Design & Engineering Services

DEMAND RESPONSE TECHNOLOGY EVALUATION OF AUTODR OCCUPANT CONTROLLED SMART THERMOSTATS

DR12.13 Report

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Acknowledgments

Southern California Edison's (SCE's) Emerging Products group is responsible for this project. It was developed as part of SCE's Emerging Markets and Technology program under internal project number DR12.13. Emerging Products project manager Neha Arora conducted this technology evaluation with overall guidance and management from Jerine Ahmed and Ishtiaq Chisti. For more information on this project, contact neha.arora@sce.com.

Disclaimer

EXECUTIVE SUMMARY

The purpose of this study, which was managed by Southern California Edison's (SCE) Emerging Products group, was to evaluate the demand response (DR) capabilities of occupant controlled smart thermostats (OCSTs). OCSTs are radio thermostats with communication modules that typically serve as direct replacements for existing thermostats for heating, ventilation, and air conditioning (HVAC) units or heat pumps. These devices leverage Open Automated Demand Response (OpenADR) 1.0 protocol, developed by Lawrence Berkley National Laboratory to promote a common communication standard for DR programs and technology manufacturers.

By studying these OCSTs on packaged rooftop HVAC units at two fast food restaurants under different DR settings (that varied in temperature offset and event duration), this project sought to achieve three main objectives:

- Determine if the OCSTs reliably receive the DR signal
- Determine if the OCSTs reduce air conditioning (AC) demand when receiving a DR signal
- Determine how much AC demand was dropped for each setting tested

APPROACH

The study was conducted at two fast food restaurants in the Inland Empire of southern California (California Climate Zone 10). It involved installing a dedicated OCST on the two packaged rooftop HVAC units on each of the two restaurants. At both sites, the HVAC units were 7.5 ton for the kitchens and 10 ton for the dining areas. The OCSTs obtained remote access to thermostat functions and controls through internet access to specially designed software. The OCSTs implemented DR by increasing the cooling setpoint temperature on the thermostat controls upon receipt of an event signal.

The project team began monitoring power consumption of all individual rooftop HVAC units for this study in February 2013, recording the average power in one-minute intervals. DR testing was conducted on weekdays between June 24, 2013 and July 1, 2013. For these tests, SCE issued automated DR events and recorded the AC response to the change in the cooling setpoints. All AutoDR event tests started at 1:00 PM and lasted either one, two, or four hours. One event was conducted on each test day for each AC unit. For all tests except one, temperature offset was 5°F above the normal cooling temperature setpoint; in the exception, the offset was 10°F above the normal cooling setpoint.

At the conclusion of the testing, the team analyzed the monitored data to determine if the OCSTs received the DR signal, determine whether demand savings occurred, and quantify any demand savings. The team also analyzed the sufficiency of the AC units at the sites, made recommendations about improving the signal between the OCSTs and an internet router, and determined the costs for the OCST and communications systems.

FINDINGS

The monitoring revealed several key findings regarding the OCST's DR capabilities:

- The OCSTs were able to receive and act on the DR signal sent by SCE, except during two days at one of the sites. Approximately 71% of the DR event signal implementations could be verified, and instances of testing failure were likely due to intermittent cell coverage.
- One location recorded six successful events (i.e., load was dropped). The other location recorded four successful and four unsuccessful events (i.e., load was not dropped).
- AC demand was reduced in 4 of the 10 instances when the OCSTs successfully received the DR signal and increased the cooling temperature setpoint above the normal setpoint. Thus, 4 of the 14 DR test events showed demand savings.
- The demand savings ranged from 0–12.6 kilowatt (kW) with an average savings of 1.8 kW per AC unit or 20% of the AC load. Because this is a case study, there is no evidence that the demand savings for these sites are typical or can be predicted for these sites.

Analysis also showed that the AC units at the two test sites ran continuously during warm and hot summer days—a sign that the AC units are undersized and may not be sufficient to maintain interior temperatures. In such cases, occupants may perceive an uncomfortably high temperature even when a DR event is not underway. At times, the site temperatures were so high that the DR offset temperature did not rise above the actual zone temperature that signals the AC unit to turn off—and no demand savings were achieved.

It is recommended that any technology that has a DR component and communicates through the internet should use a reliable and robust network connection. Repeaters can be used to improve signal strength and connectivity to an internet router, and in some instances, a hardwired connection to the router may be required to provide a reliable network connection. This connection may be provided by the facility where the OCST is installed or by the installer as part of an installation package.

It should be noted that this is a costly system for small facilities that are only able to shed a few kW. Specifically, the hardware cost was $440 for each OCST used in the study, and the cost to install the hardware and provide dedicated internet service was $635 per unit, resulting in a total cost of $1,075 per unit.

The installation and internet access cost can be substantially reduced for sites with existing, accessible routers for internet, and if the thermostat installation is conducted by trained HVAC technicians. The cost may be lowered further through utility program incentives. Some customers may choose to implement the system to obtain the remote control capability without adding a full-featured energy management system. In such cases, the DR benefits may help justify the costs.

ABBREVIATIONS AND ACRONYMS

AC	air conditioning
ADR	Automated Demand Response
CT	current transducer
DR	demand response
DRAS	demand response automated system
HVAC	heating, ventilation, and air conditioning
Hz	Hertz
ISY	Intelligent System
kW	kilowatt
NIST	National Institute of Standards and Testing
NOAA	National Oceanic Atmospheric Administration
OCST	occupant controlled smart thermostat
OpenADR	Open Automated Demand Response
rms	root mean square
RTU	roof top unit
SCE	Southern California Edison
W	Watt
°F	Degree Fahrenheit

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INTRODUCTION

The purpose of this study is to evaluate the demand response (DR) capability of the new occupant controlled smart thermostat (OCST) technology. OCSTs are radio thermostats with communication modules that can communicate through an autonomous web-enabled energy management and automation system. For the study, four commercially available OCSTs and automation systems were installed in two fast food restaurants in the Inland Empire (California Climate Zone 10). These real-world installations permitted Southern California Edison (SCE) to verify that the technology proposed by the participating manufacturer performed to the published specifications by receiving and acting on a DR signal to reliably reduce demand. Additionally, the study sought to quantify the benefit of participating in DR events that leverage OCSTs.

SCE is studying these concepts to advance the implementation of DR-enabling technologies. Ultimately, the company is considering providing incentives for installation of similar equipment.

Stress on an electric grid occurs when demand for electricity nears the capacity of available power generation and is typically most prevalent during hot summer afternoons. To provide a degree of planning for electric load curtailment, utilities can use weather forecasts to predict demand and then develop reduction tactics. For example, SCE has controlled peak demand load through various commercial programs, including demand bidding; critical peak pricing and interruptible rate programs; and, for large commercial customers, time-of-use rates. Further, SCE has developed air conditioning (AC) cycling programs to control peak demand from participating residential customers.

SCE is currently investigating the potential for DR technologies to reduce the peak electric system load for commercial AC.

SCE will benefit from fast, flexible, and responsive DR-enabling technologies that can control large energy loads. Large load reductions can be achieved either by substantially reducing loads at a few major facilities or by aggregating smaller load reductions at a large number of facilities. New technologies are providing methods to coordinate the DR program participation of a larger number of customers in a wider range of groups.

Open Automated Demand Response (OpenADR) 1.0, developed by Lawrence Berkley National Laboratory to promote a common communication standard for DR programs and technology manufacturers, is allowing utilities to effectively implement DR programs at a larger number of sites with small loads.

ASSESSMENT OBJECTIVES

This project tested OCSTs and related communications systems that controlled rooftop packaged AC units at two fast food restaurants. The OCSTs used were equipped to remotely alter the thermostat cooling or heating setpoint temperature in response to a DR event signal. When the OCST raises the cooling setpoint temperature during the cooling season, the AC unit will turn off or operate at a reduced duty cycle.

The main objectives of the project were as follows:

- Determine if the OCSTs reliably received the DR signal
- Determine if the OCSTs reduced AC demand upon receipt of a DR signal
- Determine how much AC demand was dropped for each setting tested

To achieve the objectives, the project team monitored the electric load of the AC units in each participating facility. The team also developed and conducted a schedule of automated DR tests. Following the tests, the team analyzed the monitored data to verify the implementation of the test signals and to quantify the demand savings.

TECHNOLOGY AND TEST SITE DESCRIPTION

TECHNOLOGY

This field study focused of one brand of remotely controlled thermostats that enable DR by altering the thermostat setpoints of packaged rooftop heating, ventilation, and air conditioning (HVAC) units. The project evaluated the following thermostat product components:

- An intelligent system (ISY) model ISY994 autonomous web-enabled energy management and automation system, shown in Figure 1
- An OCST technology (model TZB45), shown in Figure 2

The ISY994 is compatible with the OpenADR standards and can communicate with up to 1,024 OCSTs using ZigBee® wireless and with the internet through a network router, allowing all features and functions of the thermostat to be accessed remotely. The manufacturer has provided an internet-based administrative console to the interface that facilitates control and allows management of multiple thermostats for clients/users.

Manufacturer uses MobiLinc Connect and Java™ platform-based software to provide contact with the ISY communication modules. The software can also be used to maintain operation of the OCSTs. All data collected by the units are stored locally on the ISY, including logs of all activity and change of states or conditions, as well as actual temperature at the thermostat, cooling and heating setpoints, unit mode of operation, and date and time stamps. These data can be accessed remotely through the ISY994.

Further, clients/users can log on to the secure platform through the internet to program heating and cooling schedules and setpoints, establish OpenADR temperature offsets, and lock out local thermostat control. The administrative console also displays groups of thermostats with their temperature status at the thermostat, cooling and heating setpoints, operating mode, and fan state.

The thermostat tested is compatible with the majority of makes and models of HVAC units available in the market, including heat pumps. Generally, it can be a direct replacement for an existing manual or programmable thermostat. It can be used to operate one- and two-stage AC units, can be programmed with multiple schedules per day, and allows for advance scheduling of DR periods. As shown in Figure 2, the thermostat has a large, easy-to-read temperature display.

FIGURE 1. COMMUNICATION MODULE

FIGURE 2. THERMOSTAT MOUNTED ON WALL

TEST SITES

OVERVIEW

Two fast food restaurants in the Inland Empire region (California Climate Zone 10) were selected by SCE for the study. The study called for selecting sites from a single fast food chain to more effectively preserve uniformity in conditions and minimize the number of variables affecting results. Thus, these sites are in the same chain, owned and operated by the parent corporation, and located within 30 miles of each other. Further they shared similarities in building size and HVAC equipment type.

Both of the test sites have two packaged rooftop AC units, one dedicated to the dining room and a second dedicated to the kitchen. The HVAC units are in typical states of maintenance. For the test, an OCST was installed for each of the AC units.

