Demand Response Technology Evaluation of AutoDR Programmable Communicating Thermostats

DR10SCE1.05.01 Report

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December 2012

SOUTHERN CALIFORNIA EDISON

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Acknowledgements

Southern California Edison's (SCE's) Design & Engineering Services (D&ES) group is responsible for this project in collaboration with the Tariff Program & Services (TP&S) group. It was developed as part of SCE's Demand Response, Emerging Markets and Technology program under internal project number DR10SCE1.05.01. D&ES project manager Neha Arora conducted this technology evaluation with overall guidance and management from Carlos Haiad and Devin Rauss of D&ES and Mauro Dresti of TP&S. For more information on this project, contact neha.arora@sce.com.

Disclaimer

EXECUTIVE SUMMARY

The purpose of this study was to conduct field measurements to evaluate the Demand Response (DR) capabilities of Programmable Communicating Thermostats (PCTs) leveraging Open Automated Demand Response (OpenADR). This evaluation specifically relates to packaged rooftop Heating Ventilation and Air Conditioning (HVAC) units at fast food restaurants, a market segment generally outside of the OpenADR scope. This project examined a low-cost entry for this market segment to explore the potential demand savings. The DR study was managed by Southern California Edison's (SCE) Design and Engineering Services Group.

The main objectives of the project were to:

- Determine whether the PCTs reliably received the DR signal
- Determine whether the PCTs reduced Air Conditioning (AC) demand when receiving a DR signal
- Determine how much AC demand was dropped for each setting tested

The study was conducted at three fast food restaurants in the Inland Empire, California, where a total of eight HVAC units had PCTs installed. The PCTs are typically a direct replacement for existing thermostats for HVAC units, or heat pumps, except where the existing thermostat used a remote temperature sensor.

Remote access to the thermostat functions and controls are available through the OpenADR communication vendor's website. The PCTs implement DR by increasing the cooling set point temperature on the thermostat controls when an event signal is received.

Power monitoring of all individual rooftop HVAC units was conducted for this study. All three sites have three HVAC units apiece, and all but one of the nine HVAC units had a PCT installed. The monitoring started in May 2012 and recorded average power in 15-minute intervals. The data recording interval was reduced to 1-minute for the DR testing phase of the project. DR testing was conducted on a single day at the end of September 2012 and during 5 days in early November 2012. Automated DR events were issued by SCE to test the PCTs and the AC response to the change in the cooling set points. One event was conducted for each test day, where each day used a different configuration of degrees offset, duration of event, and start time of event. Cooling set point offsets of 2° Fahrenheit (°F), 4°F, 6°F, and 8°F were planned. Durations of two or four hours between 12:00 p.m. and 4:00 p.m. were tested per offset.

Although the PCTs were typically able to receive and implement the DR signal sent by SCE, there were some exceptions. Approximately 87% of the DR event signal implementations could be verified. Intermittent WiFi coverage is suspected as having caused the problem for the tests that were not successfully performed. Additionally, approximately 68% of the test hours had cooling set point temperature offsets. One reason for the lower offset rate was that the managers on duty could manually override the offset and return the cooling set point to the original setting. The other reason involved an issue with the communication firmware, which caused the set point to fluctuate rather than remain at a fixed temperature for the duration of the DR test.

Despite these issues, AC demand was reduced when the PCTs received the DR signal, increasing the cooling temperature set point above the temperature at the thermostat.

For each test day, a non-test day was selected to compare demand and energy use to the DR event period. The average HVAC demand savings per site for the DR test periods was 3.3 kW, or 29% savings. The energy savings were also estimated for the test days. The analysis included the energy use during the DR test window and the one hour immediately following the end of the test. The overall average weather-normalized percentage of energy savings was 25%.

At the time of testing, the hardware costs for the PCTs were $270 per unit. The installation costs of the hardware and the dedicated WiFi service was $1,462 per unit, for a total of $1,732 per unit. The installation and WiFi cost could be substantially reduced if a site has existing, accessible WiFi and if the thermostat installation is conducted by HVAC technicians who are already trained in connecting the PCT to a wireless network. The hardware costs of this system align well with other PCTs in the market (about $250), but the costs of installation and wireless service increase the total cost for bringing and maintaining the system online.

