.209	1.205	1.708
2	12-Jul-17	17	Event Hour 3	90	-0.545	1.260	1.251	1.796
2	12-Jul-17	18	Post-Event Hour 1	88	0.073	1.845	1.812	1.739
2	12-Jul-17	19	Post-Event Hour 2	82	0.203	1.778	1.746	1.543
2	12-Jul-17	20	Post-Event Hour 3	82	0.202	1.515	1.484	1.282
2	12-Jul-17	21	Post-Event Hour 4	82	0.131	1.283	1.241	1.110
2	12-Jul-17	22	Post-Event Hour 5	78	0.191	1.172	1.167	0.976
2	12-Jul-17	23	Post-Event Hour 6	77	0.105	0.971	0.968	0.863
3	20-Jul-17	15	Event Hour 1	94	-0.647	1.271	1.265	1.911
3	20-Jul-17	16	Event Hour 2	94	-0.729	1.262	1.245	1.975
3	20-Jul-17	17	Event Hour 3	92	-0.756	1.283	1.261	2.018
3	20-Jul-17	18	Post-Event Hour 1	90	-0.055	1.882	1.839	1.894
3	20-Jul-17	19	Post-Event Hour 2	84	-0.041	1.752	1.720	1.760
3	20-Jul-17	20	Post-Event Hour 3	84	-0.050	1.563	1.529	1.579
3	20-Jul-17	21	Post-Event Hour 4	83	0.158	1.417	1.373	1.215
3	20-Jul-17	22	Post-Event Hour 5	81	0.102	1.224	1.197	1.095
3	20-Jul-17	23	Post-Event Hour 6	80	0.063	1.086	1.069	1.006
4	21-Jul-17	13	Event Hour 1	96	-0.527	1.262	1.255	1.781
4	21-Jul-17	14	Event Hour 2	96	-0.816	1.272	1.261	2.077

Event	Date	Hour Beginning	Hour Type	Outside temperature (degrees F)	Est. impact per AC unit (kW)	Average Metered (kW)	Predicted (kW)	Baseline (kW)
4	21-Jul-17	15	Post-Event Hour 1	97	-0.082	2.016	1.968	2.050
4	21-Jul-17	16	Post-Event Hour 2	96	0.054	2.168	2.114	2.060
4	21-Jul-17	17	Post-Event Hour 3	93	-0.023	2.120	2.064	2.087
4	21-Jul-17	18	Post-Event Hour 4	92	0.034	2.091	2.035	2.001
4	21-Jul-17	19	Post-Event Hour 5	88	-0.016	1.928	1.862	1.878
4	21-Jul-17	20	Post-Event Hour 6	85	0.025	1.716	1.662	1.637
5	26-Jul-17	15	Event Hour 1	88	-0.429	1.321	1.337	1.766
5	26-Jul-17	16	Event Hour 2	79	-0.340	1.125	1.195	1.535
5	26-Jul-17	17	Event Hour 3	78	-0.204	1.003	1.071	1.275
5	26-Jul-17	18	Post-Event Hour 1	79	0.286	1.398	1.411	1.125
5	26-Jul-17	19	Post-Event Hour 2	79	0.417	1.435	1.438	1.021
5	26-Jul-17	20	Post-Event Hour 3	78	0.265	1.208	1.220	0.955
5	26-Jul-17	21	Post-Event Hour 4	78	0.326	1.037	1.046	0.720
5	26-Jul-17	22	Post-Event Hour 5	77	0.098	0.830	0.861	0.763
5	26-Jul-17	23	Post-Event Hour 6	77	0.137	0.704	0.743	0.606
6	21-Sep-17	15	Event Hour 1	90	-0.433	1.069	1.081	1.514
6	21-Sep-17	16	Event Hour 2	89	-0.512	1.104	1.108	1.620
6	21-Sep-17	17	Event Hour 3	83	-0.266	1.040	1.064	1.331
6	21-Sep-17	18	Post-Event Hour 1	81	0.336	1.458	1.455	1.120
6	21-Sep-17	19	Post-Event Hour 2	79	0.103	1.320	1.314	1.211
6	21-Sep-17	20	Post-Event Hour 3	76	0.253	1.078	1.095	0.843
6	21-Sep-17	21	Post-Event Hour 4	74	0.323	0.920	0.956	0.633
6	21-Sep-17	22	Post-Event Hour 5	73	0.184	0.706	0.749	0.565
6	21-Sep-17	23	Post-Event Hour 6	72	0.179	0.565	0.646	0.467
7	22-Sep-17	13	Event Hour 1	90	-0.326	0.806	0.834	1.160
7	22-Sep-17	14	Event Hour 2	90	-0.023	1.243	1.240	1.263
7	22-Sep-17	15	Event Hour 3	89	-0.398	1.029	1.045	1.442
7	22-Sep-17	16	Post-Event Hour 1	87	0.199	1.532	1.519	1.320
7	22-Sep-17	17	Post-Event Hour 2	84	0.258	1.576	1.561	1.303
7	22-Sep-17	18	Post-Event Hour 3	82	0.174	1.423	1.416	1.242
7	22-Sep-17	19	Post-Event Hour 4	75	0.493	1.183	1.206	0.713
7	22-Sep-17	20	Post-Event Hour 5	73	0.482	0.937	0.997	0.515
7	22-Sep-17	21	Post-Event Hour 6	72	0.307	0.709	0.782	0.475