Table 1 provides a summary of the two test sites, listing the area served, rated tons, and make and model of the AC units, as well as the total conditioned square footage for each site.

TABLE 1. SUMMARY OF HVAC UNITS MONITORED AND CHARACTERISTICS BY LOCATION

SITE LOCATION	THERMOSTAT LOCATION	AC#	MAKE/MODEL	TONS	TOTAL SQUARE FEET CONDITIONED
Site 1, California	Dining room	AC1	Carrier, 48HJD012---571--	10	2,100
	Kitchen	AC2	Carrier, 48HJD008---541--	7.5	
Site 2, California	Dining room	AC1	Carrier, 48HCDD12A2A5A0A0	10	2,100
	Kitchen	AC2	Carrier, 48HJD008---541--	7.5	

COMMUNICATION

The ISY requires communication to the internet through a router. Ideally, the customer's existing network has an available port on the router and a network cable can be connected between the ISY and the router. However, security levels at the test sites limited the internet access to only those places where the customer needs to conduct business. Consequently, to connect to the internet, a 3G router was installed and used for the DR test events. Due to weak or intermittent cell coverage, not all the signals were received by the ISY. A hardwired connection to the internet or a strong cell signal is required to provide the communication needed to successfully use this type of technology.

OPERATING HOURS

The posted operating hours for the two locations are relatively similar but not identical, as shown in Table 2. The long operating hours of fast food businesses allow the AC thermostats to be available for DR over a wide range of times.

TABLE 2. POSTED RESTAURANT OPERATING HOURS BY SITE

SITE LOCATION	MON-SUN
Site 1, CA	10:00 AM - 11:00 PM
Site 2, CA	9:30 AM - 11:00 PM

TECHNICAL APPROACH AND TEST METHODOLOGY

To characterize the demand reduction resulting from this demonstration project, a measurement and verification plan was prepared and adapted to these facilities.

The plan called for monitoring the baseline HVAC demand with existing thermostats at the two test sites and then testing the AC units' response to signals sent to the OCST. A schedule of DR tests was developed to determine how well the systems responded to DR signals and to quantify the achievable demand savings. Following is a description of the metering and data acquisition equipment used in the field for this study.

METERING EQUIPMENT

Below are descriptions of the equipment used:

- **Enernet K20TM multi-channel meter recorders (Figure 3):** These recorders, which can monitor electric energy, analog signals, and digital pulses, were used to monitor power consumption of the HVAC units. For this study, the recorders monitored true root mean square (rms) kilowatt (kW) power of the circuits that feed each AC unit; the recorders are shown in Figure 4. The logger accuracy for power measurement is ±0.5% from 1 to 100% of full scale.
- **Split-core current transducers (CTs), (Figure 5):** These CTs, which were mounted inside the electric panel with appropriately rated primary current, were used for the AC units. Multiple channels on each logger measured kW. The meter samples the full 60 hertz (Hz) waveform once every 5 to 9 seconds, and the data samples were averaged and recorded in 1-minute intervals for the duration of the monitoring. CT accuracy is ± 1% from 10% to 100% of full scale, ± 3% at 5% of full scale, and ±5% at 2% of full scale.

Prior to installing monitoring equipment, the power for all the AC units was traced using two CTs. The power monitoring equipment was installed in February 2013 and data were collected until DR testing was conducted in June and July of 2013.

DATA ACQUISITION

The meter recorder box was mounted near the electrical panel, and one-time power measurements were made using an AEMC 3910 true rms power meter to confirm calibration of the data logger and to ensure proper installation. Data were collected remotely via telephone land lines at each site and by modems in each of the loggers; a central computer retrieved the data daily. The OCST manufacturer uses MobiLinc Connect with a Java™ platform-based software that provides contact with the ISY994 communication modules and can be used to maintain operation of the OCSTs.

A variety of data are stored locally on the ISY, including logs of all activity and change of states or conditions, as well as actual temperature at the thermostat, cooling and heating setpoints, unit mode of operation, and date and time stamps. Data from the ISY were periodically downloaded and backed up, and the memory logs in the ISY were cleared in order to avoid large data transmissions.

Hourly dry-bulb temperature data were collected from two National Oceanic and Atmospheric Administration (NOAA) weather stations in the Inland Empire.

FIGURE 3. K20 POWER LOGGER MOUNTED NEAR ELECTRIC PANELS

FIGURE 4. AIR CONDITIONER BREAKERS IN ELECTRIC ROOM

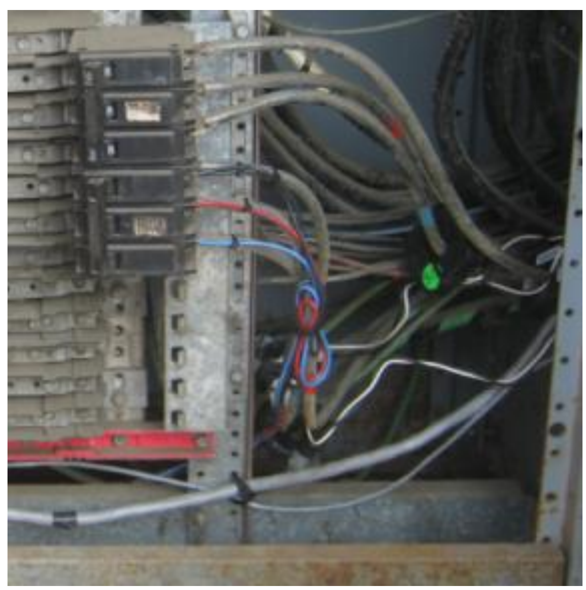

FIGURE 5. CURRENT TRANSDUCERS MOUNTED INSIDE ELECTRIC PANEL

TEST PROCEDURES

Altering thermostat setpoints can yield significantly different results depending on the amount of offset, the time of day of the offset period, the length of the offset period, and the outdoor temperature before, during, and after the offset period. To help account for these variations, the DR test plan called for two temperature offsets, one offset period start time, and three durations. Only one set of conditions was scheduled for each test day. At the end of the DR test event, the thermostat setpoints were returned to their setpoints prior to the start of the test.

Table 3 shows the planned DR test schedule. To allow comparison, data loggers also recorded demand on non-test days. Note that the June 28th 10°F offset test event scheduled for Site 1 was canceled that morning at customer request, as the temperature at sites was too hot. All future events with 10°F offsets were also cancelled at customer requests.

TABLE 3. DEMAND RESPONSE TEST EVENT SCHEDULE

2013 Test Date	Temperature Offset	Offset Period	Site
June 24	5°F	1:00 PM – 2:00 PM	Site 1
June 25	5°F	1:00 PM – 3:00 PM	Site 1
June 26	5°F	1:00 PM – 5:00 PM	Site 1
June 27	10°F	1:00 PM – 2:00 PM	Site 1
June 28	10°F	1:00 PM – 3:00 PM	Site 1 – Test Canceled
June 27	5°F	1:00 PM – 2:00 PM	Site 2
June 28	5°F	1:00 PM – 3:00 PM	Site 2
July 1	5°F	1:00 PM – 5:00 PM	Site 2

DR events were scheduled and dispatched using the DR Automated Server (DRAS), OpenADR 1.0 specification. Various event-mode levels were tested in order to determine the OCST's abilities to respond to a range of levels. The OCST operated in "auto" mode during the test. The OpenADR policy in the YST994 administrative console was configured for the desired temperature offset. During a DR event, a test signal that included the event start time and duration was sent from the test DRAS to the OCSTs at the specified time. Upon receiving this information, the OCST changed the setpoint and maintained this change until either the event was completed, the signal was over-ridden, or a manual over-ride occurred.

AC energy use is weather-dependent, meaning that energy savings are influenced by the ambient conditions. For this project, the testing was conducted in the summer. The demand reduction and energy savings will likely differ during other times of the year. All computers, equipment, and loggers used in this project were synchronized to clocks on Pacific Time, as obtained from the National Institute of Standards and Testing (NIST)[1] website's time widget.

[1] NIST web link: http://www.time.gov/widget.html

DATA ANALYSIS AND RESULTS

This section presents and discusses the data collected from monitoring OCSTs at the two test sites. Data from both sites were processed separately to identify tests that were successful in altering the thermostat setpoint and determine demand reduction. This section provides a sample of the charts and data that were collected and used in the analysis, as well as tables displaying the demand analysis results. Appendix A contains charts for each of the test days for Site 1, and Appendix B contains text day charts for Site 2. Appendix C contains embedded data files.

DR TEMPERATURE OFFSET RELIABILITY

To determine DR temperature offset reliability, the project team processed the data site-by-site and reviewed and verified data for each AC unit. Specifically, the team inspected data for each AC unit to identify whether the DR signal reached the thermostat and caused the cooling setpoint to change by the planned offset and period.

SAMPLE CHARTS

Figure 6 and Figure 7 show data from the dining room and kitchen AC units, respectively, at Site 2 on June 27, 2013 between 9:00 AM and 7:00 PM (1900). The data in Figure 6 and Figure 7 exemplify the types of chart developed from the study and characterize the data types contained in them. The charts depict data merged from three sources: monitored power data, data from the OCST, and weather station data. The figures present the 1-minute averages of the parameters displayed, except for the outdoor temperature, which is presented as an hourly value. The temperature resolution of the indoor and setpoint temperatures is 1°F.

In Figure 6, the cooling setpoint for the dining room AC rises 5°F at 1:00 PM (1300) from 80°F to 85°F and lowers back to 80°F at 2:00 PM (1400)—readings that indicate successful transmission of the DR signal to the thermostat. In response to the setpoint change, the AC turns off for about 33 minutes, and turns back on once cooling is required, and a demand reduction is seen during the beginning of the DR period.