ABBREVIATIONS

AC	Air Conditioning
ADR	Automated Demand Response
CT	Current Transducer
DR	Demand Response
DRAS	Demand Response Automated System
°F	Degrees Fahrenheit
HVAC	Heating Ventilation and Air Conditioning
Hz	Hertz
kW	Kilowatt
kWh	Kilowatt hour
NIST	National Institute of Standards and Testing
OpenADR	Open Automated Demand Response
PCT	Programmable Communicating Thermostat
RTU	Roof Top Unit
SCE	Southern California Edison
W	Watt

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INTRODUCTION

The purpose of this study was to evaluate the Demand Response (DR) capability of Programmable Communicating Thermostats (PCTs) utilizing Open Automated Demand Response (OpenADR) communication modules developed by the OpenADR communication vendor. These PCTs were installed in three fast food restaurants of the same chain in the Inland Empire (California Climate Zone 10). These real-world settings permitted researchers to verify that the technology proposed by the participating manufacturer performed to the published specifications by delivering the DR signal needed to reliably reduce demand. Additionally, it allowed for quantification of the benefit of participating in a DR event by leveraging this technology.

SCE is studying such concepts to advance the implementation of DR enabling technologies and is considering providing incentives for installation of similar equipment.

BACKGROUND

The following is an explanation of the need for DR based on stress to the electric grid. This stress occurs when demand for electricity nears the capacity of available power generation, an event which is typically most prevalent during hot summer afternoons. Weather forecasts are used to predict the need for demand and to develop reduction tactics in order to provide a degree of planning for electric load curtailment.

Peak electricity load has been controlled by various programs types, including very high customer participation in:

- Demand Bidding
- Critical Peak Pricing and Interruptible Rate programs
- Time-Of-Use rates for large commercial customers

Peak demand has also been controlled by residential customers participating in air conditioning (AC) cycling programs.

By conducting several projects this year, SCE is investigating the potential for demand response technologies to reduce the peak electric system load.

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 performing smaller load reductions at a large number of facilities. New technologies are providing methods to coordinate the DR program participation of larger and more varied customer groups.

One of the most effective methods for utilities to implement DR for many sites with small loads is by the OpenADR communication standard. OpenADR was developed by Lawrence Berkeley National Laboratory to promote a common communication standard for DR programs and technology manufacturers.

ASSESSMENT OBJECTIVES

SCE tested the implementation of PCTs controlling rooftop packaged AC units at three fast food restaurants. The PCTs have the ability to remotely alter the thermostat cooling or heating set point temperature in response to a DR event signal. By raising the cooling set point 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 to:

- Determine whether the PCTs reliably receive the DR signal
- Determine whether the PCTs reduce AC demand when receiving a DR signal
- Determine how much AC demand is dropped for each setting tested

In order to achieve the project objectives, electric load monitoring was conducted for the AC units in each participating facility. A schedule of automated DR testing was also conducted. Following the tests, monitored data was analyzed to verify the implementation of the test signals and to quantify the demand savings.

Although controls that temporarily alter the thermostat set point may provide demand reduction, energy savings are more difficult to determine because of rebound effects. These occur when the AC units increase their operating level at the end of the DR period, at which time, the temperature set point returns to the original setting.

TECHNOLOGY/PRODUCT EVALUATION

This study examined one brand of remotely controlled thermostats that enable DR by altering the thermostat set points of packaged rooftop HVAC units. Three sites with similar characteristics were selected to field test the product and to monitor the demand savings of the technology.

The thermostat product evaluated in this study has a built-in communication module. This module communicates through a wireless network to the internet, allowing all features and functions of the thermostat to be accessed remotely. The module is compatible with the OpenADR standard. The communication vendor facilitates the control by providing a web interface for managing multiple thermostats for clients. Clients can log on to the secure website to program heating and cooling schedules and set points, to establish OpenADR moderate and high temperature offsets, and to lockout local thermostat control. The vendor's website also displays groups of thermostats, showing their connection status, temperature and humidity at the thermostat, cooling and heating set points, operating mode, and fan state.

The PCT studied is compatible with most HVAC units, including heat pumps. Generally, it can be a direct replacement for an existing manual or programmable thermostat. The PCT can operate one- and two-stage AC units, and can be programmed with up to seven schedules per day. As shown in Figure 1~~Figure 1~~, the PCT has a large, easy-to-read temperature display. Demand response periods can be scheduled in advance.

FIGURE 1. PCT MOUNTED ON WALL

Five fast food restaurants in the Inland Empire region (California Climate Zone 10) were selected by SCE for consideration in the study. The study was designed to limit facility selection to one fast food chain for all sites because this more effectively preserves uniformity in conditions and minimizes the number of variables affecting results. Initial site inspections excluded one of the five sites due to poor maintenance of the HVAC units. Before installation of the PCTs, another site was dropped because the existing thermostats used remote temperature sensors. The PCT evaluated in this study does not have remote temperature sensor capability, so it could not be installed as a replacement thermostat at that location.

