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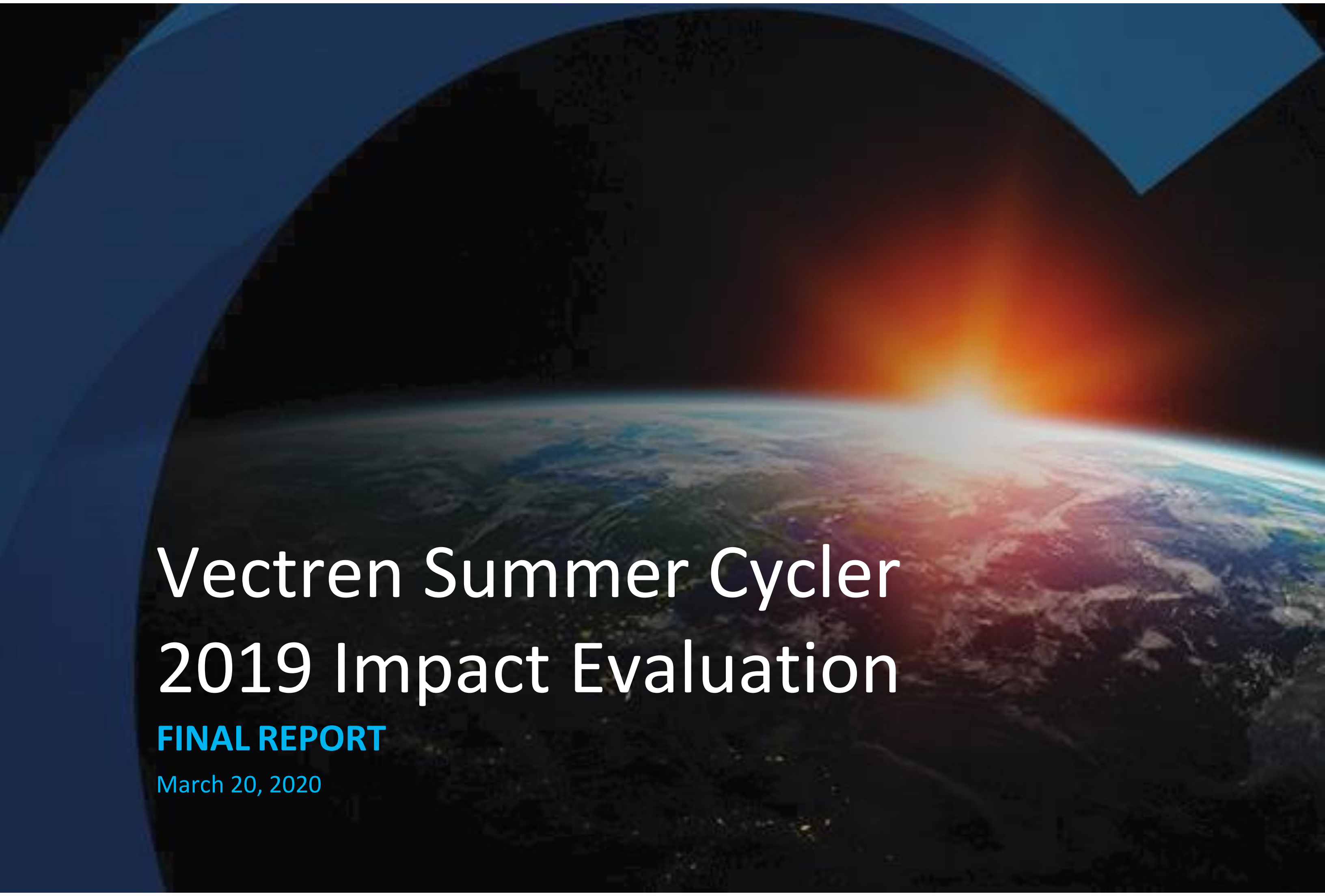

Vectren Summer Cycler 2019 Impact Evaluation

FINAL REPORT

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Prepared for:

Vectren Energy Delivery of Indiana

1 Vectren Square

Evansville, Indiana

Prepared by:
Shannon Greene
Taylor La Prairie
Jeana Swedenburg
Steve Cofer

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Executive Summary

Vectren, a CenterPoint Energy Company, operates the Summer Cycler Program to reduce residential and small commercial air-conditioning and water-heating electricity loads during summer peak hours. Vectren uses radio communication equipment and control switches to turn off participating water heaters and to cycle air conditioner compressors during load-control events.

In 2019, Vectren initiated 16 load-control events. This report estimates the demand and energy savings from the 2019 Summer Cycler Program.

Research Approach

To evaluate the 2019 Summer Cycler Program impacts, 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 (or meters) as "the logger analysis sample."

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

To estimate savings from water-heating load control, the installation contractor 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. To minimize the number of water heater data loggers needed for the analysis, the design did not employ a control group. To collect the water heater logger data, Vectren's logger installation contractor (Schneider Electric) had to enter customer homes (unnecessary for air conditioners because loggers were installed on outdoor compressor units). Similar to the approach for air conditioners, Cadmus estimated hourly water heater demand using regression analysis.

Key Impact Findings

Cadmus evaluated savings for two types of load-control events:

STANDARD LOAD-CONTROL EVENTS

Days with high forecasted temperatures in the service territory (85˚F or higher), simulating days with higher system peak demand than usual. Average event temperature for 2019 was 89˚F

MIDCONTINENT INDEPENDENT SYSTEM OPERATOR (MISO) PROXY EVENTS

Events to simulate when MISO could request load curtailment. These events were called on lower temperature days (lower than 85˚F) and gave Vectren the opportunity to test program impacts during non-peak conditions. Average event temperature for 2019 was 81˚F

2019 Summer Cycler Program Impacts

	Standard Load-Control Events		MISO Proxy Events	
	Air Conditioners Per Unit	Water Heaters Per Unit	Air Conditioners Per Unit	Water Heaters Per Unit
Average Event kW Impact	-0.268*	-0.098*	-0.143*	-0.104*
Average Event kW Hour 1	-0.263*	-0.085*	-0.144*	-0.102*
Average Event kW Hour 2	-0.273*	-0.112*	-0.142*	-0.107*
Average Post-Event Hour 1 kW Impact	0.029	0.104*	0.153*	0.137*
Average Event Energy kWh Impact	-0.78	-0.27	0.25	-0.22

*This estimate is statistically significant at the 10% level.
A negative impact indicates a reduction in usage (and therefore savings).

Historical Summer Cycler Program Evaluated Energy and Demand Savings

Standard Load-Control Event Impacts*	Per Air Conditioner 2015	Per Air Conditioner 2017	Per Air Conditioner 2019	Per Water Heater 2015	Per Water Heater 2017	Per Water Heater 2019
Average Event Temperature (˚F)	90	91	89	90	91	89
Average Event kW Impact	-0.2**	-0.5**	-0.3**	-0.2**	-0.1**	-0.1**
Average Post-Event Hour 1 kW Impact	-0.05	0.01	0.03	0.3**	0.3**	0.1**
Average Event Energy kWh Impact	-0.37	-0.45	-0.78	0.03	-0.03	-0.27

* Cadmus did not evaluate MISO Proxy Event impacts during the 2015 and 2017 evaluations. Cadmus does not include 2019 MISO proxy events in this table.

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

From the results of the impact analysis, Cadmus found the following:

Air conditioners

Demand savings from air-conditioning load control were lower in 2019 than in 2017, primarily due to lower outdoor temperatures during events in 2019.

Water heaters

Water heaters generated lower unit-demand savings than their potential because of low average baseline water-heating energy use during event hours (2 p.m. to 6 p.m.). Peak usage for water heaters does not align with peak system hours for space cooling needs. Additionally, most of the water heater load-control switches malfunctioned during at least one event.

Rebound

Cadmus found no significant post-event impacts (rebound) from air conditioner cycling. However, Cadmus found significant demand rebound from water heating load-control, resulting in an increase of 0.121 kW (60%) in the first hour after events ended. Vectren can call events without resulting in greater air conditioner demand during post-event hours; however, events will result in an increase in water-heating demand immediately following the event.

Energy Savings

The program primarily targets demand reduction. Similar to previous program years, there were no statistically significant energy savings due to the 2019 Summer Cycler load control events.

Potential MISO Impacts by Hour

	Air Conditioners		Water Heaters	
Time of Day	Baseline kW	Potential Impacts (kW)	Baseline kW	Potential Impacts (kW)
0:00	0.41	-0.06	0.11	-0.07
1:00	0.34	-0.05	0.11	-0.07
2:00	0.28	-0.04	0.12	-0.07
3:00	0.25	-0.04	0.13	-0.07
4:00	0.23	-0.03	0.12	-0.07
5:00	0.22	-0.03	0.13	-0.08
6:00	0.21	-0.03	0.19	-0.11
7:00	0.25	-0.04	0.21	-0.12
8:00	0.30	-0.04	0.22	-0.13
9:00	0.39	-0.06	0.21	-0.12
10:00	0.49	-0.07	0.20	-0.11
11:00	0.64	-0.10	0.19	-0.11
12:00	0.78	-0.12	0.18	-0.11
13:00	0.90	-0.13	0.17	-0.10
14:00	1.02	-0.15	0.17	-0.10
15:00	1.08	-0.16	0.17	-0.10
16:00	1.13	-0.17	0.18	-0.11
17:00	1.13	-0.17	0.19	-0.11
18:00	1.05	-0.16	0.22	-0.13
19:00	0.88	-0.13	0.22	-0.13
20:00	0.74	-0.11	0.20	-0.12
21:00	0.65	-0.10	0.17	-0.10
22:00	0.56	-0.08	0.15	-0.09
23:00	0.48	-0.07	0.13	-0.07

A negative impact indicates a reduction in usage (and therefore savings).

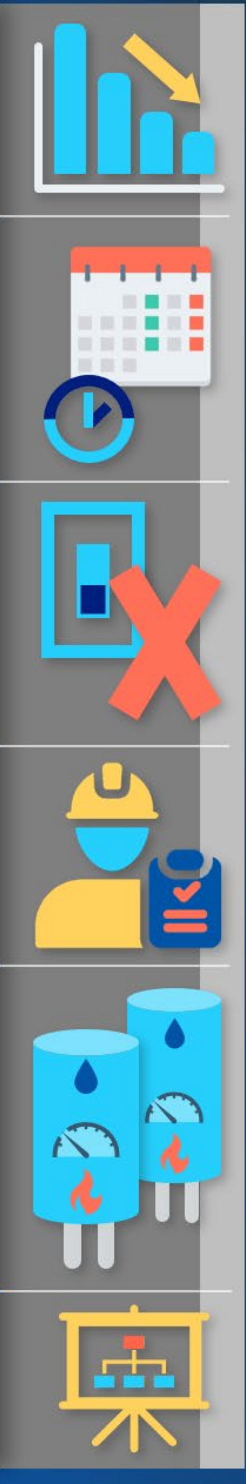
Estimated monthly potential average kW impact during a MISO event. Potential savings for water heaters are more consistent across months because they are not weather-sensitive.