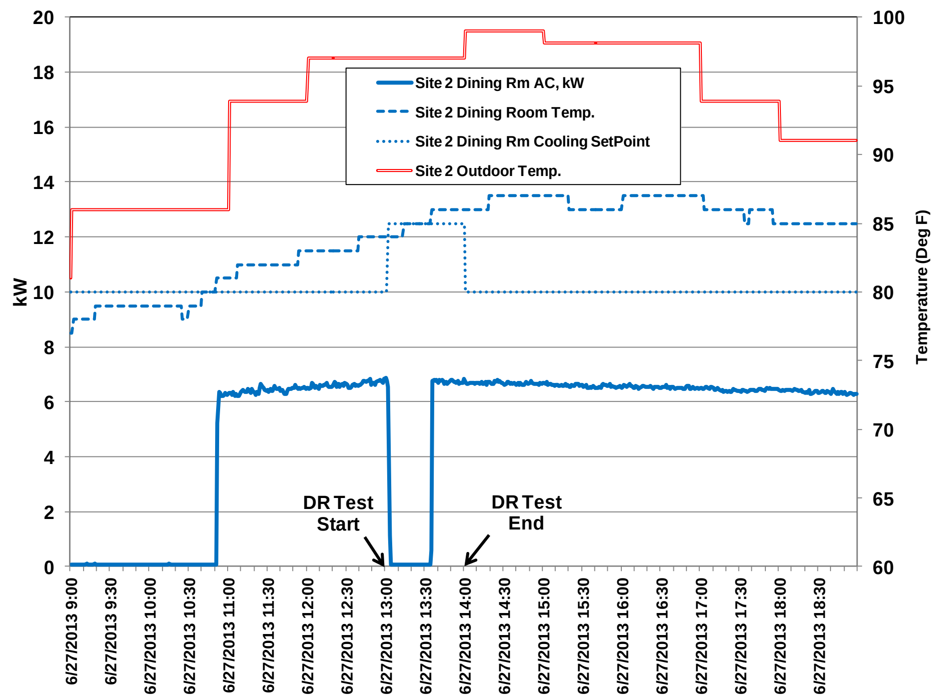

FIGURE 6. DINING ROOM PROFILES FOR AC DEMAND, COOLING SETPOINT, INDOOR AND OUTDOOR TEMPERATURES

In Figure 7 the cooling setpoint for the kitchen AC rises 5°F at 1:00 PM (1300) from 72°F to 77°F and lowers back to 72°F at 2:00 PM (1400)—a sign that the DR signal was successfully transmitted to the thermostat. Because the 84°F temperature in the kitchen at the beginning of the test was well above the new setpoint, the AC unit did not turn off, but continued to run continuously. No demand savings were achieved for the kitchen AC unit on this day.

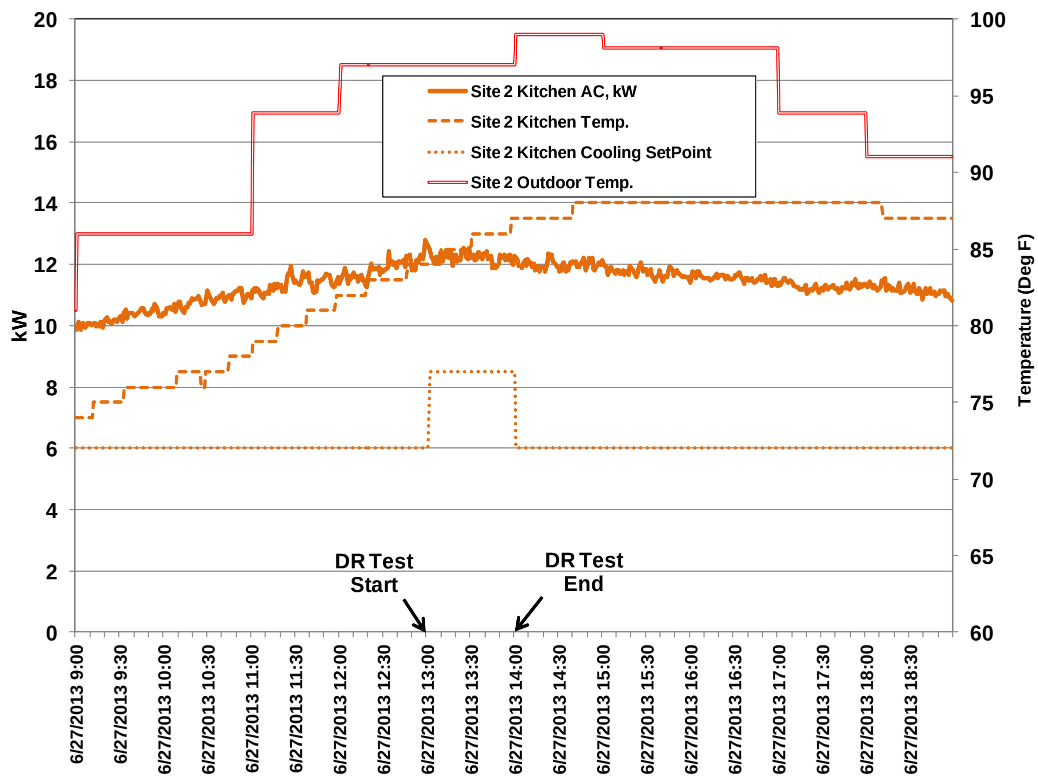

FIGURE 7. KITCHEN PROFILES FOR AC DEMAND, COOLING SETPOINT, INDOOR AND OUTDOOR TEMPERATURES

DATA REVIEW

The project team reviewed the data from each AC for each DR test day and compared the cooling setpoint data from the OCSTs to the planned schedule of operation of the DR tests. Each site and each AC unit was considered to be a separate test, meaning that there were 14 tests conducted in total.

A summary of the cooling setpoint observations is presented in Table 4. The notation "N/O" signifies that there was no observed time during the test that the setpoint was changed for that AC unit on that day. The notation "Yes" in the "Successful" column indicates that the OCST executed the DR planned schedule as intended. That is, the duration and temperature offset of the setpoint and the duration are the same as the AutoDR signal that was sent. Ten of the tests (71%) successfully changed the cooling setpoint by the intended amount.

The lack of success of the four remaining tests is likely due to poor communications between the OCST and the internet. The link with the poor connectivity is assumed to be between the network router and the cell service provider company. This type of communication problem could have been eliminated if a landline-based internet had been available with a port for the ISY994 and if the customer had provided the necessary security access.

During one test event at Site 1 on June 27th, the temperature offset was only 2°F and not the intended 5°F. The test did not terminate at the scheduled time by lowering the setpoint but continued with the same temperature offset until the next thermostat programmed scheduled change.

At Site 2 on June 28th, the temperature setpoint of the dining room OCST was lowered by 5°F at 17 minutes into the event. Since this was a particularly hot day, the staff entered a manual override of the temperature setting. The override is reflected in the EMS system used for OCST communication. Ten minutes after the manual override, the kitchen OCST setpoint was lowered by 3°F. For unknown reasons, the OCSTs were set back to the DR test setpoints one hour after the DR event started.

TABLE 4. DEMAND RESPONSE TEST OBSERVED COOLING SETPOINT RESULTS

2013 Test Dates	Target Temperature Offset	Target Offset Period	Observed Temperature Offset	Observed Offset Period	Site/AC unit*	Successful?
June 24	5°F	1:00 PM – 2:00 PM	5°F	1:00 PM – 2:00 PM	Site 1/AC1	Yes
June 24	5°F	1:00 PM – 2:00 PM	5°F	1:00 PM – 2:00 PM	Site 1/AC2	Yes
June 25	5°F	1:00 PM – 3:00 PM	0°F	N/O	Site 1/AC1	No
June 25	5°F	1:00 PM – 3:00 PM	0°F	N/O	Site 1/AC2	No
June 26	5°F	1:00 PM – 5:00 PM	0°F	N/O	Site 1/AC1	No
June 26	5°F	1:00 PM – 5:00 PM	0°F	N/O	Site 1/AC2	No
June 27	10°F	1:00 PM – 2:00 PM	10°F	1:00 PM – 2:00 PM	Site 1/AC1	Yes
June 27	10°F	1:00 PM – 2:00 PM	10°F	1:00 PM – 2:00 PM	Site 1/AC2	Yes
June 27	5°F	1:00 PM – 2:00 PM	5°F	1:00 PM – 2:00 PM	Site 2/AC1	Yes
June 27	5°F	1:00 PM – 2:00 PM	5°F	1:00 PM – 2:00 PM	Site 2/AC2	Yes
June 28	5°F	1:00 PM – 3:00 PM	5°F	1:00 PM – 3:00 PM**	Site 2/AC1	Yes
June 28	5°F	1:00 PM – 3:00 PM	5°F	1:00 PM – 3:00 PM***	Site 2/AC2	Yes
July 1	5°F	1:00 PM – 5:00 PM	5°F	1:00 PM – 5:00 PM	Site 2/AC1	Yes
July 1	5°F	1:00 PM – 5:00 PM	5°F	1:00 PM – 5:00 PM	Site 2/AC2	Yes

* Where AC1 = Dining Room AC unit and AC2 = Kitchen AC Unit

** Cooling setpoint lowered by 3°F during middle of test for 43 minutes.

*** Cooling setpoint lowered by 5°F during middle of test for 33 minutes.

DR ANALYSIS

Some distinctive conditions partly drive the operation of the AC units at the test sites. As noted, each site has one AC unit for the dining area and one for the kitchen area. Because the two zones are not completely isolated from each other, the two units sometimes share loads. As another complication, the thermostat for the dining area is located near the entrance and is influenced by the outside air temperature; the doors are frequently opened during busy periods of the day.

Further, the AC unit compressors are typically on or off, as the units do not have variable speed compressors. Therefore, the monitored AC demand data are averaged over the entire event period. Demand savings can only be achieved if the OCST cooling setpoint temperature can be adjusted above the zone temperature, thereby allowing the AC unit to cycle off during the DR event. This is because the demand savings is the difference between the average baseline AC demand for the event period minus the average actual demand for the event period. It is also important to pay attention to the duration of DR event. If the DR period is set too short much of the DR savings will be lost during the period immediately following the event, when the AC unit attempts to restore the space to the original temperature.

For AC units that run continuously, except when the DR signal raises the cooling setpoint to the level where the AC units turn off, the average baseline demand is the average of the demand prior to the beginning of the DR event and the period after the end of the DR event. In other words, the test day itself provides the baseline data rather than a similar non-test day. Non-event data were collected for several months but were not needed for the analysis due to the continuous operation characteristics of the AC units at these two sites.

The conditions of each DR test event and the observed demand savings are presented in Table 5. The right-hand column tabulates average demand savings in kW for each DR event. Of the 14 DR test events, 4 showed demand savings. These demand savings ranged from 0 kW to 12.6 kW, with an average of 1.8 kW per unit or 20% of the AC load.

However, there is no evidence that the demand savings for these sites can be predicted for future implementations. The demand savings for a given AC unit is largely dependent on the outdoor temperature, initial AC cooling setpoint, initial temperature in the zone of the OCST, and size of AC unit. For many commercial establishments, the thermostat setpoint is fixed or relatively consistent and indoor temperatures can be relatively stable if the AC units are correctly sized. If the temperature setpoints and indoor temperatures are stable, the predicting variables for the demand savings are primarily the outdoor temperature and AC unit size. However, for the AC units in these tests, setpoints and indoor temperatures showed wide variation. The setpoint temperatures ranged from 66°F to 80°F during the test days, and the zone temperatures at the beginning of the DR test events ranged from 73°F to 85°F, despite a uniform 1:00 PM start time.