Each of the three test sites had three AC units, one dedicated to the kitchen and two dedicated to the public areas of the restaurant. A summary of the three test sites is provided in Table 1. The table lists the area served, rated tons, and make and model of the AC units. The total conditioned square footage for each site is also listed in the table.

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

Site Location	Thermostat Location, AC#	Make/Model	Tons	Total Square Feet
Corona – Magnolia Ave.	Kitchen, AC1	York, DH078N10N2AAA3A	6.5	2,967
	Dining Rm, AC2	Lennox, no nameplate	6 est.	
	Dining Rm, AC3	Lennox, no nameplate	6 est.	
Corona – Temescal Canyon	Dining Rm, AC1	BDP, 580CPV09125	8.5	3,111
	Dining Rm, AC2	Carrier, 48TMD008-A-501	7.5	
	Kitchen, AC3	York, DH090N15PGAA6A	7.5	
Rancho Cucamonga	Dining Rm, AC1	Trane, YSC060A3LA24	5	2,251

Site Location	Thermostat Location, AC#	Make/Model	Tons	Total Square Feet
	Lobby, AC2	Trane, YSC060A3LA24	5	
	Kitchen, AC3	Carrier, 48LHD008540	7.5	

Eight of the nine AC units at the test sites had radio thermostats installed. One AC unit at the Temescal Canyon site had the thermostat located inside the rooftop control panel and a remote temperature sensor located in the return duct. This did not allow for installation of a radio thermostat. Table 2 lists the AC units with radio thermostats, also referred to as PCTs.

Table 2. Summary of AC Units with PCTs

Site Location	Thermostat Location, AC#	PCT
Corona – Magnolia Ave.	Kitchen, AC1	Yes
	Dining Rm, AC2	Yes
	Dining Rm, AC3	Yes
Corona – Temescal Canyon	Dining Rm, AC1	No
	Dining Rm, AC2	Yes
	Kitchen, AC3	Yes
Rancho Cucamonga	Dining Rm, AC1	Yes
	Lobby, AC2	Yes
	Kitchen, AC3	Yes

Communication

The communication modules leverage a wireless WiFi network, and a dedicated WiFi hotspot was installed at each of the three test sites. Originally, cellular service provider hotspot devices were installed. The modules in the PCTs were set up with a password to allow connection through the hotspot communication link, and no other devices were authorized to use the hotspot connection. The hotspot connections worked well throughout most of the testing. On two occasions, the hotspot communication with the PCTs was lost and could not be recovered without a site visit. The communication vendor then recommended the use of an alternative hotspot device to provide a WiFi network at each of the sites via broadband mobile signal. The alternative device improved the communication with the PCT, but did not solve all the problems associated with the programming of the thermostat.

OPERATING HOURS

The posted operating hours for the three locations are relatively similar but not identical, as shown in Table 3~~Table 3~~. The long operating hours of fast food businesses allow the AC thermostats to be available for DR over a wide range of times.

TABLE 3. POSTED RESTAURANT OPERATING HOURS BY DAY OF WEEK AND SITE

SITE LOCATION	MON-THU	FRI	SAT	SUN
Corona – Magnolia Ave.	6AM-11PM	6AM-Midnight	6AM-Midnight	7AM-10PM
Corona – Temescal Canyon	6AM-11PM	6AM-Midnight	6AM-Midnight	6AM-11PM
Rancho Cucamonga	6AM-Midnight	6AM-Midnight	24 hrs	24 hrs

TECHNICAL APPROACH/TEST METHODOLOGY

In order to characterize the demand reductions resulting from the use of PCTs, a Measurement and Verification plan was prepared and adapted for the three test sites.

The facilities were chosen due to similarities in building size and HVAC equipment type. The three restaurants are all the same chain, are owned and operated by two independent franchises, and are located within 30 miles of each other. All controlled HVAC units are packaged rooftop units.

The methodology for the study was to monitor the baseline HVAC demand and test the units' response to signals sent to the thermostats. The HVAC units were in various states of maintenance. A schedule of DR tests was developed to determine how the systems respond to DR requests and to quantify the achievable demand savings. The following is a description of the metering equipment used in the field for this study.