	Average Estimated Impact Across All Hours		Average Estimated Impact Between 2 p.m. to 6 p.m.	
Month	Air Conditioners	Water Heaters	Air Conditioners	Water Heaters
June	-0.06	-0.12	-0.12	-0.13
July	-0.10	-0.09	-0.17	-0.10
August	-0.08	-0.09	-0.14	-0.10
September	-0.09	-0.09	-0.16	-0.10

MISO events could be called on any summer day and at any time (June through September, non-holidays).

Conclusions

Based on these findings, Cadmus offers the following conclusions:



The Summer Cycler Program continues to provide significant demand reductions from air-conditioning load control during high outdoor temperature events.

Vectren's per unit demand reductions from water heaters are lower than the potential maximum savings partially because the typical Summer Cycler event window (2 p.m. to 6 p.m.) does not coincide with peak water-heating use.

The high failure rate among water heater switches is decreasing the demand reduction potential for water heating loads. In 2017 and 2019, only 30% of switches were working during all event hours, a decrease from 51% in 2015.

Vectren is limited in the number of water heaters sampled for analysis due to inconvenience and difficulty of installing loggers inside people's homes.

The Summer Cycler Program can achieve significant demand reductions on lower temperature event days. Air conditioners achieved average per-unit event savings of 0.14 kW (15%), and water heaters achieved average per-unit event savings of 0.10 kW (58%) during MISO proxy events.

Vectren actively calling MISO proxy events allowed for more accurate planning for potential MISO event savings.

Recommendations

Based on the findings and conclusions from the 2019 Summer Cycler evaluation, Cadmus recommends the following:

Investigate causes of the water heater switch failure by utilizing the time when thermostat installation technicians enter Summer Cycler customer homes to transition them to Smart Cycle and simultaneously troubleshoot or repair existing water heater switches.

Since AMI was deployed to all Vectren customers in 2018, export AMI data for future analyses so that logger installation and collection are no longer necessary. AMI data will facilitate an expanded evaluation to all installed water heaters and air conditioners, as well as whole-home impacts, while potentially reducing cost.

If Vectren assumes that a MISO event can be called at any hour, Vectren should plan for the following impacts:

Air Conditioner	Water Heater
-0.6 kW to -0.10 kW	-0.09 kW to -0.12 kW

If Vectren assumes that a MISO event can be called between 2 p.m. and 6 p.m., Vectren should plan for the following impacts:

Air Conditioner	Water Heater
-0.12 kW to -0.17 kW	-0.10 kW to -0.13 kW

Program Overview

Vectren can initiate load-control events through the Summer Cycler Program to reduce residential and small commercial air-conditioning and water-heating electric loads for several reasons:

- Balancing utility system supply and demand
- Alleviating transmission or distribution constraints
- Responding to load curtailment requests from MISO, the regional electricity transmission grid authority[3]
- Evaluation, measurement, and verification (EM&V) purposes

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-control 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 up to $28 per cooling season as an incentive for participation.

Table 5 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. Some premises had multiple switches installed.

Table 5. Number of Residential Customers and Premises in the Summer Cycler Program for 2019

Load Control	Customers	Premises	Switches
Air Conditioners	14,462	14,896	20,984
Water Heaters	5,740	6,058	6,066
Total	**20,202**	**20,954**	**27,050**

Summer Cycler Load-Control Event Summary

In 2019, Vectren initiated 16 load-control events for EM&V purposes. Cadmus categorized the load-control events in two ways:

- **Standard load-control events** were called by Vectren primarily on days with high forecasted temperatures in the service territory (85˚F or higher), simulating days with higher system peak demand than usual. Vectren called 10 standard load-control events during August and September 2019.
- **MISO proxy events** were called by Vectren on lower temperature days (lower than 85˚F) to simulate when MISO could request load curtailment, as MISO events are not weather

[3] MISO is a not-for-profit Regional Transmission Organization. MISO ensures reliable and least-cost delivery of electricity to 15 U.S. states (including Indiana) and Manitoba, Canada. MISO calls load control events to manage system demand across the region. For more information, please visit https://www.misoenergy.org/.

dependent to Vectren's service territory. Vectren called six MISO proxy events during August and September 2019.

Table 6 lists the 16 load-control events in the 2019 Summer Cycler Program. Temperatures during event days were lower in 2019 (88˚F) compared to 2017, the previous evaluation year (91 ˚F). Only two of the 2019 events had average hourly temperatures above 90˚F. The maximum temperature across all events was 94˚F.

Table 6. 2019 Summer Cycler Events

Event	Event Type	Event Date	Day	Time	Average Outside Event Temperature (°F)
1	Standard	8/5/2019	Monday	2:00 pm - 4:00 pm	89
2	Standard	8/8/2019	Thursday	2:00 pm - 4:00 pm	86
3	Standard	8/12/2019	Monday	4:00 pm - 6:00 pm	87
4	Standard	8/13/2019	Tuesday	4:00 pm - 6:00 pm	85
5	MISO Proxy	8/14/2019	Wednesday	4:00 pm - 6:00 pm	84
6	Standard	8/19/2019	Monday	4:00 pm - 6:00 pm	89
7	MISO Proxy	8/20/2019	Tuesday	2:00 pm - 4:00 pm	71
8	MISO Proxy	8/21/2019	Wednesday	2:00 pm - 4:00 pm	84
9	MISO Proxy	9/3/2019	Tuesday	4:00 pm - 6:00 pm	84
10	Standard	9/10/2019	Tuesday	2:00 pm - 4:00 pm	94
11	Standard	9/11/2019	Wednesday	3:00 pm - 5:00 pm	91
12	Standard	9/12/2019	Thursday	4:00 pm - 6:00 pm	89
13	MISO Proxy	9/24/2019	Tuesday	3:00 pm - 5:00 pm	78
14	MISO Proxy	9/25/2019	Wednesday	3:00 pm - 5:00 pm	84
15	Standard	9/27/2019	Friday	3:00 pm - 5:00 pm	89
16	Standard	9/30/2019	Monday	4:00 pm - 6:00 pm	87

Methodology

This section describes the methodology Cadmus used to estimate 2019 Summer Cycler Program demand and energy savings from the load-control events.

Participant Assignment

In the beginning of the summer 2019, Vectren's installation contractor (Schneider Electric) installed end-use meters (loggers) on a random and representative sample of Summer Cycler Program residential air conditioners.[4] Cadmus randomly assigned air conditioners in the logger analysis sample to a treatment group and a control group (those who would experience load curtailment during load-control events and those who would not), 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 2017,[5] then by randomly assigning homes within each stratum to the treatment or control group.[6] A further discussion of the randomization can be found in *Appendix A: Detailed Demand Reduction Analysis*.

Cadmus assigned approximately one-half of metered air conditioners customers to the treatment group and the other half to the control group. As some customers have multiple air conditioners, this resulted in more loggers in each group than customers.

Data Collection and Preparation

To conduct the analysis, Cadmus cleaned the logger data provided by Vectren. The analyzed treatment and control groups were not identical in size as some loggers were damaged, missing, or inaccessible for data collection after the summer event season concluded. Table 7 presents the attrition of the logger data.

Table 7. 2019 Summer Cycler Analysis Sample Size

	Air Conditioner Loggers			Water Heater Loggers
	Treatment	Control	Total	
Randomized	**88**	**84**	**172**	**53**
Gone/Bad*	8	13	21	2
Can't Access	0	0	0	6
Out of Date Range**	1	1	2	1
Analyzed	**79**	**70**	**149**	**44**

*Loggers that Vectren classified as missing or malfunctioned.
**Logger read dates were outside the June 2019 through September 2019 evaluation window.

4 Vectren recruited Summer Cycler participants to the impact study. 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.

5 2017 data were used because they were the most recent consumption data Cadmus was provided with.

6 Stratifying the sample before the random assignment increased the likelihood that the resulting treatment and control groups would have balanced consumption.

Cadmus analyzed five-minute interval energy-use data from 149 air conditioner and 44 water heater loggers. The air conditioner loggers collected kWh while the water heater loggers collected momentary amperage readings. Cadmus converted these interval data to average demand (kW) in each hour between June 01, 2019, and September 30, 2019. A further description of the data collection and preparation can be found in *Appendix A. Detailed Demand Reduction Analysis Methodology*.

Demand Savings Estimation

Cadmus estimated demand savings from Vectren's Summer Cycler Program using data from the logger analysis sample. The methodology included these elements (*Appendix A. Detailed Demand Reduction Analysis 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 01, 2019, to September 30, 2019, 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[7]
- 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, 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.[8]

Cadmus estimated potential demand savings from MISO events for each summer month. The methodology to do this included these elements:

- Modeling load per unit as function of temperature[9] for each non-event, non-holiday, weekday hour for each summer month
    - Predicts load shape for each month for both air-conditioners and water heaters
- Multiplying the evaluated MISO proxy percentage savings and the predicted load shape.
    - Potential kW savings for each month and each hour
- Averaging potential demand response savings:

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

8 This is not necessary for the water heater models as water heating load curtailment is not dependent on outdoor temperatures.

9 Temperature only relevant for air-conditioners.

- Across each hour to estimate average potential kW impact across all possible hours that an event could be called.
- Across all peak hours (2 p.m. to 6 p.m.) to estimate average potential kW impact during peak hours. Cadmus has not observed MISO calling events outside of peak hours.

Energy Savings Estimation

Cadmus estimated energy savings from air-conditioning load control by aggregating the hour interval kWh to daily kWh for each air conditioner and water heater unit and then estimating a regression daily kWh. Cadmus controlled for fixed effect by capturing effects specific to a day. The daily regression models include an indicator for treatment customer event days to estimate possible event day kWh savings. *Appendix B: Detailed Event Day Energy Savings Estimation Methodology* describes the regression model specification and estimation procedures.

Detailed Impact Evaluation Findings

This section presents Cadmus' detailed findings from the 2019 Summer Cycler Program impact evaluation. Table 8 summarizes the 2019 Summer Cycler Program impacts; a negative impact indicates a reduction in usage (and therefore savings). Based on current program enrollments, Cadmus estimates that the Summer Cycler Program could have generated up to 6 MW in peak demand savings from residential air-conditioning load control and 0.6 MW in peak demand savings from residential water-heating load control during 2019 standard load-control events.

Table 8. 2019 Summer Cycler Program Evaluated Energy and Demand Savings

	Standard Load-Control Events				MISO Proxy Events			
	Air Conditioners		Water Heaters		Air Conditioners		Water Heaters	
	Per Unit	Total Achievable Program Impact**	Per Unit	Total Achievable Program Impact**	Per Unit	Total Achievable Program Impact**	Per Unit	Total Achievable Program Impact**
Average Event kW Impact	**-0.268***	**-5,630**	**-0.098***	**-596**	**-0.143***	**-3,004**	**-0.104***	**-633**
Average Event kW Hour 1	-0.263*	-5,519	-0.085*	-513	-0.144*	-3,027	-0.102*	-619
Average Event kW Hour 2	-0.273*	-5,729	-0.112*	-679	-0.142*	-2,982	-0.107*	-648
Average Post-Event Hour 1 kW Impact	0.029	616	0.104*	633	0.153*	3,206	0.137*	830
Average Event Energy kWh Impact	**-0.78**	**-16,292**	**-0.27**	**-1,610**	**0.25**	**5,168**	**-0.22**	**-1,304**

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

**The total achievable program impact represents possible program savings if Vectren had cycled all Summer Cycler customers instead of just the treatment group of the program.