Table 5. Demand Reduction Conditions and Analysis Results from the Demand Response Tests

2013 Test Dates	Target Temperature Offset	Target Offset Period	Site/AC unit*	Outdoor Temperature	Initial AC Cooling Setpoint	Initial Area Temperature	Average kW Demand Savings during Event
June 24	5°F	1:00 PM – 2:00 PM	Site 1/AC1	71°F	73°F	73°F	2.1
June 24	5°F	1:00 PM – 2:00 PM	Site 1/AC2	71°F	73°F	74°F	6.7
June 25	5°F	1:00 PM – 3:00 PM	Site 1/AC1	80°F	74°F	75°F	0**
June 25	5°F	1:00 PM – 3:00 PM	Site 1/AC2	80°F	77°F	76°F	0**
June 26	5°F	1:00 PM – 5:00 PM	Site 1/AC1	92°F	75°F	75°F	0**
June 26	5°F	1:00 PM – 5:00 PM	Site 1/AC2	92°F	80°F	80°F	0**
June 27	10°F	1:00 PM– 2:00 PM	Site 1/AC1	96°F	72°F	76°F	12.6
June 27	10°F	1:00 PM – 2:00 PM	Site 1/AC2	96°F	66°F	83°F	0
June 27	5°F	1:00 PM – 2:00 PM	Site 2/AC1	97°F	80°F	84°F	3.6
June 27	5°F	1:00 PM – 2:00 PM	Site 2/AC2	97°F	72°F	84°F	0
June 28	5°F	1:00 PM – 3:00 PM	Site 2/AC1	99°F	70°F	85°F	0
June 28	5°F	1:00 PM – 3:00 PM	Site 2/AC2	99°F	70°F	85°F	0
July 1	5°F	1:00 PM – 5:00 PM	Site 2/AC1	90°F	72°F	80°F	0
July 1	5°F	1:00 PM – 5:00 PM	Site 2/AC2	90°F	74°F	81°F	0

* Where AC1 = Dining room AC unit and AC2 = Kitchen AC Unit

** No savings were estimated for event days on which no offset was observed.

AC Units Sizing

Additional evidence from the data is presented to support the claim that the AC units at the test sites are undersized. During the tests, these AC units spent a considerable amount of time running continuously. For a typical AC unit, the demand versus outdoor temperature starts off at the balance point (outdoor temperature where internal gains are equal to heat loss dissipated through the envelope and air exchange) and increases with temperature until the HAVC unit reaches the design conditions and the demand levels off. The leveling off occurs when the unit runs continuously, but the leveling is not a flat line because the outdoor temperature impacts the air density and the ability of the condenser to reject heat.

The scatter plots in Figure 8 – Figure 11 show the average hourly data from four weeks of summer operation. Figure 8 shows the Site 1 demand curves for both AC units starting to level off in the 70°F range, rather than in the 95°F typical for a right-sized unit. Lines have been drawn on the chart to emphasize the data that show the unit running continuously.

The kitchen unit in Site 2 is a two-stage unit (two compressors). The chart in Figure 9 shows two lines for the kitchen AC unit; the top line represents both stages running and the lower line represents one stage running. Note that there is no time when stage one turns off.

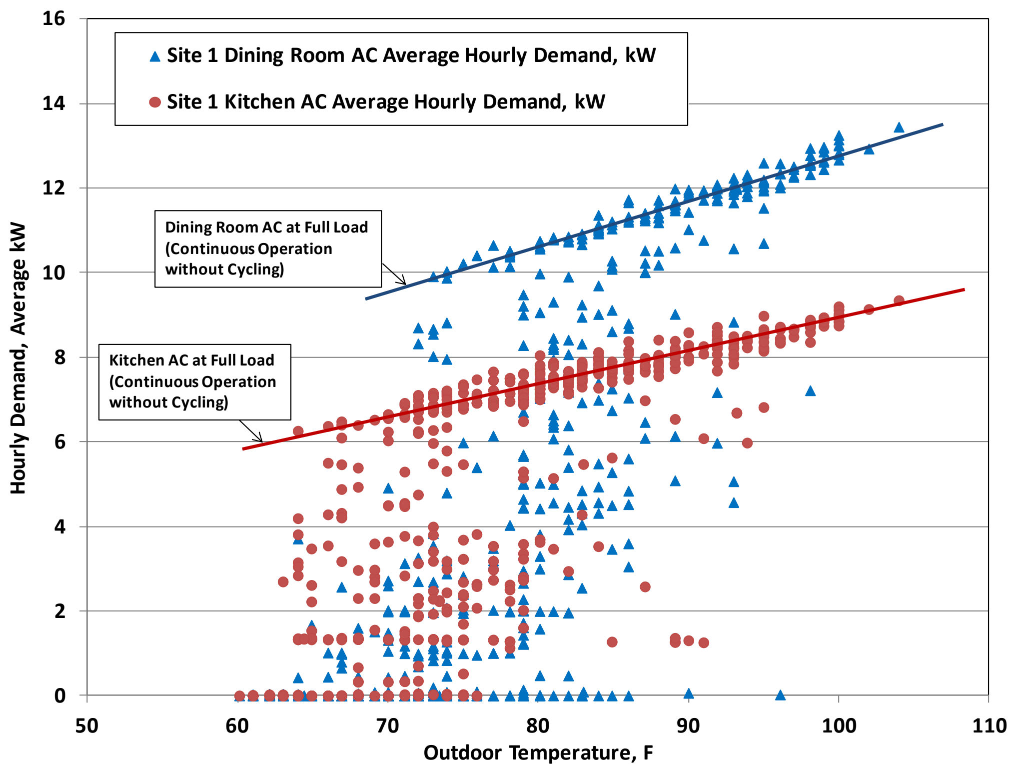

FIGURE 8. AVERAGE HOURLY DEMAND FOR AC UNITS AT SITE 1 VS. OUTDOOR TEMPERATURE

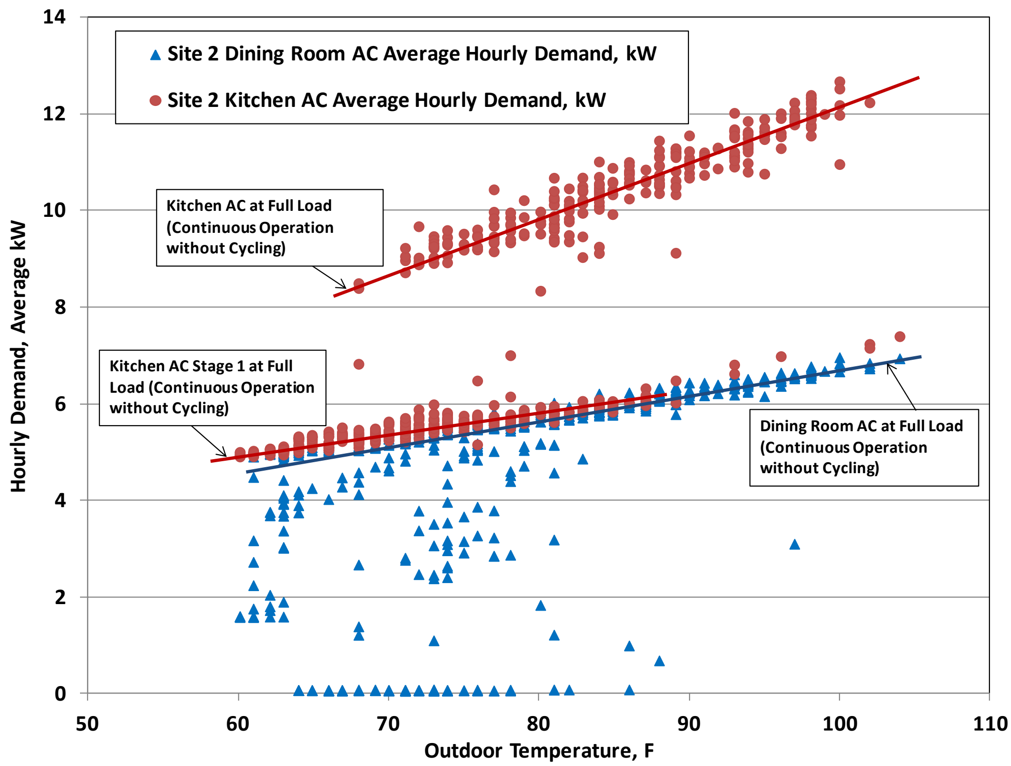

FIGURE 9. AVERAGE HOURLY DEMAND FOR AC UNITS AT SITE 2 VS. OUTDOOR TEMPERATURE

A zone temperature that is more than a couple of degrees above the cooling setpoint generally indicates that the AC unit is unable to maintain the temperature in the space and that the unit is undersized. A sudden heat gain, such as through an open door to the outside, can also trigger this condition. Figure 10 shows a scatter plot of the indoor temperature minus zone cooling setpoint versus the outdoor temperature.

The kitchen temperature is above the setpoint for the majority of the conditions. The figure also highlights the 5°F line, which represents the conditions in which most of the DR event tests were conducted. All points above the highlighted line show no demand savings because the conditions would not allow the AC unit to turn off.

Figure 11 shows a similar situation with the temperatures and setpoints for Site 2. At this site, no demand savings occurred with a 5°F offset when the outdoor temperature was above 97°F. Both AC units also showed a significant number of conditions where the temperature in the zone was more than 5°F higher than the setpoint.