Appendix C. Water Heater kW Impacts by Event Hour

Table C-1 shows estimates of demand impacts during each event hour and for each of the six post-event hours. The *Water-Heating Load Control Demand Savings* section of this report defines metered, predicted, and baseline kW.

Table C-1. Water Heater kW Impacts for Each Event Hour

Event	Date	Hour Beginning	Hour Type	Est. impact per AC unit (kW)	Average Metered (kW)	Predicted (kW)	Baseline (kW)
1	11-Jul-17	15	Event Hour 1	-0.056	0.151	0.152	0.209
1	11-Jul-17	16	Event Hour 2	0.144	0.247	0.305	0.160
1	11-Jul-17	17	Event Hour 3	0.047	0.104	0.258	0.211
1	11-Jul-17	18	Post-Event Hour 1	-0.021	0.389	0.257	0.277
1	11-Jul-17	19	Post-Event Hour 2	-0.017	0.361	0.256	0.273
1	11-Jul-17	20	Post-Event Hour 3	-0.012	0.503	0.272	0.284
1	11-Jul-17	21	Post-Event Hour 4	0.068	0.335	0.279	0.212
1	11-Jul-17	22	Post-Event Hour 5	0.074	0.198	0.220	0.146
1	11-Jul-17	23	Post-Event Hour 6	0.034	0.112	0.157	0.123
2	12-Jul-17	15	Event Hour 1	-0.008	0.197	0.179	0.187
2	12-Jul-17	16	Event Hour 2	0.063	0.500	0.252	0.189
2	12-Jul-17	17	Event Hour 3	0.121	0.232	0.305	0.184
2	12-Jul-17	18	Post-Event Hour 1	-0.034	0.197	0.249	0.283
2	12-Jul-17	19	Post-Event Hour 2	0.093	0.222	0.324	0.232
2	12-Jul-17	20	Post-Event Hour 3	0.066	0.233	0.320	0.254
2	12-Jul-17	21	Post-Event Hour 4	0.037	0.324	0.260	0.223
2	12-Jul-17	22	Post-Event Hour 5	0.019	0.150	0.186	0.168
2	12-Jul-17	23	Post-Event Hour 6	0.030	0.128	0.155	0.124
3	20-Jul-17	15	Event Hour 1	-0.200	0.006	0.084	0.284
3	20-Jul-17	16	Event Hour 2	-0.165	0.101	0.126	0.291
3	20-Jul-17	17	Event Hour 3	-0.162	0.099	0.142	0.304
3	20-Jul-17	18	Post-Event Hour 1	0.453	0.635	0.583	0.129
3	20-Jul-17	19	Post-Event Hour 2	-0.010	0.403	0.260	0.271
3	20-Jul-17	20	Post-Event Hour 3	-0.059	0.416	0.245	0.303
3	20-Jul-17	21	Post-Event Hour 4	0.011	0.293	0.244	0.234
3	20-Jul-17	22	Post-Event Hour 5	0.085	0.151	0.227	0.142
3	20-Jul-17	23	Post-Event Hour 6	0.054	0.101	0.169	0.115
4	21-Jul-17	13	Event Hour 1	-0.185	0.007	0.096	0.281