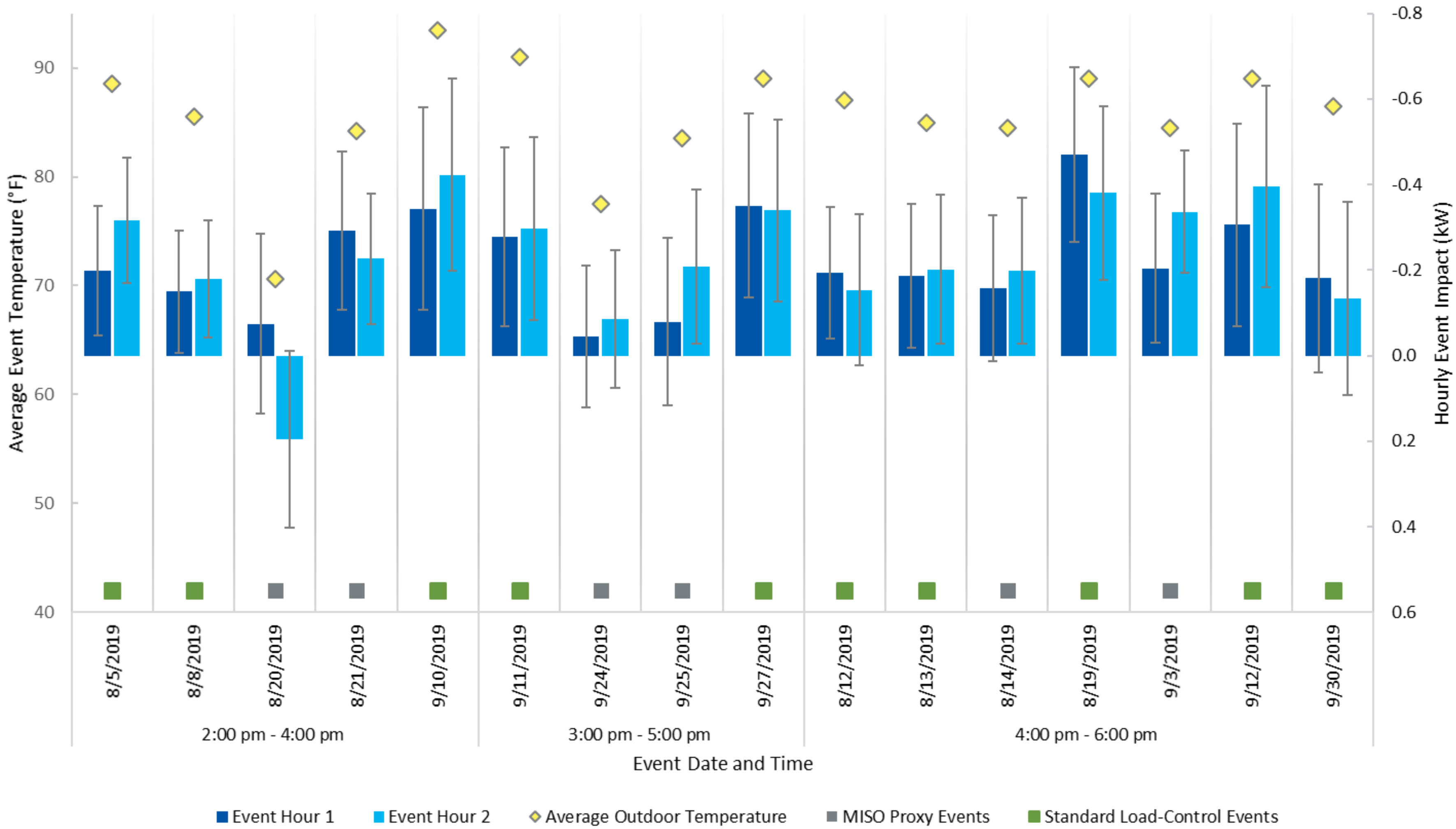
Demand Savings

Cadmus evaluated demand reduction from the 2019 Summer Cycler load-control events for air conditioners and water heaters.

Air Conditioners

Figure 2 presents the savings for each event hour as well as the average outdoor temperature during each event. Please note the events are organized by event window (2 p.m. to 4 p.m., 3 p.m. to 5 p.m., and 4 p.m. to 6 p.m.). They are not listed chronologically by the date the event occurred. Across all event hours, event impacts ranged from -0.2 kW to 0.5 kW. The -0.2-kW savings impact took place on 8/20/2019 (event 7) when there was a thunderstorm in the Evansville area that dropped the temperature from 90°F prior to the event to 71°F during the event. This allowed Cadmus to estimate the impact of lower temperatures associated with thunderstorms upon demand reduction impacts.

Figure 2. Average Air-Conditioning Demand Reduction during Load-Control Events



Standard Load-Control Events

Table 9 lists estimates of the average kW impact per air conditioner by event window during the standard load-control events. All event hour impacts were statistically significant at 90% confidence. Demand reduction ranged from 0.23 kW to 0.32 kW. Overall, the events with hours between 3 p.m. to 5 p.m. achieved the highest savings; this is most likely driven by these events having the highest average outdoor temperatures. Overall, standard load-control events achieved an average reduction of 0.27 kW per air conditioner and an average percentage savings of 21%.

Table 9. Average Air-Conditioning Demand Reduction during Standard Load-Control Events

Event Hours	Number of Events	Average Event Temperature (°F)	Hour Beginning	Impact per Air Conditioner (kW)	90% Confidence Intervals (kW)		Percent Reduction	Achievable Savings** (kW)
					Lower Bound	Upper Bound		
2 p.m. - 4 p.m.	3	89	Event hour 1	-0.228*	-0.356	-0.100	20%	4,790
			Event hour 2	-0.294*	-0.427	-0.161	23%	6,168
3 p.m. - 5 p.m.	2	90	Event hour 1	-0.306*	-0.490	-0.122	25%	6,428
			Event hour 2	-0.320*	-0.504	-0.136	25%	6,719
4 p.m. - 6 p.m.	5	87	Event hour 1	-0.267*	-0.398	-0.136	19%	5,603
			Event hour 2	-0.250*	-0.392	-0.109	18%	5,252

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

**The total achievable program impact represents possible program savings if Vectren had cycled all Summer Cycler customers instead of just the treatment group of the program

MISO Proxy Events

Table 10 presents estimates of the average kW impact per air conditioner by event window during the MISO proxy events. Demand reduction ranged from 0.01 kW to 0.27 kW. Overall, the events with hours between 4 p.m. to 6 p.m. achieved the highest savings; this is most likely driven by these events having the highest average outdoor temperatures (despite being below 85°F). MISO proxy events achieved an average reduction of 0.14 kW per air conditioner and an average percentage savings of 15%.

Table 10. Average Air-Conditioning Demand Reduction during MISO Proxy Events

Event Hours	Number of Events	Average Event Temperature (°F)	Hour Beginning	Impact per Air Conditioner (kW)	90% Confidence Intervals (kW)		Percent Reduction	Achievable Savings (kW)**
					Lower Bound	Upper Bound		
2 p.m. - 4 p.m.	2	77	Event hour 1	-0.182*	-0.337	-0.027	16%	3,819
			Event hour 2	-0.009	-0.150	0.133	1%	182
3 p.m. - 5 p.m.	2	81	Event hour 1	-0.054	-0.204	0.095	10%	1,138
			Event hour 2	-0.147*	-0.292	-0.002	23%	3,078
4 p.m. - 6 p.m.	2	84	Event hour 1	-0.181*	-0.332	-0.029	15%	3,790
			Event hour 2	-0.267*	-0.406	-0.128	21%	5,595

*This estimate is statistically significant at the 10% level

**The total achievable program impact represents possible program savings if Vectren had cycled all Summer Cycler customers instead of just the treatment group of the program.

Using the MISO proxy events percentage saving, Cadmus estimated potential impacts of MISO for air conditioners by month. Table 11 presents average estimated impacts across all hours and average estimated impacts during peak hours.

Table 11. Estimated Potential Average Air-Conditioning Demand Reduction during MISO Events by Month

Month	Average Estimated Air Conditioner Impact Across All Hours	Average Estimated Air Conditioner Impact Between 2 p.m. to 6 p.m.
June	-0.06	-0.12
July	-0.10	-0.17
August	-0.08	-0.14
September	-0.09	-0.16

Post-Event Impact (Rebound)

For most events, Cadmus did not find statistically significant post-event impacts (rebound). This result is consistent with the findings in 2017, implying that there is no significant air conditioner post-event snap-back (a system using more energy than it normally would due to the event cycling). Post-event impacts for up to six hours after each event can be found in *Appendix C: Air Conditioner kW Impacts for Each Event Hour*.

Potential MISO Impact

Table 12 shows the average hourly potential demand reduction for air conditioners for non-event days. MISO-proxy days were used to generate the results. At peak hours, potential savings are .17 kW per hour per air conditioner, from 4:00 PM through 6:00 PM. Compared to last year, the potential savings are lower, most likely due to using additional days with lower temperatures to make these predictions.