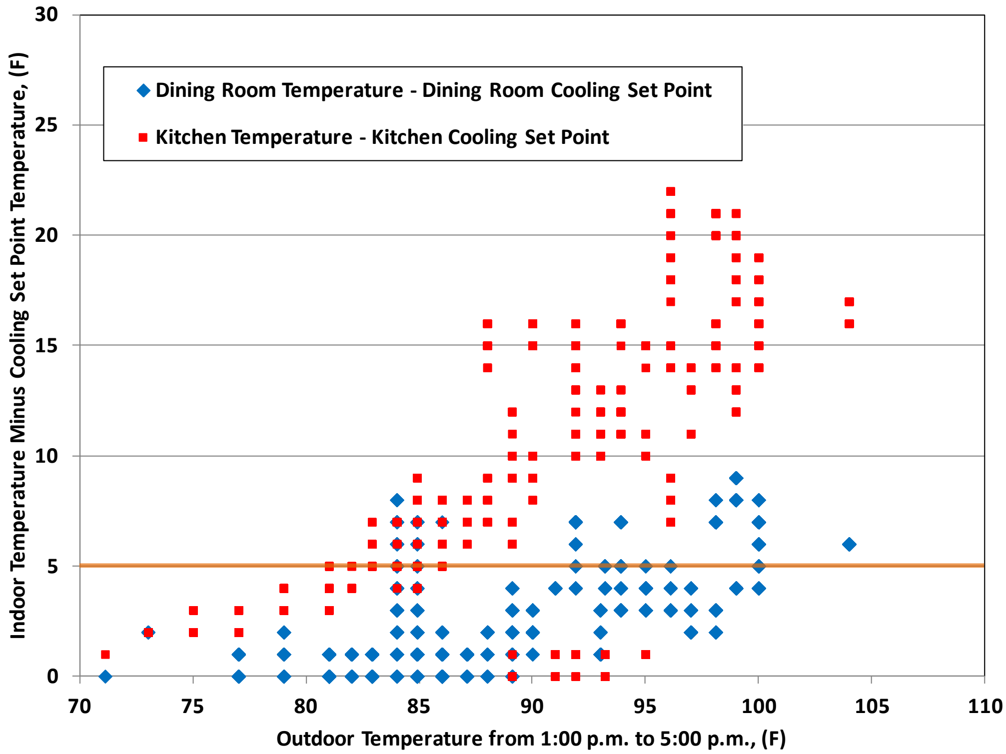

FIGURE 10. SITE 1 ZONE TEMPERATURE MINUS COOLING SETPOINT VS. OUTDOOR TEMPERATURE

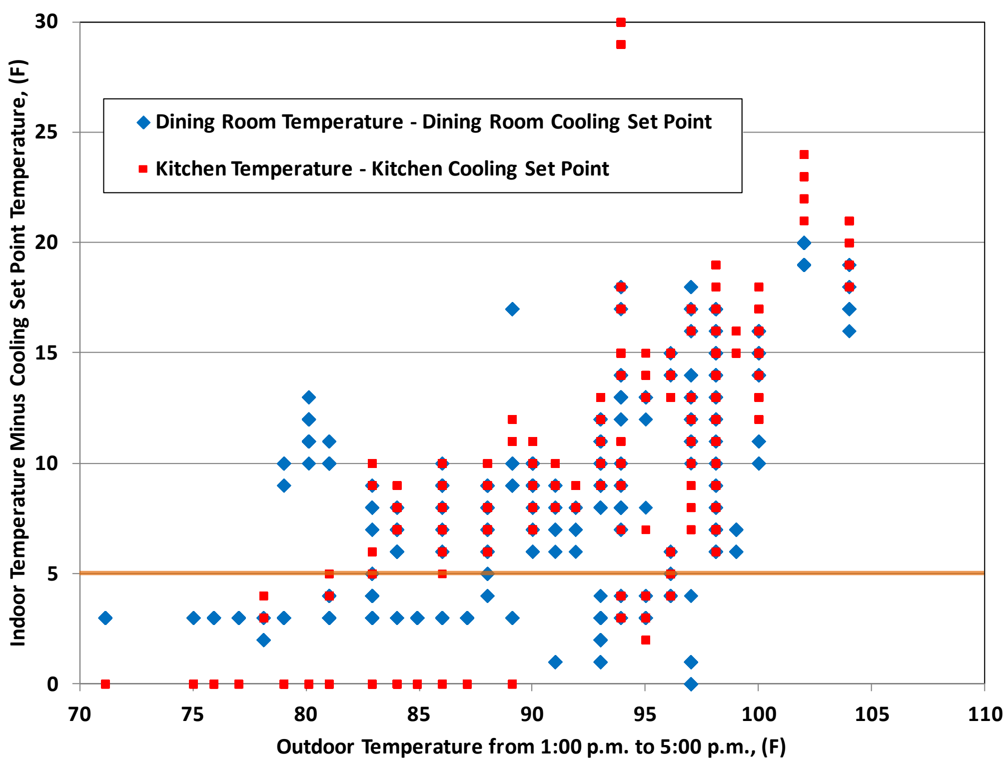

FIGURE 11. SITE 2 ZONE TEMPERATURE MINUS COOLING SETPOINT VS. OUTDOOR TEMPERATURE

ECONOMIC ANALYSIS

Installed costs for each OCST unit totaled $1,075, a sum that includes a per-OCST hardware cost of $440 and a $635 per-unit cost for hardware installation and provision of dedicated internet service. The installation and internet access cost can be substantially reduced for sites with existing accessible routers for internet, and if the thermostat installation is conducted by trained HVAC technicians. The cost may also be lower for other projects if utility program incentives are received.

It should be noted that this is a costly system for small facilities that are only able to shed a few kW. Some customers may choose to implement the system to obtain the remote control capability without adding a full-featured energy management system. In such cases, the DR benefits may help to justify the costs.

CONCLUSIONS

Based on the testing performed during this project, the following can be concluded:

- The OCSTs reliably received DR signal during approximately 71% of the tests. The cell service signal is suspect in the cases where the signal was not received. This underlines the importance of a strong, reliable internet connection as part of the communication chain.
- The OCSTs were able to reduce demand in 4 of the 10 successful events (that is, the OCST received the DR signal and changed the cooling temperature offset accordingly). AC demand was reduced when the temperature at the OCST was lower than the temperature offset requested by the DR signal. If the AC unit was not meeting the load before the DR signal was received, and if the temperature had drifted above the new setpoint, the demand could be reduced.
- The study found a single quantitative result for AC demand drop: an average demand savings of 1.8 kW, or about 20%, per AC unit measured. This result represents what actually happened on the test event days during one case study.

Many factors influence the demand savings results, including occasionally intermittent cell coverage at the site, unstable temperature setpoints due to manual adjustments, and AC units that are not properly sized for the cooling load.

The savings realization rate will be less than 100% if manual override is allowed. Although manual override should be allowed to increase participation, additional research is needed to determine what impact it will have on an actual DR event.

This evaluation consists of a set of case studies and should not be used to imply endorsement of any particular product or rejection of products not tested in this study.

RECOMMENDATIONS

The results of this field evaluation show that demand savings can be achieved through the use of OCSTs responding to a demand reduction request. The study implied that the demand savings could be greater at sites with correctly sized HVAC units. As with some new technologies, the OCST system had compatibility issues that need to be addressed during specification of equipment prior to installation. For example, the project team recommends specifying hardwired network connection to an internet router at the facility, whether provided by the customer or as part of an installation package. Also, in facilities that have remote temperature sensors, it should be noted if the OCST is capable of using these sensors.

In order to effectively reduce demand, the AC units cannot be undersized. If the space is overheating, raising the cooling setpoint may not turn the AC unit off, and no DR will be realized.

The DR period for AC units should not be set too short or much of the DR savings will be lost during the period immediately following the event, when the AC unit attempts to restore the space to the original temperature. However, since the largest demand reduction occurs at the beginning of the DR period, units should be staged so that the starts of the DR periods are staggered for sites with multiple units.

In addition, HVAC installation technicians must be trained on how to pair the units with network routers that may exist at customer facilities.

Further study of applications that identify customers with right-sized AC units may provide sites where savings can be reliably achieved without customer discomfort. In addition, further studies on units with variable speed drives or compressors should be conducted to fully understand the potential of OCST technology and help better inform the program to cover this market.

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Southern California Edison, November 2011, “Demand Response Tests of Lighting in a Typical College Corridor,” Demand Response Program, DR11SCE05.01.

Southern California Edison, December 2012, “Demand Response Technology Evaluation of Fast Food Restaurant Interior Lighting,” Demand Response Program, DR12SCE1205.

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APPENDIX A – SITE 1 CHARTS

This appendix contains data charts for all four test event days for Site 1. The charts show data monitored from 9:00 AM to 7:00 PM (1900), including outdoor and inside temperatures, cooling setpoints, and AC unit kW draw for either the dining room or the kitchen areas, as follows:

- Figure 12. Dining room measurements on June 24, 2013
- Figure 13. Kitchen measurements on June 24, 2013
- Figure 14. Dining room measurements on June 25, 2013
- Figure 15. Kitchen measurements on June 25, 2013
- Figure 16. Dining room measurements on June 26, 2013
- Figure 17. Kitchen measurements on June 26, 2013
- Figure 18. Dining room measurements on June 27, 2013
- Figure 19. Kitchen measurements on June 27, 2013