Event	Date	Hour Beginning	Hour Type	Est. impact per AC unit (kW)	Average Metered (kW)	Predicted (kW)	Baseline (kW)
4	21-Jul-17	14	Event Hour 2	-0.156	0.008	0.096	0.252
4	21-Jul-17	15	Post-Event Hour 1	0.370	0.511	0.437	0.067
4	21-Jul-17	16	Post-Event Hour 2	0.218	0.126	0.355	0.137
4	21-Jul-17	17	Post-Event Hour 3	0.109	0.377	0.298	0.188
4	21-Jul-17	18	Post-Event Hour 4	-0.091	0.293	0.217	0.307
4	21-Jul-17	19	Post-Event Hour 5	-0.182	0.192	0.166	0.349
4	21-Jul-17	20	Post-Event Hour 6	-0.130	0.148	0.205	0.335
5	26-Jul-17	15	Event Hour 1	-0.258	0.006	0.063	0.321
5	26-Jul-17	16	Event Hour 2	-0.283	0.098	0.077	0.360
5	26-Jul-17	17	Event Hour 3	-0.279	0.054	0.091	0.370
5	26-Jul-17	18	Post-Event Hour 1	0.425	0.488	0.561	0.136
5	26-Jul-17	19	Post-Event Hour 2	-0.066	0.151	0.228	0.294
5	26-Jul-17	20	Post-Event Hour 3	-0.161	0.146	0.189	0.350
5	26-Jul-17	21	Post-Event Hour 4	-0.112	0.152	0.175	0.287
5	26-Jul-17	22	Post-Event Hour 5	0.033	0.119	0.195	0.162
5	26-Jul-17	23	Post-Event Hour 6	-0.008	0.054	0.132	0.140
6	21-Sep-17	15	Event Hour 1	-0.268	0.004	0.060	0.328
6	21-Sep-17	16	Event Hour 2	-0.270	0.009	0.082	0.352
6	21-Sep-17	17	Event Hour 3	-0.241	0.008	0.107	0.347
6	21-Sep-17	18	Post-Event Hour 1	1.094	0.597	1.116	0.022
6	21-Sep-17	19	Post-Event Hour 2	0.347	0.887	0.500	0.153
6	21-Sep-17	20	Post-Event Hour 3	-0.035	0.006	0.258	0.293
6	21-Sep-17	21	Post-Event Hour 4	0.364	0.006	0.484	0.120
6	21-Sep-17	22	Post-Event Hour 5	0.069	0.006	0.217	0.148
6	21-Sep-17	23	Post-Event Hour 6	0.101	0.006	0.199	0.098
7	22-Sep-17	13	Event Hour 1	-0.189	0.005	0.094	0.283
7	22-Sep-17	14	Event Hour 2	0.256	0.888	0.345	0.089
7	22-Sep-17	15	Event Hour 3	-0.268	0.009	0.060	0.328
7	22-Sep-17	16	Post-Event Hour 1	0.364	0.595	0.460	0.097
7	22-Sep-17	17	Post-Event Hour 2	-0.061	0.006	0.195	0.255
7	22-Sep-17	18	Post-Event Hour 3	-0.001	0.006	0.268	0.270
7	22-Sep-17	19	Post-Event Hour 4	0.027	0.006	0.283	0.256
7	22-Sep-17	20	Post-Event Hour 5	-0.099	0.006	0.222	0.321
7	22-Sep-17	21	Post-Event Hour 6	0.018	0.006	0.249	0.230

Appendix D. Energy Savings Estimation Methodology

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

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

Where:

kWh_{id} = Daily electricity use of air conditioner ‘i,’ i=1, 2, …, N, in logger analysis sample on day ‘d’, d=1, 2, …, D of the estimation period.

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

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

$Test_i$ = Indicator variable for whether air conditioner i is in the logger analysis sample test (treatment) group. $Test_i$ equals 1 if air conditioner i is in the treatment 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 air conditioners.

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

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