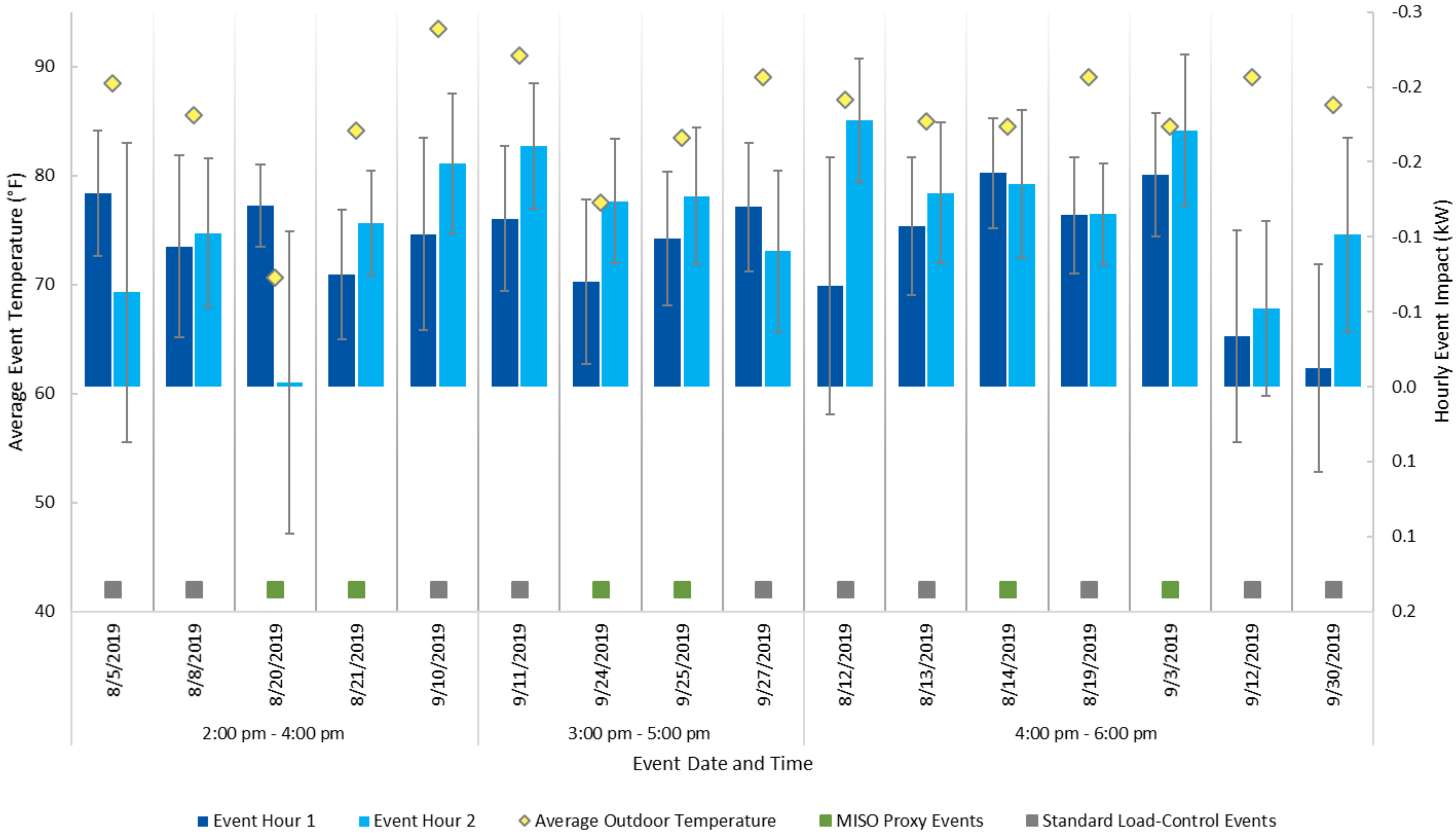
Table 12: Potential MISO AC Impacts by Hour

Time of Day	Baseline kW	Potential Impacts (kW)	Time of Day	Baseline kW	Potential Impacts (kW)
0:00	0.41	-0.06	12:00	0.78	-0.12
1:00	0.34	-0.05	13:00	0.90	-0.13
2:00	0.28	-0.04	14:00	1.02	-0.15
3:00	0.25	-0.04	15:00	1.08	-0.16
4:00	0.23	-0.03	16:00	1.13	-0.17
5:00	0.22	-0.03	17:00	1.13	-0.17
6:00	0.21	-0.03	18:00	1.05	-0.16
7:00	0.25	-0.04	19:00	0.88	-0.13
8:00	0.30	-0.04	20:00	0.74	-0.11
9:00	0.39	-0.06	21:00	0.65	-0.10
10:00	0.49	-0.07	22:00	0.56	-0.08
11:00	0.64	-0.10	23:00	0.48	-0.07

Water Heaters

Figure 3 presents the savings for each event hour as well as the average temperature during each event. Similar to Figure 2, the events are organized by event window (2 p.m. to 4 p.m., 3 p.m. to 5 p.m., and 4 p.m. to 6 p.m.). They are not listed chronologically by the date the event occurred. Across all event hours, event impacts ranged from 0.05 kW to 0.2 kW. Temperatures during events do not influence event hour impacts.

Figure 3. Event Impact Average Water Heater DLC



Standard Load-Control Events

Table 13 presents estimates of the average kW impact per water heater by event window during the standard load-control events. All event hour impacts were statistically significant at 90% confidence. Savings ranged from 0.099 kW to 0.118 kW. Standard load control events achieved an average reduction of 0.10 kW per water heater and an average percentage savings of 54%.

Table 13. Average Water Heater Demand Reduction during Standard Load-Control Events

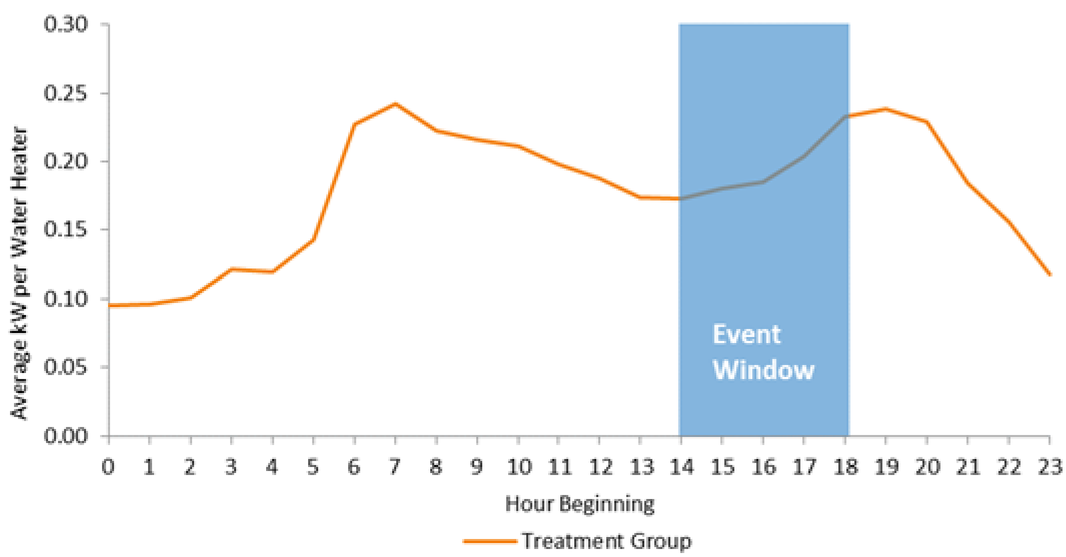
Event Hours	Number of Events	Average Event Temperature (°F)	Hour Beginning	Impact per Air Conditioner (kW)	90% Confidence Intervals (kW)		Percent Reduction	Achievable Savings (kW)**
					Lower Bound	Upper Bound		
2 p.m. - 4 p.m.	3	89	Event hour 1	-0.100*	-0.145	-0.055	61%	608
			Event hour 2	-0.099*	-0.153	-0.045	57%	600
3 p.m. - 5 p.m.	2	90	Event hour 1	-0.110*	-0.146	-0.075	63%	669
			Event hour 2	-0.123*	-0.162	-0.085	67%	748
4 p.m. - 6 p.m.	5	87	Event hour 1	-0.065*	-0.105	-0.024	35%	392
			Event hour 2	-0.118*	-0.148	-0.088	59%	716

*This estimate is statistically significant at the 10% level

** The total achievable program impact represents possible program savings if Vectren had cycled all Summer Cycler customers instead of just the treatment group of the program

Water heaters generated lower unit-demand savings than their potential in part because of low average baseline water-heating energy use during event hours (2 p.m. to 6 p.m.). Figure 1 presents the typical summer daily load of a water heater. Peak usage for water heaters does not necessarily align with peak system hours for space cooling needs, with the system peak being from 6 a.m. to 9 a.m. and again from 6 p.m. to 8 p.m.

Figure 4. Water Heater Demand (kW) on Non-Event Weekdays



MISO Proxy Events

Table 14 presents estimates of the average kW impact per water heater by event window during the MISO proxy events. Most event hour impacts were statistically significant at 90% confidence. Savings ranged from 0.05 to 0.15 kW. MISO proxy events achieved an average reduction of 0.10 kW and an average percentage savings of 58%. The MISO proxy event savings were consistent with the non-MISO proxy events due to water heater's load not being weather driven.

Table 14. Average Water Heater Demand Reduction during MISO Proxy Events

Event Hours	Number of Events	Average Event Temperature (°F)	Hour Beginning	Impact per Air Conditioner (kW)	90% Confidence Intervals (kW)		Percent Reduction	Achievable Savings (kW)**
					Lower Bound	Upper Bound		
2 p.m. - 4 p.m.	2	77	Event hour 1	-0.090*	-0.121	-0.059	54%	546
			Event hour 2	-0.050	-0.104	0.004	29%	304
3 p.m. - 5 p.m.	2	81	Event hour 1	-0.079*	-0.123	-0.034	45%	477
			Event hour 2	-0.123*	-0.163	-0.083	67%	747
4 p.m. - 6 p.m.	2	84	Event hour 1	-0.140*	-0.175	-0.104	76%	848
			Event hour 2	-0.149*	-0.194	-0.104	75%	904

*This estimate is statistically significant at the 10% level
** The total achievable program impact represents possible program savings if Vectren had cycled all Summer Cycler customers instead of just the treatment group of the program

Using the MISO proxy event percentage savings, Cadmus estimated potential impacts of MISO for water heaters by month. Table 15 presents average estimated impacts across all hours and average estimated impacts during peak hours.

Table 15. Estimated Potential Average Water Heater Demand Reduction during MISO Events

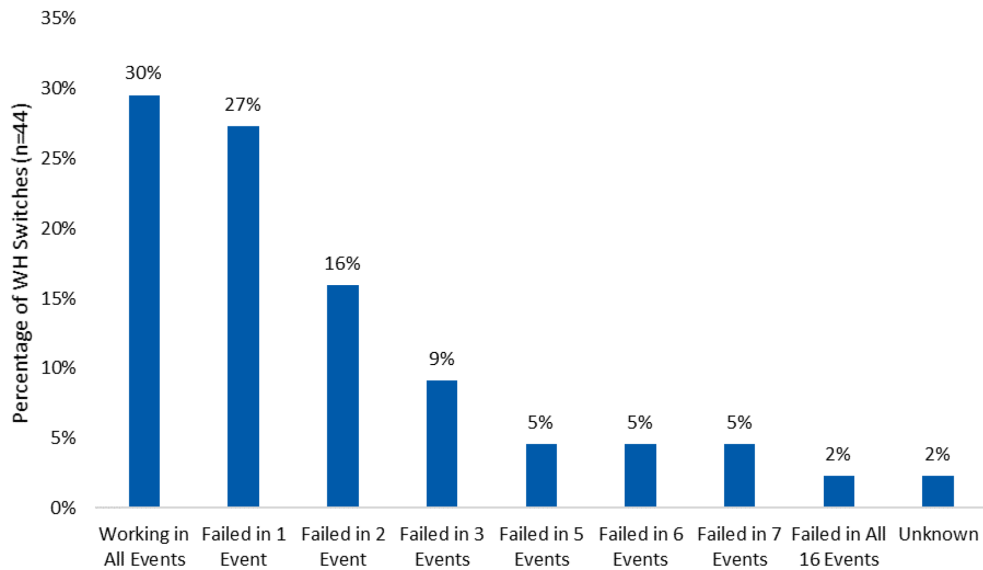
Month	Average Estimated Water Heater Impact Across All Hours	Average Estimated Water Heater Impact Between 2 p.m. to 6 p.m.
June	-0.12	-0.13
July	-0.09	-0.10
August	-0.09	-0.10
September	-0.09	-0.10

Water Heater Switch Failure

Cadmus would expect to see percentage savings closer to 100% since the switches are supposed to completely cycle off the water heaters during events. By analyzing loads for individual water heaters, Cadmus determined that 70% of water heater switches did not function correctly during at least one event, thus decreasing the percentage savings. Water heaters should have been completely switched off for all event hours. Cadmus categorized each of the 44 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 the end hour of an event. During this last hour of the event period, the switch should have turned off the water heater for the whole hour.