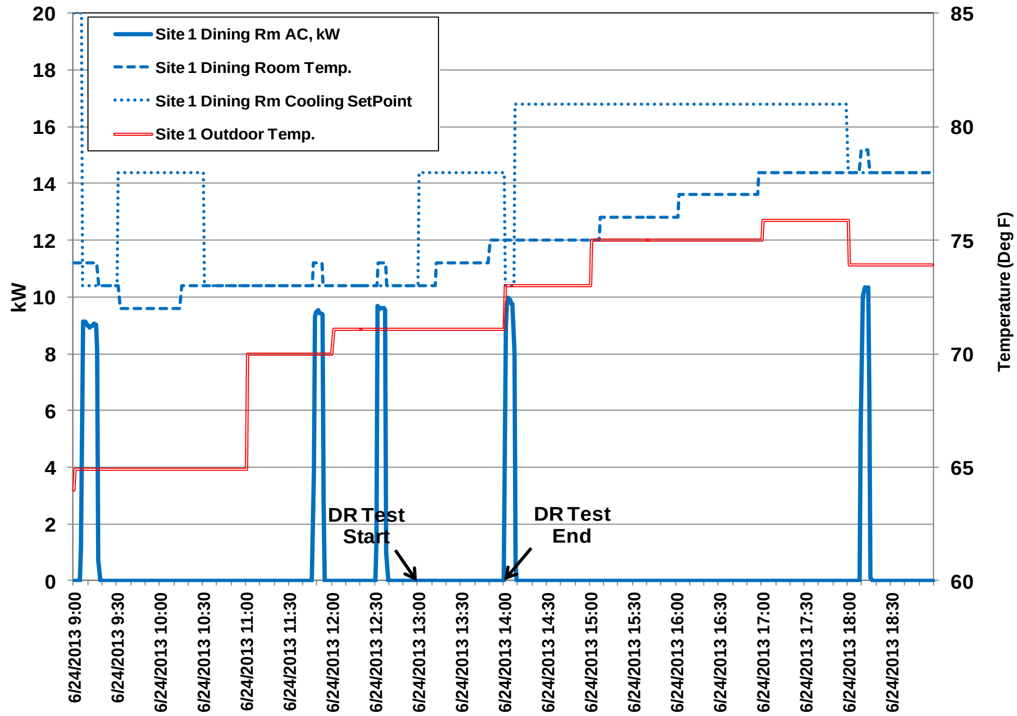

FIGURE 12. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 24, 2013

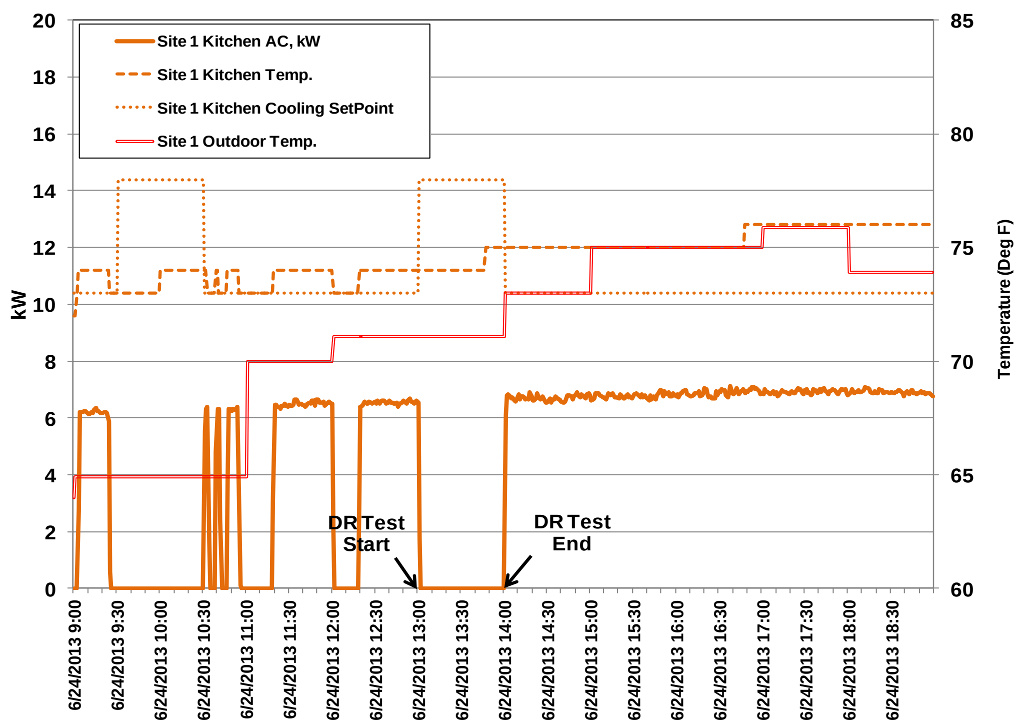

FIGURE 13. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 24, 2013

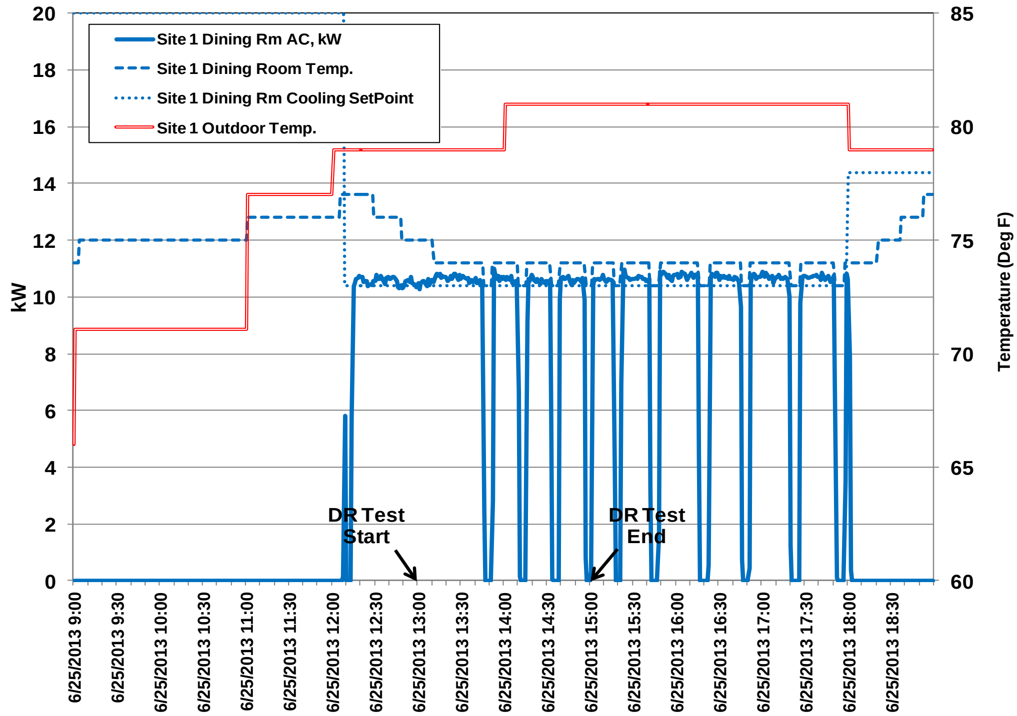

FIGURE 14. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 25, 2013

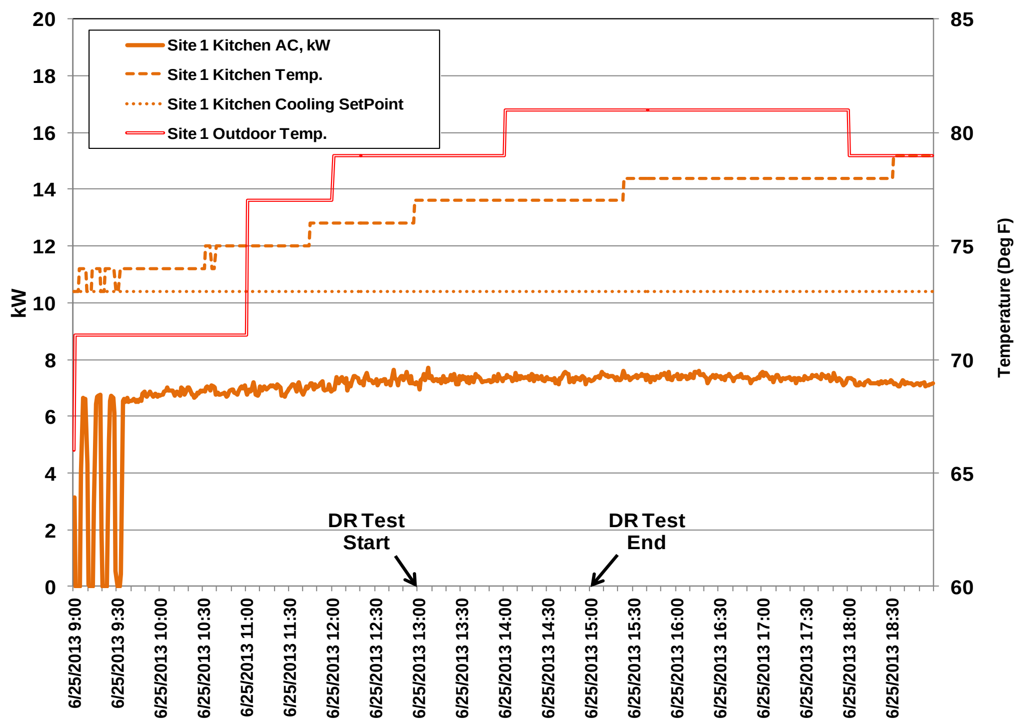

FIGURE 15. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 25, 2013

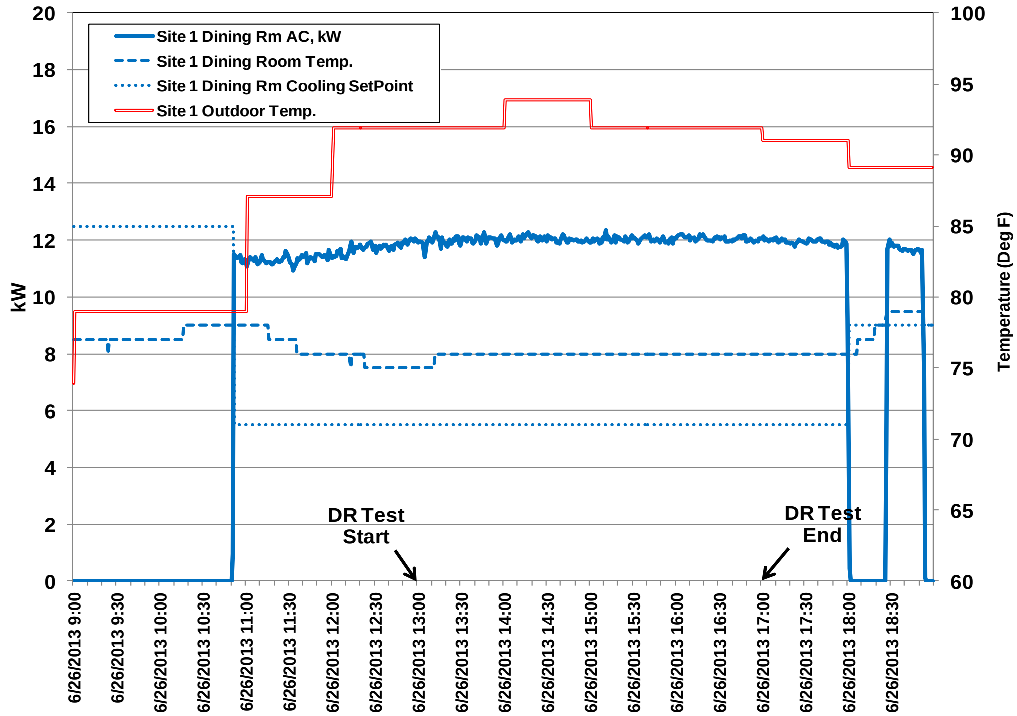

FIGURE 16. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 26, 2013

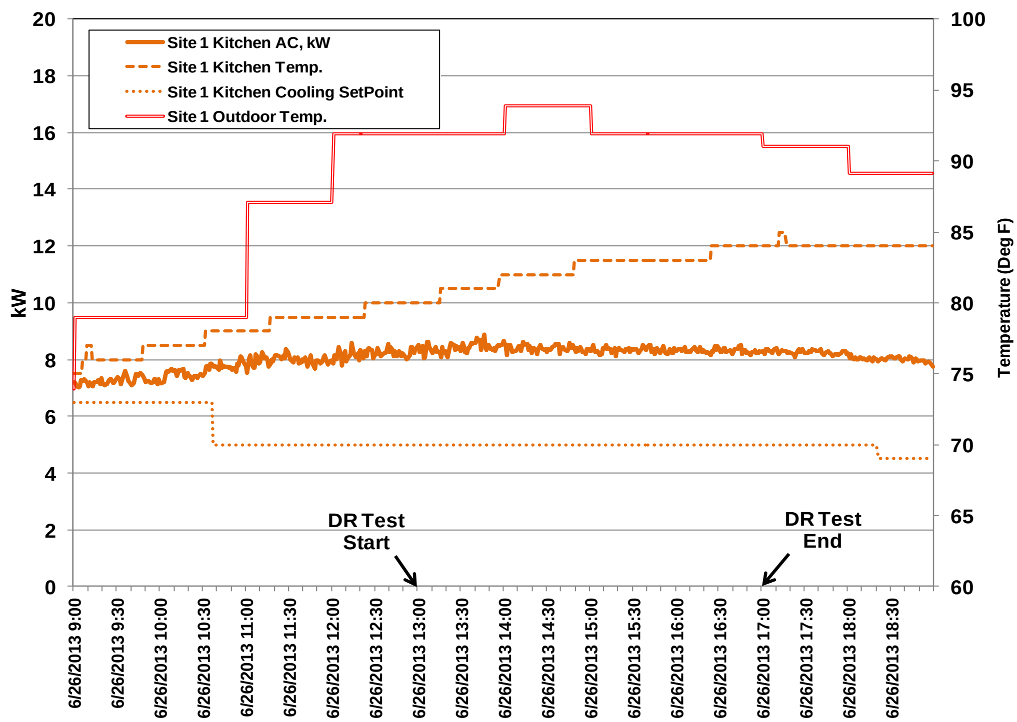

FIGURE 17. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 26, 2013

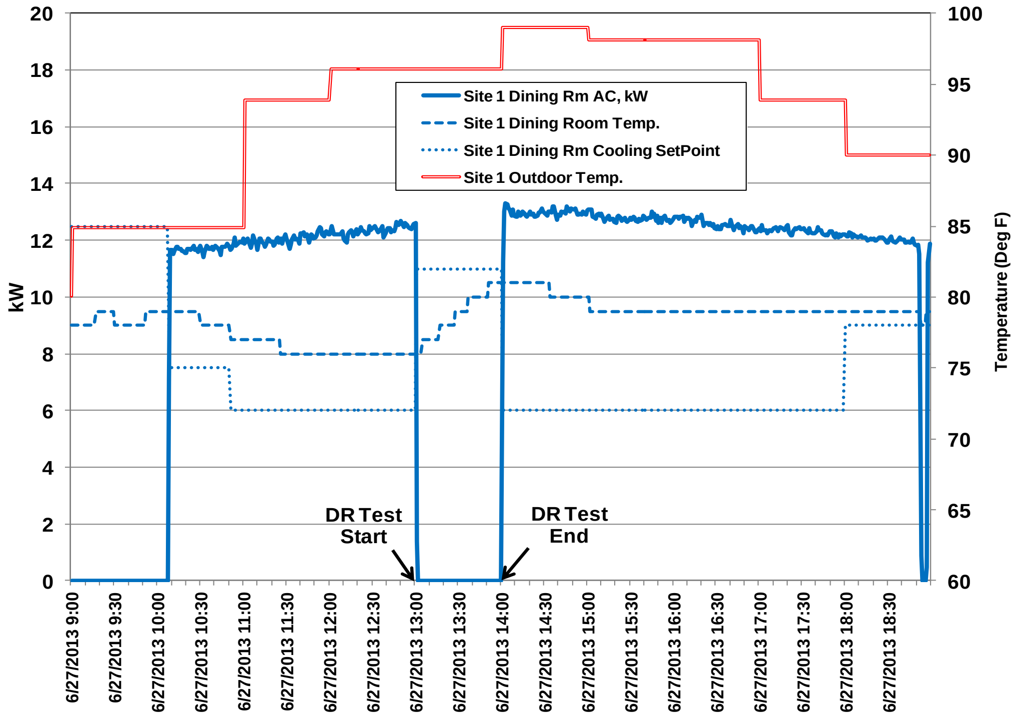

FIGURE 18. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT JUNE 27, 2013

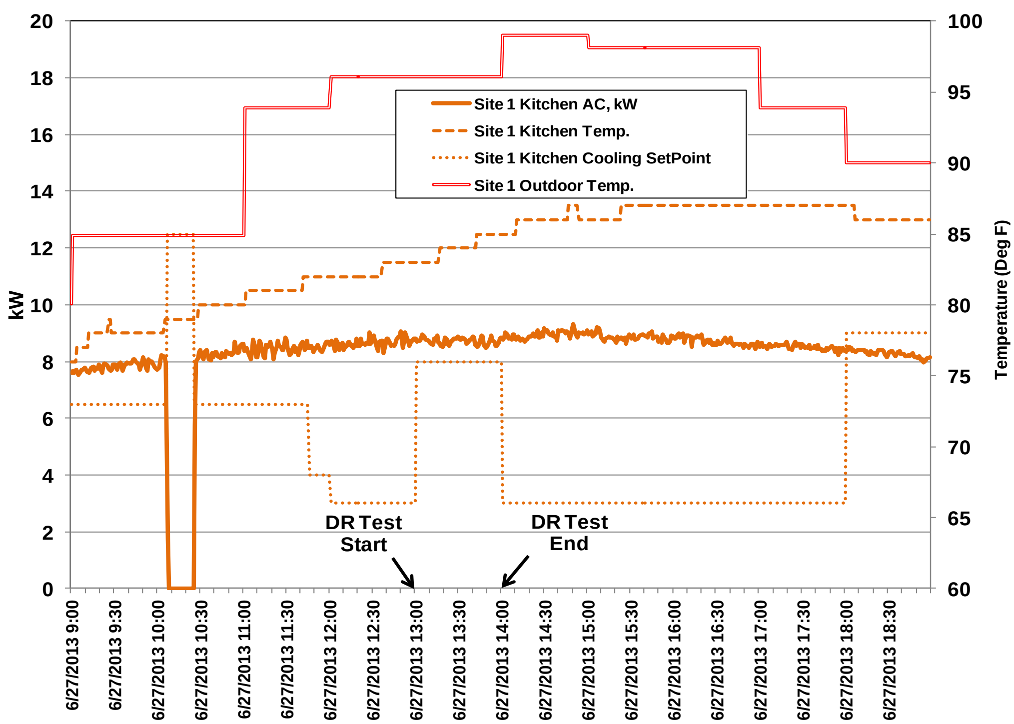

FIGURE 19. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 1 ON DR EVENT DAY JUNE 27, 2013