As shown in Figure 5, 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. Only one switch failed during all 16 events, suggesting that the switch problems are intermittent, not permanent. The functionality of the water heater switches across the 16 events in summer 2019 was not consistent, and the switch problems were not associated specifically with any one of the 16 events. This issue was also present in the 2017 evaluation. 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 5. Water Heater Switch Failures



Post-Event Impacts (Rebound)

Cadmus evaluated a significant post-event snap-back in water heating demand during the first hour following each event window but did not find significant post-event impacts outside the first post-event hour (no significant demand increases in post-even hours 2 through 6). Table 16 presents the average kW impact of the first post-event hour by event window and event type (standard load-control events and MISO proxy events). Overall, Cadmus estimated an average post-event increase in demand of 0.12 kW per water heater and an average percentage increase of 60%. This means water heating demand events will result in greater demand immediately following the event. Additional details on post-event hourly demand can be found in *Appendix D. Water Heater kW Impacts for Each Event Hour*.

Table 16. Estimates of Average Water Heater Post-Event Hour 1 Impacts

Event Hours	Event Type	Impact per Air Conditioner (kW)	90% Confidence Intervals (kW)		Percent Usage Increase	Achievable Savings (kW)**
			Lower Bound	Upper Bound		
2 p.m. - 4 p.m.	Standard	0.113*	0.046	0.180	62%	-687
	MISO Proxy	0.101*	0.039	0.162	55%	-610
3 p.m. - 4 p.m.	Standard	0.110*	0.037	0.183	55%	-668
	MISO Proxy	0.123*	0.031	0.215	61%	-743
4 p.m. - 6 p.m.	Standard	0.093*	0.036	0.151	42%	-567
	MISO Proxy	0.185*	0.065	0.305	82%	-1,122

*This estimate is statistically significant at the 10% level

** The total achievable program impact represents possible program savings if Vectren had cycled all Summer Cycler customers instead of just the treatment group of the program

Potential MISO Impact

Table 17 shows the average hourly potential demand reduction for air conditioners for non-event days. MISO-proxy days were used to generate the results. At peak hours, potential savings are .13 kW per hour per water heater, occurring from 8:00 AM to 9:00 AM and from 6:00 to 8:00 PM.

Table 17: Potential MISO WH Impacts by Hour

Time of Day	Baseline kW	Potential Impacts (kW)	Time of Day	Baseline kW	Potential Impacts (kW)
0:00	0.11	-0.07	12:00	0.18	-0.11
1:00	0.11	-0.07	13:00	0.17	-0.10
2:00	0.12	-0.07	14:00	0.17	-0.10
3:00	0.13	-0.07	15:00	0.17	-0.10
4:00	0.12	-0.07	16:00	0.18	-0.11
5:00	0.13	-0.08	17:00	0.19	-0.11
6:00	0.19	-0.11	18:00	0.22	-0.13
7:00	0.21	-0.12	19:00	0.22	-0.13
8:00	0.22	-0.13	20:00	0.20	-0.12
9:00	0.21	-0.12	21:00	0.17	-0.10
10:00	0.20	-0.11	22:00	0.15	-0.09
11:00	0.19	-0.11	23:00	0.13	-0.07

Energy Impacts

Energy impacts from the 2019 Summer Cycler events depended on the relative magnitude of event hour demand impact and the post-event rebound in energy demand. Table 18 shows average event-day energy savings per air conditioner, per water heater, and for the overall program for each event type. None of the energy savings estimate were statistically different from zero at the 10% significance level. The MISO proxy event air conditioner events resulted in an estimated increase in kWh usage; however, the estimate is not significant, and the confidence interval is very wide.

Table 18. Average Energy Impacts per Event Type

	Standard Load-Control Events				MISO Proxy Events			
	Per Unit (kWh)	90% Confidence Limits		Program (kWh)*	Per Unit (kWh)	90% Confidence Limits		Program (kWh)*
		Lower Bound	Upper Bound			Lower Bound	Upper Bound	
Air Conditioners	-0.78	-1.71	0.16	-134	0.25	-0.56	1.06	42
Water Heaters	-0.27	-0.74	0.21	-14	-0.22	-0.54	0.11	-11
Total	NA			**-148**	NA			**31**

*Not total achievable program impacts, logger analysis sample only.

Conclusions and Recommendations

Based on the findings from the 2019 Summer Cycler Program impact evaluation, Cadmus offers the following conclusions and recommendations.

Conclusion: The Summer Cycler Program continues to provide significant demand reductions from air-conditioning load control during high outdoor temperatures.

Standard load-control events achieved average event savings of 0.3 kW (21%) per air conditioner, where temperatures averaged 89˚F. Events with the highest outdoor temperature, achieved the highest kW savings. Across the summer, demand reduction during load-control events is most directly impacted by outdoor temperature, with higher temperatures leading to larger reductions. On most days, the greatest capacity for demand reduction during the day takes place between 4 p.m. and 6 p.m.

Conclusion: Demand reductions from water heaters are lower than the potential maximum savings partially due to the typical Summer Cycler event window (2 p.m. to 6 p.m.) not coinciding with peak water-heating use.

Water heaters achieved an average event savings of 0.1 kW (54%) per water heater. Water heaters were cycled from 2 p.m. to 6 p.m. while the water heater peak times are from 6 a.m. to 9 a.m. and again from 6 p.m. to 8 p.m. As, MISO events can be called during any time of day, water heaters could achieve larger demand reduction during MISO events if called during water heater peak periods.

Conclusion: A high failure rate among water heater switches is decreasing the demand reduction potential for water heating loads.

Over the past three evaluations (2015, 2017, 2019), Cadmus found many water heater switches that failed during at least one event. In 2017 and 2019, Cadmus found that only 30% of switches were working during all event hours, a decrease from 51% in 2015. The large failure rate is most likely the driving factor behind water heaters achieving savings that are lower than 100% (since water heaters are turned completely off during events). Despite the failure rates, the more than 6,000 water heaters enrolled in the program can provide over 0.6 MW of demand savings during event periods.

Recommendation:

- Investigate what is causing the water heater switch failure. Cadmus understands Vectren visits select Summer Cycler homes each year as part of the transition to the Smart Cycle Program.[10] Vectren could utilize the time when Summer Cycler customer homes are entered by thermostat installation technicians to simultaneously troubleshoot or repair existing water heater switches.

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[10] In 2018, Vectren launched the Smart Cycle Program to enable control of selected residential central air conditioning loads during summer hours of system peak demand via Nest smart thermostats. Each year, Vectren recruits up to 1,000 participants from the Summer Cycler Program to participate in Smart Cycle by installing smart thermostats directly for the customer.

Conclusion: Vectren is limited in the number of water heaters sampled for analysis due to inconvenience and difficulty of installing loggers inside people's homes.

To increase the sample size of the water heater loggers, Vectren's logger installation contractor (Schneider Electric) had to enter customer homes (unlike for air conditioners where loggers were installed on outdoor compressor units). Vectren had originally planned to increase the water heater sample size for the 2019 evaluation but ultimately decided it was not cost effective and too burdensome on customers. However, any further reduction in sample size could result in findings that are not statistically significant. In 2018, Vectren finished its deployment of AMI to all customers. Use of this AMI data would expand the Summer Cycler evaluation to all installed water heaters and air conditioners rather than only a sample of customers. AMI data would also provide the opportunity to evaluate whole-home impacts rather than just air conditioner and water heater program impacts.

Recommendation:

- Export AMI data for future analyses so that logger installation and collection are no longer necessary. AMI data will facilitate an expanded evaluation with potentially reduced cost.

Conclusion: The Summer Cycler Program can achieve significant demand reductions on lower temperature event days.

Air conditioners achieved average per-unit event savings of 0.14 kW (15%), and water heaters achieved average per-unit event savings of 0.10 kW (58%) during MISO proxy events. Standard load-control events achieved 0.27 kW (21%) per air conditioner and 0.10 kW (54%) per water heaters. Like with the standard load control events, the event times coincided with air conditioner peak times but did not with the water heater times. Unlike with air conditioners, low temperature events will provide similar water heater demand reduction as high temperature events because water heater demand is not driven by weather, rather driven by time of the day.

Conclusion: Vectren actively calling MISO proxy events allowed for more accurate planning for potential MISO event savings.

In 2019, Vectren called six MISO proxy events on lower temperature days to simulate circumstances when MISO could trigger a load-control event. By calling these proxy events, Vectren gathered data to improve upon previous estimations for MISO event planning. Prior to any MISO proxy events being called, in July 2019, Cadmus estimated a reduction of 21% during MISO events.[11] However, after collecting more precise data through the MISO proxy events, called in August and September 2019, Cadmus refined its estimate to a 15% reduction.

[11] Cadmus. July 11, 2019.*Vectren Summer Cycler Smart Cycle Memo.xlsx*. Prepared for Vectren Energy Delivery of Indiana.

Recommendations:

- If Vectren assumes that MISO events can be called at any hour, Vectren should plan for a 0.06 kW to 0.10 kW reduction in usage per air conditioner and 0.09 kW to 0.12 kW reduction per water heaters during MISO events depending on the month.
- If Vectren assumes that MISO events will be called between 2 p.m. and 6 p.m., Vectren should plan for a 0.12 kW to 0.17 kW reduction in usage per air conditioner and 0.10 kW to 0.13 kW reduction per water heaters during MISO events depending on the month.

Appendix A. Detailed Demand Reduction Analysis Methodology

Data Collection and Preparation

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

- Hourly kW vs. time (June 15, 2019, to September 30, 2019)
- 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

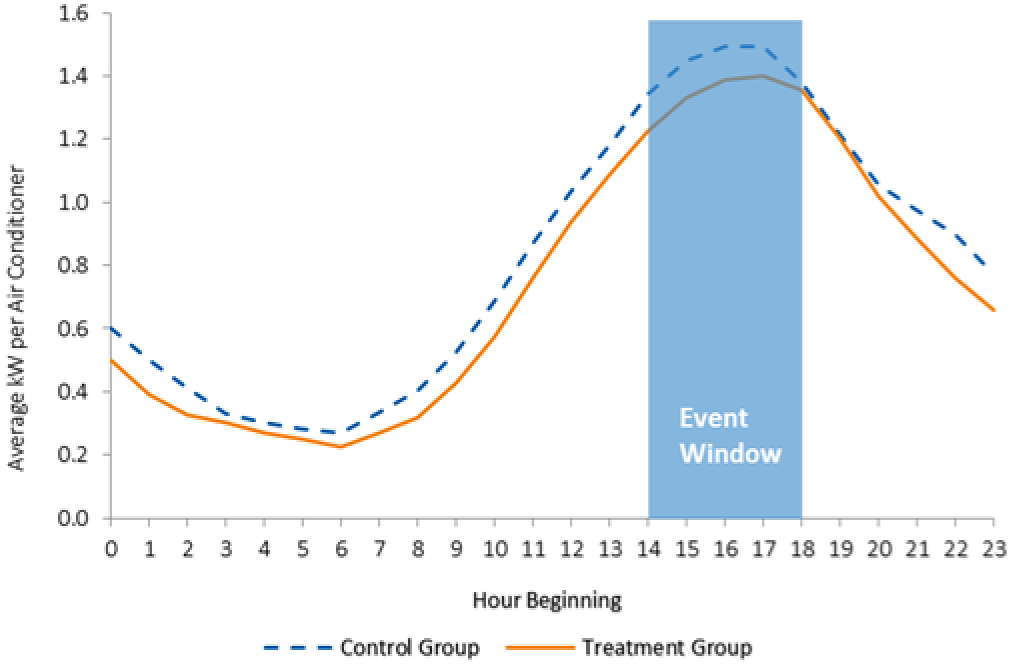
Cadmus identified hourly air conditioner demand observations greater than 6 kW. Cadmus' research suggested that these readings were implausibly large for residential air conditioners (which generally did not exceed 4 kW) and were therefore likely to be bad data, so these observations were not included in the analysis sample.

While cleaning the logger data, 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 a few loggers had been set to a time zone other than GMT -5. To correct these 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 raw data; therefore, Cadmus confirmed that the average daily usage curve and average daily peak hours matched those of the previous evaluation (2017). Cadmus found that the summer 2019 average non-event air conditioner usage curve matched the curve observed in the 2017 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.

Cadmus plotted the load shapes to further verify the data. Figure A-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 2:00 p.m. and 6:00 p.m. (simulating circumstances when Vectren may call standard load-control events). The shaded area indicates hours between 2:00 p.m. and 6:00 p.m.—the period during which Vectren called events in summer 2019.

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

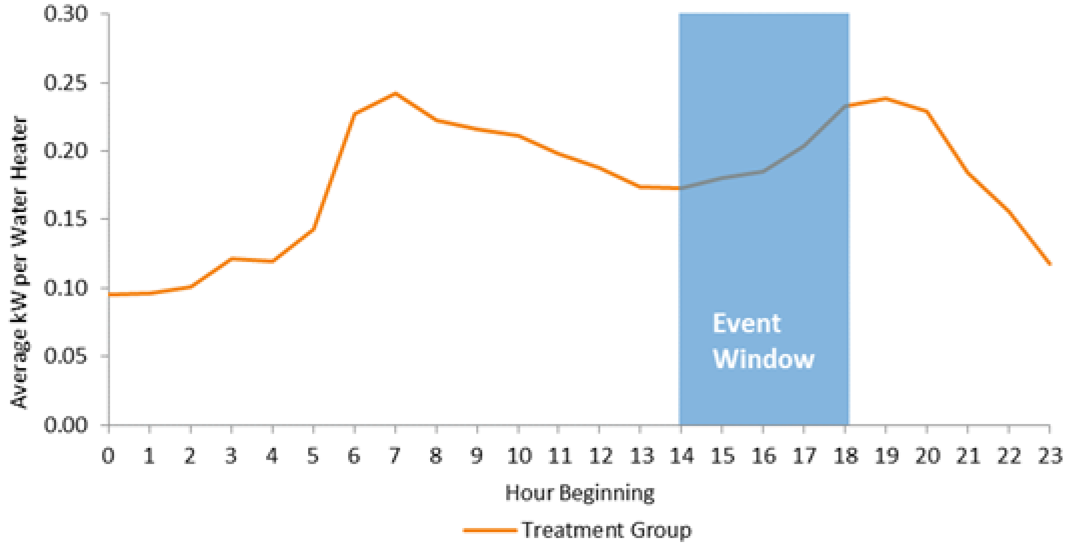


The average electricity demand per air conditioner increased over weekday afternoons and evenings, from approximately 0.9 kW at 12:00 p.m. to a peak of approximately 1.4 kW between 5:00 p.m. and 6:00 p.m. Demand decreased during the evening and was at its lowest during early morning hours.

Cadmus found a statistical difference in air-conditioning load between the control and treatment groups on nonevent days. These differences arose despite Cadmus' stratified random assignment of the logger analysis sample by peak energy use during the summer of 2017. 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 A-2 shows the average demand per water heater in the logger analysis sample during warm, nonevent weekdays. The evaluation did not employ a control group, so all sample water heaters experienced cycling. 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 windows did not cover either peak. Despite this, 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.

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



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 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.

Modeling Technique

A generalized linear model provided the appropriate econometric model to fit the end-use data and to estimate demand savings. 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):

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

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.)

Cadmus estimated electricity savings in an event hour as the difference between expected kW in the hour and baseline kW, the expected kW, conditional on the event not occurring.

Appendix B. Detailed Event Day Energy Savings Estimation Methodology

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

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

Where:

kWh_{id}	=	Daily electricity use of air conditioner/water heaters 'i,' i=1, 2, …, N, on day 'd', d=1, 2, …, D of the estimation period.
α_i	=	Unobservable, time-invariant electricity use for air conditioner/water heaters 'i.' These effects are controlled for with air conditioner/water heaters fixed effects (i.e., the regression includes a separate dummy variable for each air conditioner/water heaters).
τ_d	=	Day of the analysis sample fixed effect. This variable captures effects specific to a day, such as weather on air conditioner/water heaters electricity use.
$Test_i$	=	Indicator variable for whether air conditioner/water heaters i is in the test group. $Test_i$ equals 1 if air conditioner/water heaters i is in the test group and equals 0 if it is in the control group.
$Event_d$	=	Indicator variable for an event day. This variable equals 1 if day 'd' is an event day and equals 0 otherwise.
β	=	Average impact of an event day on daily electricity use of air conditioners/water heaters.

Cadmus estimated the model by ordinary least squares and clustered the standard errors on loggers to account for unobserved correlation in a logger energy use over time.

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

Appendix C. Air Conditioner kW Impacts for Each Event Hour

Table C-1 shows estimates of the demand impacts for air conditioners during each event hour and each of the six post-event hours.

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

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per AC Unit (kW)	Average Metered (kW)	Baseline (kW)
1	Standard	5-Aug-19	14	Event Hour 1*	89	-0.20	0.96	1.15
1	Standard	5-Aug-19	15	Event Hour 2*	88	-0.32	1.03	1.34
1	Standard	5-Aug-19	16	Post Event Hour 1	87	0.00	1.51	1.51
1	Standard	5-Aug-19	17	Post Event Hour 2	83	-0.13	1.42	1.55
1	Standard	5-Aug-19	18	Post Event Hour 3*	82	-0.21	1.32	1.53
1	Standard	5-Aug-19	19	Post Event Hour 4	77	0.02	1.22	1.20
1	Standard	5-Aug-19	20	Post Event Hour 5	74	0.02	1.04	1.02
1	Standard	5-Aug-19	21	Post Event Hour 6	74	-0.01	0.93	0.94
2	Standard	8-Aug-19	14	Event Hour 1*	85	-0.15	0.82	0.97
2	Standard	8-Aug-19	15	Event Hour 2*	86	-0.18	0.92	1.10
2	Standard	8-Aug-19	16	Post Event Hour 1	85	0.15	1.44	1.29
2	Standard	8-Aug-19	17	Post Event Hour 2	84	-0.05	1.28	1.33
2	Standard	8-Aug-19	18	Post Event Hour 3	83	0.03	1.25	1.22
2	Standard	8-Aug-19	19	Post Event Hour 4	77	0.01	1.10	1.09
2	Standard	8-Aug-19	20	Post Event Hour 5	75	0.00	0.95	0.96
2	Standard	8-Aug-19	21	Post Event Hour 6	74	0.09	0.92	0.82
3	Standard	12-Aug-19	16	Event Hour 1*	87	-0.19	0.87	1.07
3	Standard	12-Aug-19	17	Event Hour 2	87	-0.15	0.84	1.00
3	Standard	12-Aug-19	18	Post Event Hour 1	86	0.16	1.35	1.19
3	Standard	12-Aug-19	19	Post Event Hour 2*	83	0.20	1.38	1.18
3	Standard	12-Aug-19	20	Post Event Hour 3*	83	0.21	1.31	1.10
3	Standard	12-Aug-19	21	Post Event Hour 4	82	0.12	1.12	1.00
3	Standard	12-Aug-19	22	Post Event Hour 5	83	0.01	0.81	0.80
3	Standard	12-Aug-19	23	Post Event Hour 6	82	-0.01	0.75	0.76
4	Standard	13-Aug-19	16	Event Hour 1*	86	-0.19	1.09	1.27
4	Standard	13-Aug-19	17	Event Hour 2*	84	-0.20	1.09	1.29
4	Standard	13-Aug-19	18	Post Event Hour 1*	83	0.19	1.49	1.31
4	Standard	13-Aug-19	19	Post Event Hour 2	79	0.14	1.32	1.18
4	Standard	13-Aug-19	20	Post Event Hour 3*	78	0.22	1.19	0.97
4	Standard	13-Aug-19	21	Post Event Hour 4*	77	0.18	1.09	0.91
4	Standard	13-Aug-19	22	Post Event Hour 5	76	0.02	0.76	0.73
4	Standard	13-Aug-19	23	Post Event Hour 6	75	0.05	0.69	0.64
5	MISO Proxy	14-Aug-19	16	Event Hour 1	86	-0.16	1.10	1.26
5	MISO Proxy	14-Aug-19	17	Event Hour 2*	83	-0.20	0.98	1.17
5	MISO Proxy	14-Aug-19	18	Post Event Hour 1*	82	0.20	1.54	1.34
5	MISO Proxy	14-Aug-19	19	Post Event Hour 2	78	0.17	1.34	1.17
5	MISO Proxy	14-Aug-19	20	Post Event Hour 3	76	0.14	1.07	0.93
5	MISO Proxy	14-Aug-19	21	Post Event Hour 4	75	0.03	0.89	0.86
5	MISO Proxy	14-Aug-19	22	Post Event Hour 5	74	-0.04	0.68	0.71
5	MISO Proxy	14-Aug-19	23	Post Event Hour 6	72	0.03	0.70	0.67
6	Standard	19-Aug-19	16	Event Hour 1*	90	-0.47	1.17	1.64
6	Standard	19-Aug-19	17	Event Hour 2*	88	-0.38	1.21	1.59
6	Standard	19-Aug-19	18	Post Event Hour 1	86	-0.05	1.69	1.73
6	Standard	19-Aug-19	19	Post Event Hour 2	81	0.04	1.62	1.58
6	Standard	19-Aug-19	20	Post Event Hour 3	80	0.17	1.43	1.26