APPENDIX B – SITE 2 CHARTS

This appendix contains data charts for all three test event days for Site 2. The charts show data monitored from 9:00 AM to 7:00 PM (1900), including outdoor and inside temperatures, cooling setpoints, and AC unit kW draw for either the dining room or the kitchen areas, as follows:

- Figure 20 Chart of Dining room measurements on June 27, 2013
- Figure 21 Chart of Kitchen measurements on June 27, 2013
- Figure 22 Chart of Dining room measurements on June 28, 2013
- Figure 23 Chart of Kitchen measurements on June 28, 2013
- Figure 24 Chart of Dining room measurements on July 1, 2013
- Figure 25 Chart of Kitchen measurements on July 1, 2013

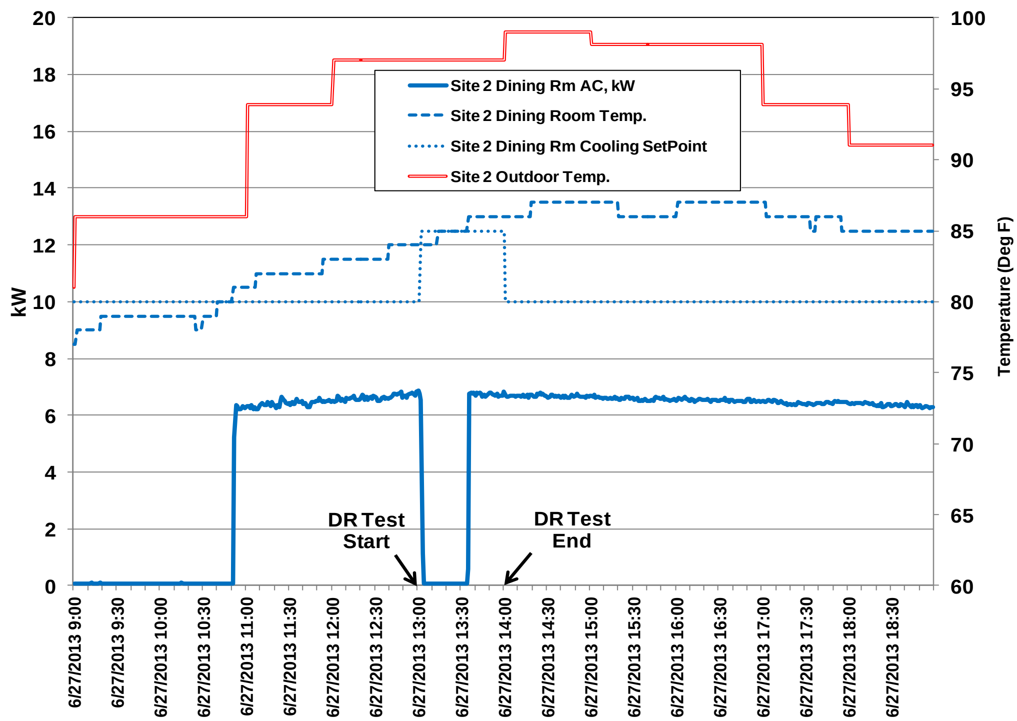

FIGURE 20. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 2 ON DR EVENT DAY JUNE 27, 2013

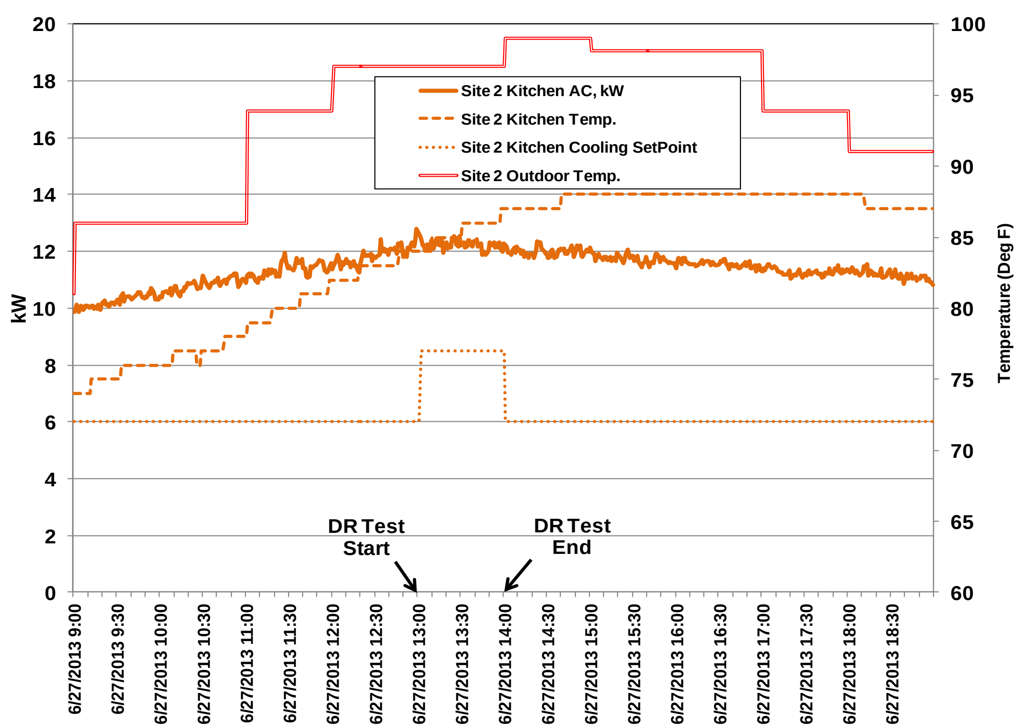

FIGURE 21. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 2 ON DR EVENT DAY JUNE 27, 2013