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per AC Unit (kW)	Average Metered (kW)	Baseline (kW)
6	Standard	19-Aug-19	21	Post Event Hour 4	80	0.11	1.27	1.16
6	Standard	19-Aug-19	22	Post Event Hour 5*	80	0.19	1.07	0.88
6	Standard	19-Aug-19	23	Post Event Hour 6	78	0.05	0.87	0.83
7	MISO Proxy	20-Aug-19	14	Event Hour 1	71	-0.07	1.00	1.07
7	MISO Proxy	20-Aug-19	15	Event Hour 2	71	0.20	0.97	0.77
7	MISO Proxy	20-Aug-19	16	Post Event Hour 1*	72	0.18	0.85	0.67
7	MISO Proxy	20-Aug-19	17	Post Event Hour 2	72	-0.03	0.63	0.66
7	MISO Proxy	20-Aug-19	18	Post Event Hour 3*	72	0.17	0.70	0.53
7	MISO Proxy	20-Aug-19	19	Post Event Hour 4	71	0.05	0.50	0.45
7	MISO Proxy	20-Aug-19	20	Post Event Hour 5	70	0.11	0.53	0.42
7	MISO Proxy	20-Aug-19	21	Post Event Hour 6	70	0.02	0.48	0.47
8	MISO Proxy	21-Aug-19	14	Event Hour 1*	85	-0.29	0.89	1.18
8	MISO Proxy	21-Aug-19	15	Event Hour 2*	83	-0.23	0.96	1.19
8	MISO Proxy	21-Aug-19	16	Post Event Hour 1*	86	0.22	1.40	1.18
8	MISO Proxy	21-Aug-19	17	Post Event Hour 2	84	0.04	1.41	1.37
8	MISO Proxy	21-Aug-19	18	Post Event Hour 3	83	0.01	1.36	1.35
8	MISO Proxy	21-Aug-19	19	Post Event Hour 4	80	-0.01	1.15	1.16
8	MISO Proxy	21-Aug-19	20	Post Event Hour 5	80	-0.09	0.96	1.05
8	MISO Proxy	21-Aug-19	21	Post Event Hour 6	78	0.11	0.94	0.83
9	MISO Proxy	3-Sep-19	16	Event Hour 1*	86	-0.20	1.03	1.23
9	MISO Proxy	3-Sep-19	17	Event Hour 2*	83	-0.34	0.99	1.33
9	MISO Proxy	3-Sep-19	18	Post Event Hour 1	80	0.04	1.32	1.27
9	MISO Proxy	3-Sep-19	19	Post Event Hour 2	78	0.08	1.13	1.05
9	MISO Proxy	3-Sep-19	20	Post Event Hour 3	79	-0.01	0.89	0.90
9	MISO Proxy	3-Sep-19	21	Post Event Hour 4	74	0.01	0.84	0.83
9	MISO Proxy	3-Sep-19	22	Post Event Hour 5	73	0.03	0.69	0.66
9	MISO Proxy	3-Sep-19	23	Post Event Hour 6	74	-0.04	0.66	0.70
10	Standard	10-Sep-19	14	Event Hour 1*	94	-0.34	0.97	1.32
10	Standard	10-Sep-19	15	Event Hour 2*	93	-0.42	1.05	1.47
10	Standard	10-Sep-19	16	Post Event Hour 1	90	-0.02	1.54	1.55
10	Standard	10-Sep-19	17	Post Event Hour 2	83	-0.04	1.56	1.60
10	Standard	10-Sep-19	18	Post Event Hour 3	82	0.02	1.36	1.34
10	Standard	10-Sep-19	19	Post Event Hour 4	81	-0.02	1.20	1.22
10	Standard	10-Sep-19	20	Post Event Hour 5	77	0.10	1.12	1.02
10	Standard	10-Sep-19	21	Post Event Hour 6	76	0.05	1.00	0.94
11	Standard	11-Sep-19	15	Event Hour 1*	92	-0.28	1.19	1.47
11	Standard	11-Sep-19	16	Event Hour 2*	90	-0.30	1.21	1.50
11	Standard	11-Sep-19	17	Post Event Hour 1	85	-0.06	1.59	1.65
11	Standard	11-Sep-19	18	Post Event Hour 2	84	-0.02	1.47	1.50
11	Standard	11-Sep-19	19	Post Event Hour 3	81	-0.04	1.30	1.34
11	Standard	11-Sep-19	20	Post Event Hour 4	77	-0.04	1.15	1.19
11	Standard	11-Sep-19	21	Post Event Hour 5	75	-0.05	1.00	1.05
11	Standard	11-Sep-19	22	Post Event Hour 6	74	-0.01	0.85	0.85
12	Standard	12-Sep-19	16	Event Hour 1*	91	-0.31	1.15	1.46
12	Standard	12-Sep-19	17	Event Hour 2*	87	-0.40	1.11	1.51
12	Standard	12-Sep-19	18	Post Event Hour 1	84	0.15	1.51	1.36
12	Standard	12-Sep-19	19	Post Event Hour 2*	80	0.20	1.40	1.20
12	Standard	12-Sep-19	20	Post Event Hour 3	77	-0.16	1.10	1.25
12	Standard	12-Sep-19	21	Post Event Hour 4	76	-0.08	0.96	1.04
12	Standard	12-Sep-19	22	Post Event Hour 5	74	-0.19	0.82	1.01
12	Standard	12-Sep-19	23	Post Event Hour 6	73	-0.03	0.81	0.84
13	MISO Proxy	24-Sep-19	15	Event Hour 1	79	-0.04	0.40	0.45
13	MISO Proxy	24-Sep-19	16	Event Hour 2	76	-0.09	0.42	0.51

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per AC Unit (kW)	Average Metered (kW)	Baseline (kW)
13	MISO Proxy	24-Sep-19	17	Post Event Hour 1	70	0.14	0.55	0.41
13	MISO Proxy	24-Sep-19	18	Post Event Hour 2	67	0.05	0.46	0.41
13	MISO Proxy	24-Sep-19	19	Post Event Hour 3	66	0.12	0.40	0.28
13	MISO Proxy	24-Sep-19	20	Post Event Hour 4	62	0.00	0.26	0.26
13	MISO Proxy	24-Sep-19	21	Post Event Hour 5	57	-0.08	0.22	0.31
13	MISO Proxy	24-Sep-19	22	Post Event Hour 6	60	-0.12	0.22	0.34
14	MISO Proxy	25-Sep-19	15	Event Hour 1	85	-0.08	0.54	0.61
14	MISO Proxy	25-Sep-19	16	Event Hour 2*	82	-0.21	0.56	0.76
14	MISO Proxy	25-Sep-19	17	Post Event Hour 1	80	0.13	0.87	0.74
14	MISO Proxy	25-Sep-19	18	Post Event Hour 2	79	0.09	0.80	0.71
14	MISO Proxy	25-Sep-19	19	Post Event Hour 3	75	0.00	0.68	0.68
14	MISO Proxy	25-Sep-19	20	Post Event Hour 4	73	-0.19	0.61	0.80
14	MISO Proxy	25-Sep-19	21	Post Event Hour 5	72	-0.17	0.54	0.71
14	MISO Proxy	25-Sep-19	22	Post Event Hour 6	74	0.02	0.51	0.48
15	Standard	27-Sep-19	15	Event Hour 1*	89	-0.35	0.67	1.03
15	Standard	27-Sep-19	16	Event Hour 2*	89	-0.34	0.72	1.06
15	Standard	27-Sep-19	17	Post Event Hour 1	85	-0.20	1.06	1.26
15	Standard	27-Sep-19	18	Post Event Hour 2*	83	-0.25	1.00	1.25
15	Standard	27-Sep-19	19	Post Event Hour 3	78	-0.12	0.85	0.96
15	Standard	27-Sep-19	20	Post Event Hour 4	81	-0.11	0.71	0.82
15	Standard	27-Sep-19	21	Post Event Hour 5	79	0.02	0.68	0.66
15	Standard	27-Sep-19	22	Post Event Hour 6	76	0.18	0.67	0.49
16	Standard	30-Sep-19	16	Event Hour 1	90	-0.18	1.42	1.60
16	Standard	30-Sep-19	17	Event Hour 2	83	-0.13	1.34	1.47
16	Standard	30-Sep-19	18	Post Event Hour 1	83	-0.09	1.33	1.42
16	Standard	30-Sep-19	19	Post Event Hour 2	79	0.05	1.20	1.14
16	Standard	30-Sep-19	20	Post Event Hour 3	76	-0.05	1.05	1.10
16	Standard	30-Sep-19	21	Post Event Hour 4*	76	-0.21	0.82	1.03
16	Standard	30-Sep-19	22	Post Event Hour 5	75	-0.04	0.61	0.65
16	Standard	30-Sep-19	23	Post Event Hour 6	71	-0.13	0.54	0.67

*Hourly estimates which are significant at 90% confidence are bold.

Appendix D. Water Heater kW Impacts for Each Event Hour

Table D-1 shows estimates of the demand impacts for water heaters during each event hour and each of the six post-event hours.

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

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per WH Unit (kW)	Average Metered (kW)	Baseline (kW)
1	Standard	5-Aug-19	14	Event Hour 1*	89	-0.12	0.04	0.17
1	Standard	5-Aug-19	15	Event Hour 2	88	-0.06	0.12	0.17
1	Standard	5-Aug-19	16	Post Event Hour 1*	87	0.14	0.33	0.18
1	Standard	5-Aug-19	17	Post Event Hour 2	83	-0.06	0.14	0.20
1	Standard	5-Aug-19	18	Post Event Hour 3	82	-0.06	0.17	0.22
1	Standard	5-Aug-19	19	Post Event Hour 4	77	0.07	0.30	0.23
1	Standard	5-Aug-19	20	Post Event Hour 5*	74	0.13	0.35	0.22
1	Standard	5-Aug-19	21	Post Event Hour 6	74	-0.04	0.13	0.18
2	Standard	8-Aug-19	14	Event Hour 1*	85	-0.09	0.08	0.17
2	Standard	8-Aug-19	15	Event Hour 2*	86	-0.10	0.08	0.17
2	Standard	8-Aug-19	16	Post Event Hour 1*	85	0.10	0.29	0.18
2	Standard	8-Aug-19	17	Post Event Hour 2*	84	-0.08	0.12	0.20
2	Standard	8-Aug-19	18	Post Event Hour 3	83	0.01	0.24	0.22
2	Standard	8-Aug-19	19	Post Event Hour 4	77	0.10	0.33	0.23
2	Standard	8-Aug-19	20	Post Event Hour 5	75	0.02	0.25	0.22
2	Standard	8-Aug-19	21	Post Event Hour 6	74	0.03	0.21	0.18
3	Standard	12-Aug-19	16	Event Hour 1	87	-0.07	0.12	0.18
3	Standard	12-Aug-19	17	Event Hour 2*	87	-0.17	0.03	0.20
3	Standard	12-Aug-19	18	Post Event Hour 1*	86	0.24	0.46	0.22
3	Standard	12-Aug-19	19	Post Event Hour 2	83	0.06	0.29	0.23
3	Standard	12-Aug-19	20	Post Event Hour 3	83	0.00	0.23	0.22
3	Standard	12-Aug-19	21	Post Event Hour 4	82	0.10	0.27	0.18
3	Standard	12-Aug-19	22	Post Event Hour 5*	83	-0.07	0.08	0.15
3	Standard	12-Aug-19	23	Post Event Hour 6*	82	-0.04	0.07	0.11
4	Standard	13-Aug-19	16	Event Hour 1*	86	-0.10	0.08	0.18
4	Standard	13-Aug-19	17	Event Hour 2*	84	-0.13	0.07	0.20
4	Standard	13-Aug-19	18	Post Event Hour 1*	83	0.15	0.38	0.22
4	Standard	13-Aug-19	19	Post Event Hour 2	79	0.02	0.25	0.23
4	Standard	13-Aug-19	20	Post Event Hour 3	78	-0.06	0.17	0.22
4	Standard	13-Aug-19	21	Post Event Hour 4	77	-0.02	0.16	0.18
4	Standard	13-Aug-19	22	Post Event Hour 5*	76	-0.07	0.08	0.15
4	Standard	13-Aug-19	23	Post Event Hour 6	75	0.06	0.17	0.11
5	MISO Proxy	14-Aug-19	16	Event Hour 1*	86	-0.14	0.04	0.18
5	MISO Proxy	14-Aug-19	17	Event Hour 2*	83	-0.13	0.07	0.20

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per WH Unit (kW)	Average Metered (kW)	Baseline (kW)
5	MISO Proxy	14-Aug-19	18	Post Event Hour 1*	82	0.21	0.44	0.22
5	MISO Proxy	14-Aug-19	19	Post Event Hour 2	78	0.07	0.30	0.23
5	MISO Proxy	14-Aug-19	20	Post Event Hour 3	76	0.00	0.22	0.22
5	MISO Proxy	14-Aug-19	21	Post Event Hour 4	75	0.00	0.17	0.18
5	MISO Proxy	14-Aug-19	22	Post Event Hour 5*	74	-0.06	0.09	0.15
5	MISO Proxy	14-Aug-19	23	Post Event Hour 6	72	0.04	0.15	0.11
6	Standard	19-Aug-19	16	Event Hour 1*	90	-0.11	0.07	0.18
6	Standard	19-Aug-19	17	Event Hour 2*	88	-0.15	0.05	0.20
6	Standard	19-Aug-19	18	Post Event Hour 1*	86	0.08	0.30	0.22
6	Standard	19-Aug-19	19	Post Event Hour 2	81	-0.02	0.21	0.23
6	Standard	19-Aug-19	20	Post Event Hour 3	80	0.07	0.30	0.22
6	Standard	19-Aug-19	21	Post Event Hour 4	80	-0.02	0.16	0.18
6	Standard	19-Aug-19	22	Post Event Hour 5*	80	-0.07	0.08	0.15
6	Standard	19-Aug-19	23	Post Event Hour 6	78	0.01	0.12	0.11
7	MISO Proxy	20-Aug-19	14	Event Hour 1*	71	-0.11	0.05	0.17
7	MISO Proxy	20-Aug-19	15	Event Hour 2	71	0.00	0.18	0.17
7	MISO Proxy	20-Aug-19	16	Post Event Hour 1*	72	0.15	0.33	0.18
7	MISO Proxy	20-Aug-19	17	Post Event Hour 2	72	0.02	0.22	0.20
7	MISO Proxy	20-Aug-19	18	Post Event Hour 3	72	-0.06	0.17	0.22
7	MISO Proxy	20-Aug-19	19	Post Event Hour 4	71	0.00	0.23	0.23
7	MISO Proxy	20-Aug-19	20	Post Event Hour 5	70	-0.07	0.15	0.22
7	MISO Proxy	20-Aug-19	21	Post Event Hour 6	70	0.07	0.25	0.18
8	MISO Proxy	21-Aug-19	14	Event Hour 1*	85	-0.07	0.10	0.17
8	MISO Proxy	21-Aug-19	15	Event Hour 2*	83	-0.10	0.07	0.17
8	MISO Proxy	21-Aug-19	16	Post Event Hour 1	86	0.05	0.23	0.18
8	MISO Proxy	21-Aug-19	17	Post Event Hour 2	84	0.06	0.26	0.20
8	MISO Proxy	21-Aug-19	18	Post Event Hour 3	83	0.04	0.27	0.22
8	MISO Proxy	21-Aug-19	19	Post Event Hour 4*	80	0.13	0.36	0.23
8	MISO Proxy	21-Aug-19	20	Post Event Hour 5	80	-0.03	0.20	0.22

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per WH Unit (kW)	Average Metered (kW)	Baseline (kW)
8	MISO Proxy	21-Aug-19	21	Post Event Hour 6	78	0.00	0.18	0.18
9	MISO Proxy	3-Sep-19	16	Event Hour 1*	86	-0.14	0.04	0.18
9	MISO Proxy	3-Sep-19	17	Event Hour 2*	83	-0.17	0.03	0.20
9	MISO Proxy	3-Sep-19	18	Post Event Hour 1*	80	0.16	0.38	0.22
9	MISO Proxy	3-Sep-19	19	Post Event Hour 2	78	-0.05	0.19	0.23
9	MISO Proxy	3-Sep-19	20	Post Event Hour 3	79	0.06	0.28	0.22
9	MISO Proxy	3-Sep-19	21	Post Event Hour 4*	74	-0.07	0.10	0.18
9	MISO Proxy	3-Sep-19	22	Post Event Hour 5*	73	-0.08	0.07	0.15
9	MISO Proxy	3-Sep-19	23	Post Event Hour 6	74	-0.01	0.10	0.11
10	Standard	10-Sep-19	14	Event Hour 1*	94	-0.09	0.07	0.17
10	Standard	10-Sep-19	15	Event Hour 2*	93	-0.14	0.03	0.17
10	Standard	10-Sep-19	16	Post Event Hour 1	90	0.09	0.28	0.18
10	Standard	10-Sep-19	17	Post Event Hour 2	83	-0.02	0.18	0.20
10	Standard	10-Sep-19	18	Post Event Hour 3	82	-0.06	0.16	0.22
10	Standard	10-Sep-19	19	Post Event Hour 4	81	-0.04	0.20	0.23
10	Standard	10-Sep-19	20	Post Event Hour 5	77	0.00	0.22	0.22
10	Standard	10-Sep-19	21	Post Event Hour 6	76	-0.07	0.11	0.18
11	Standard	11-Sep-19	15	Event Hour 1*	92	-0.11	0.07	0.17
11	Standard	11-Sep-19	16	Event Hour 2*	90	-0.16	0.02	0.18
11	Standard	11-Sep-19	17	Post Event Hour 1	85	0.08	0.28	0.20
11	Standard	11-Sep-19	18	Post Event Hour 2	84	0.05	0.28	0.22
11	Standard	11-Sep-19	19	Post Event Hour 3	81	-0.03	0.20	0.23
11	Standard	11-Sep-19	20	Post Event Hour 4	77	0.00	0.22	0.22
11	Standard	11-Sep-19	21	Post Event Hour 5	75	-0.01	0.17	0.18
11	Standard	11-Sep-19	22	Post Event Hour 6	74	0.01	0.15	0.15
12	Standard	12-Sep-19	16	Event Hour 1	91	-0.03	0.15	0.18
12	Standard	12-Sep-19	17	Event Hour 2	87	-0.05	0.15	0.20
12	Standard	12-Sep-19	18	Post Event Hour 1	84	0.00	0.23	0.22
12	Standard	12-Sep-19	19	Post Event Hour 2*	80	0.17	0.41	0.23
12	Standard	12-Sep-19	20	Post Event Hour 3*	77	0.14	0.36	0.22
12	Standard	12-Sep-19	21	Post Event Hour 4	76	-0.01	0.17	0.18
12	Standard	12-Sep-19	22	Post Event Hour 5	74	-0.03	0.11	0.15
12	Standard	12-Sep-19	23	Post Event Hour 6	73	0.02	0.13	0.11
13	MISO Proxy	24-Sep-19	15	Event Hour 1*	79	-0.06	0.11	0.17
13	MISO Proxy	24-Sep-19	16	Event Hour 2*	76	-0.12	0.06	0.18
13	MISO Proxy	24-Sep-19	17	Post Event Hour 1*	70	0.12	0.32	0.20
13	MISO Proxy	24-Sep-19	18	Post Event Hour 2	67	-0.02	0.21	0.22

Event	Event Type	Date	Hour Beginning	Hour Type	Outside Temperature (°F)	Est. Impact per WH Unit (kW)	Average Metered (kW)	Baseline (kW)
13	MISO Proxy	24-Sep-19	19	Post Event Hour 3	66	-0.03	0.21	0.23
13	MISO Proxy	24-Sep-19	20	Post Event Hour 4	62	0.02	0.25	0.22
13	MISO Proxy	24-Sep-19	21	Post Event Hour 5*	57	-0.08	0.10	0.18
13	MISO Proxy	24-Sep-19	22	Post Event Hour 6	60	0.00	0.15	0.15
14	MISO Proxy	25-Sep-19	15	Event Hour 1*	85	-0.09	0.08	0.17
14	MISO Proxy	25-Sep-19	16	Event Hour 2*	82	-0.12	0.06	0.18
14	MISO Proxy	25-Sep-19	17	Post Event Hour 1	80	0.13	0.33	0.20
14	MISO Proxy	25-Sep-19	18	Post Event Hour 2	79	-0.02	0.20	0.22
14	MISO Proxy	25-Sep-19	19	Post Event Hour 3*	75	-0.07	0.16	0.23
14	MISO Proxy	25-Sep-19	20	Post Event Hour 4*	73	-0.11	0.11	0.22
14	MISO Proxy	25-Sep-19	21	Post Event Hour 5	72	-0.05	0.13	0.18
14	MISO Proxy	25-Sep-19	22	Post Event Hour 6	74	0.03	0.18	0.15
15	Standard	27-Sep-19	15	Event Hour 1*	89	-0.11	0.06	0.17
15	Standard	27-Sep-19	16	Event Hour 2*	89	-0.09	0.09	0.18
15	Standard	27-Sep-19	17	Post Event Hour 1*	85	0.14	0.34	0.20
15	Standard	27-Sep-19	18	Post Event Hour 2*	83	-0.11	0.12	0.22
15	Standard	27-Sep-19	19	Post Event Hour 3	78	-0.04	0.20	0.23
15	Standard	27-Sep-19	20	Post Event Hour 4	81	0.11	0.33	0.22
15	Standard	27-Sep-19	21	Post Event Hour 5	79	-0.04	0.14	0.18
15	Standard	27-Sep-19	22	Post Event Hour 6*	76	-0.09	0.06	0.15
16	Standard	30-Sep-19	16	Event Hour 1	90	-0.01	0.17	0.18
16	Standard	30-Sep-19	17	Event Hour 2*	83	-0.10	0.10	0.20
16	Standard	30-Sep-19	18	Post Event Hour 1	83	0.00	0.23	0.22
16	Standard	30-Sep-19	19	Post Event Hour 2	79	0.08	0.31	0.23
16	Standard	30-Sep-19	20	Post Event Hour 3	76	0.06	0.28	0.22
16	Standard	30-Sep-19	21	Post Event Hour 4	76	0.08	0.26	0.18
16	Standard	30-Sep-19	22	Post Event Hour 5	75	0.02	0.17	0.15
16	Standard	30-Sep-19	23	Post Event Hour 6	71	-0.02	0.08	0.11

*Hourly estimates which are significant at 90% confidence are bold.