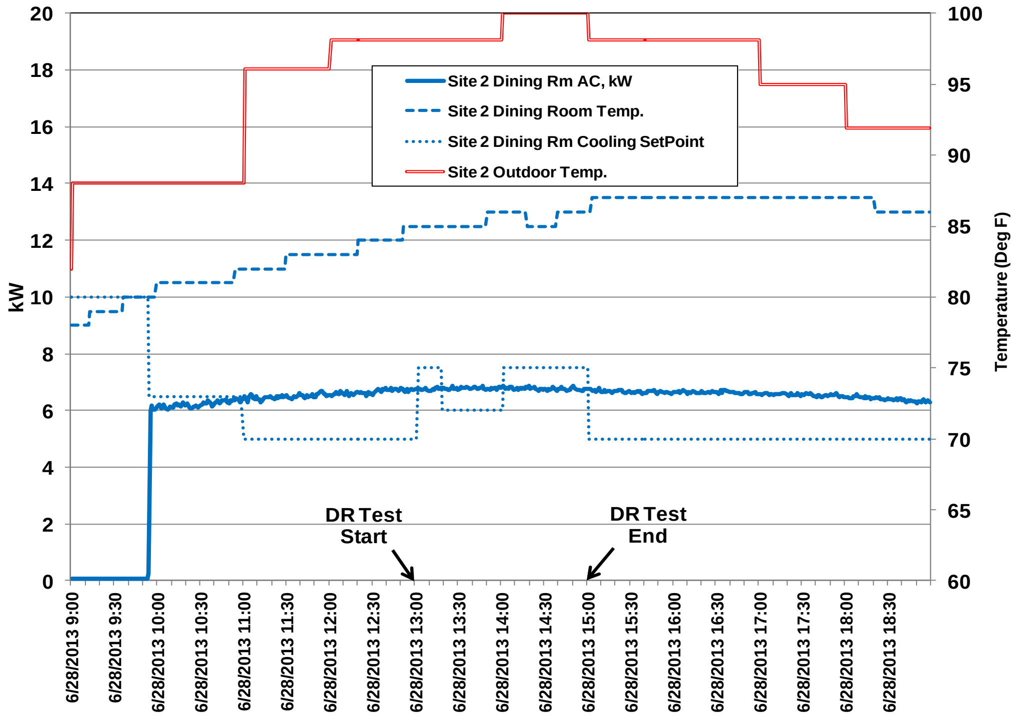

FIGURE 22. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 2 ON DR EVENT DAY JUNE 28, 2013

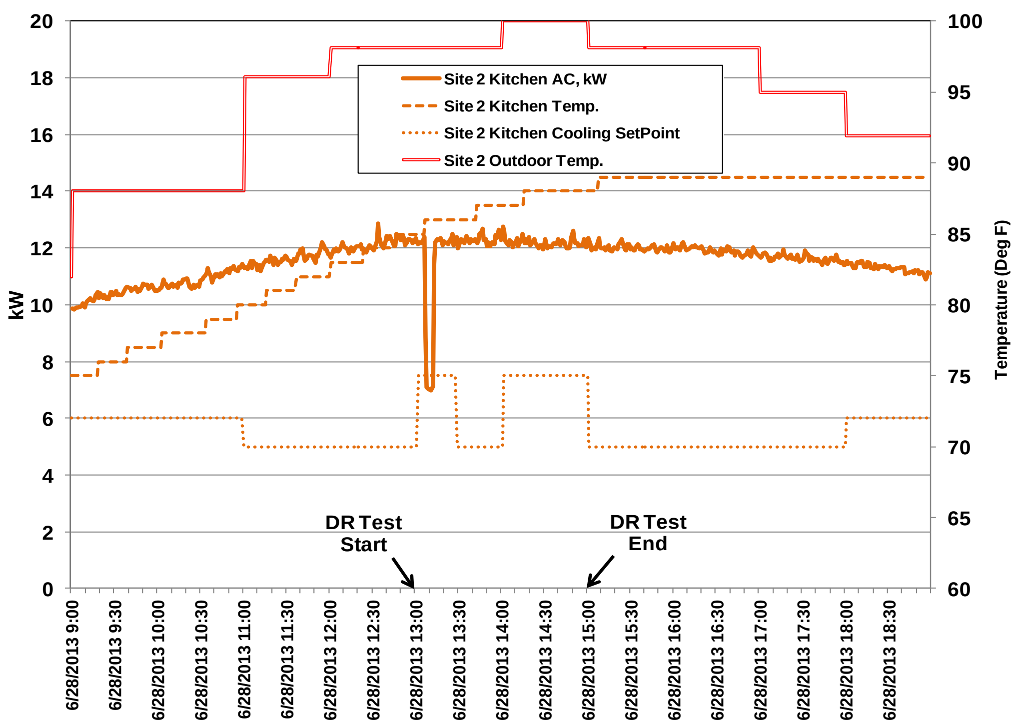

FIGURE 23. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 2 ON DR EVENT DAY JUNE 28, 2013

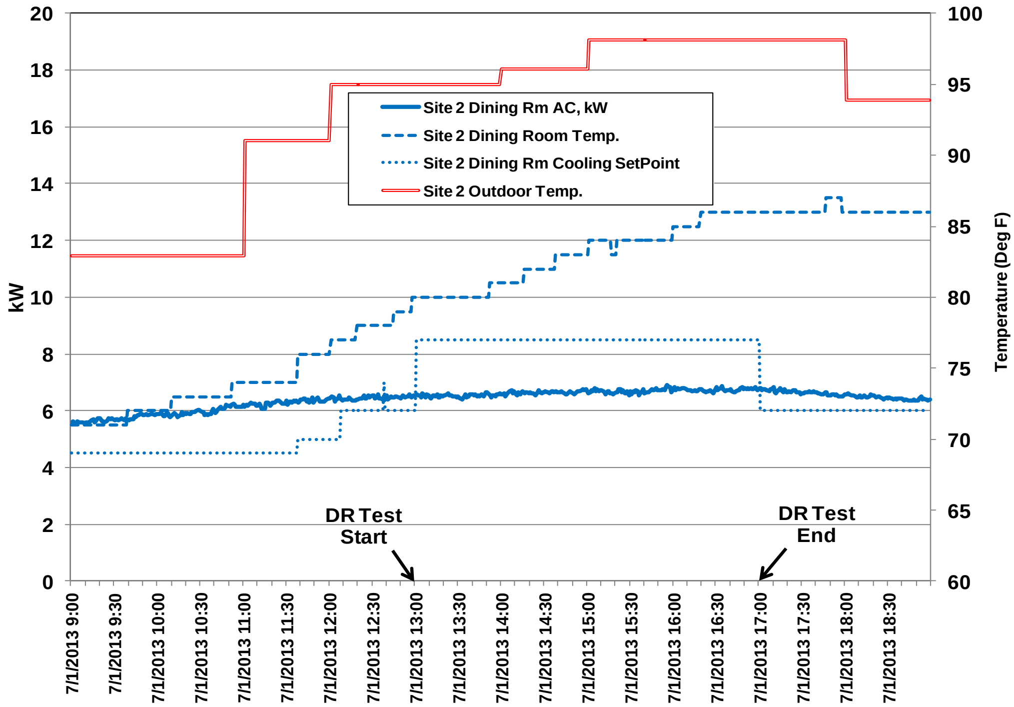

FIGURE 24. DINING ROOM AC DEMAND AND TEMPERATURES FOR SITE 2 ON DR EVENT DAY JULY 1, 2013

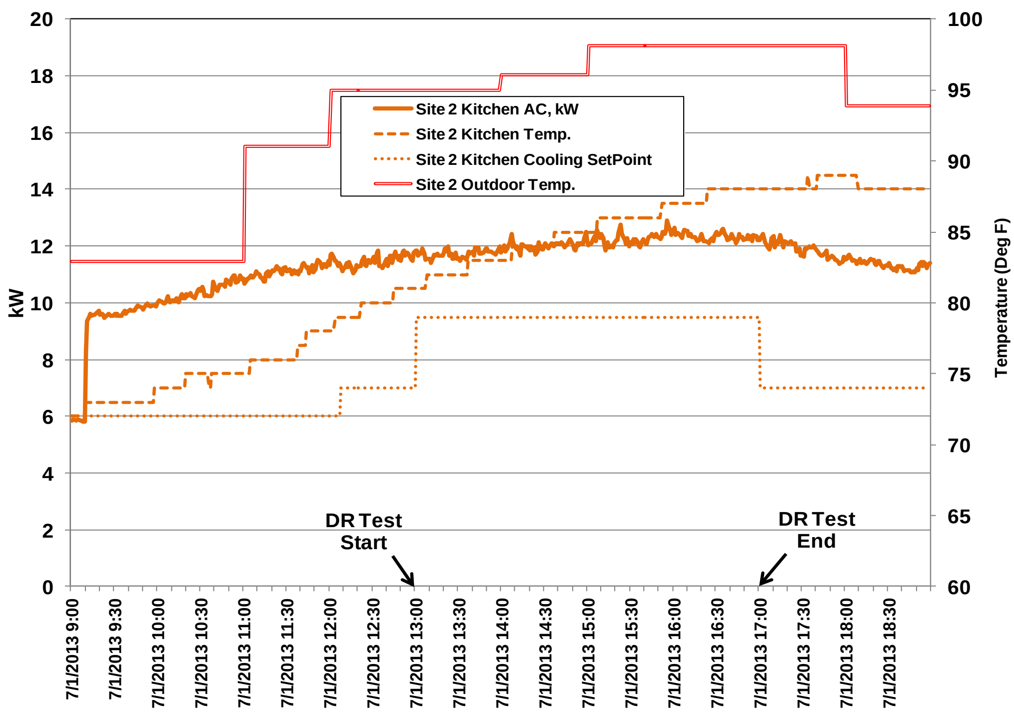

FIGURE 25. KITCHEN AC DEMAND AND TEMPERATURES FOR SITE 2 ON DR EVENT DAY JULY 1, 2013

APPENDIX C – EMBEDDED DATA FILES

Data collected during this technology evaluation can be found in the embedded Excel files. There is one file for each of the two HVAC control sites tested.

1. EPLMontAC vSCE.xlsx
2. EPLRivAC vSCE.xlsx