METERING EQUIPMENT AND DATA ACQUISITION

Enernet K-20 multi-channel meter recorders (as shown in Figure 2) were used to monitor power consumption of the HVAC units. These recorders can monitor electric energy, analog signals, and digital pulses. For this study, the recorders were used to monitor true root square mean (RMS) kW power of the circuits (as shown in Figure 3) feeding each AC unit. Three roof top units (RTUs) were monitored separately at each of the sites. The logger accuracy for power measurements is ± 0.5% from 1 to 100% of full scale. Current transducer (CT) accuracy is ± 1% from 10% to 100% of full scale, ± 3% at 5% of full scale, and ± 5% at 2% of full scale. Split-core CTs (as shown in Figure 4) with appropriately rated primary current were used for the AC units. Multiple channels on each logger were used to measure kW. The meter sampled the full 60 hertz (Hz) waveform once every 5 to 9 seconds, and the data samples were averaged and recorded in 15-minute intervals for the baseline and 1-minute intervals for the test days. During the site installation visit, the meter recorder box was mounted near the electrical panel. One-time power measurements were made using an AEMC 3910 true RMS power meter to confirm calibration of the data logger and to assure proper installation. Data were collected remotely via telephone land lines at each site, which were connected to modems in each of the loggers. A central computer retrieved data daily.

Prior to installing monitoring equipment, the power for all the AC units was traced. Two CTs were installed to monitor the power of each AC unit.

The communication vendor's website collected and maintained all data from the thermostat operation. The stored data included actual temperature at the thermostat, cooling and heating set points, and unit mode of operation. Data from the website were downloaded as 10-minute averages for the testing periods, although finer increments are available directly from the vendor.

Hourly dry-bulb temperature data were collected from two National Oceanic and Atmospheric Administration weather stations, one in Corona and one in Chino.

FIGURE 2. K20 POWER LOGGER MOUNTED NEXT TO ELECTRIC PANELS

FIGURE 3. AIR CONDITIONER BREAKERS IN ELECTRIC ROOM

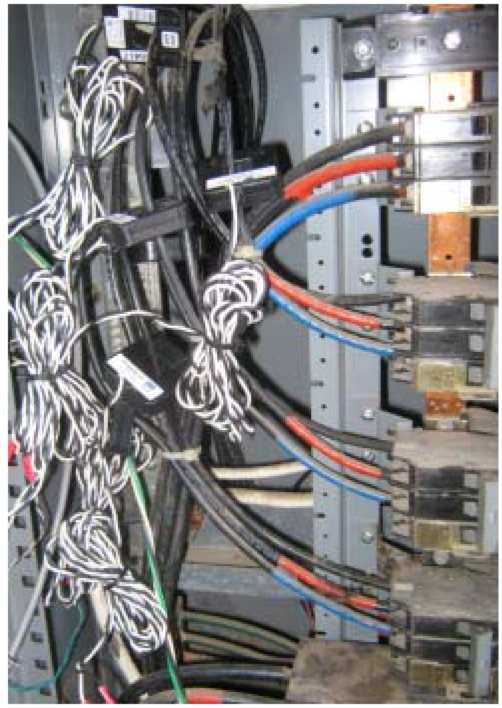

FIGURE 4. CURRENT TRANSDUCERS MOUNTED INSIDE ELECTRIC PANEL

TEST PROCEDURES

Altering thermostat set points can have 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. Several temperature offsets, offset period start times, and durations were planned for the DR testing. Only one set of conditions were scheduled for each test day. At the end of the DR test period, the thermostat set points were returned to the set point before the start of the test. Power was recorded at 1-minute intervals all day for test days. Table 4 shows the planned DR test schedule. Non-test days were also recorded by the data loggers as a comparison to demand during the test days.

TABLE 4. DEMAND RESPONSE TEST SCHEDULE

TEST DATES	TEMPERATURE OFFSET	OFFSET PERIOD	SITES
September 27	2°F	2 p.m. – 6 p.m.	Corona – Temescal Canyon
September 28	2°F	2 p.m. – 6 p.m.	Corona – Magnolia Ave.

Test Dates	Temperature Offset	Offset Period	Sites
November 2	4°F	12 p.m. – 2 p.m.	All Three Sites
November 5	8°F	12 p.m. – 4 p.m.	All Three Sites
November 6	8°F	4 p.m. – 6 p.m.	All Three Sites
November 7	6°F	12 p.m. – 4 p.m.	All Three Sites
November 8	6°F	4 p.m. – 6 p.m.	All Three Sites

SCE personnel implemented the DR testing by using the Demand Response Automated Server (DRAS), and DR events were sent using the OpenADR specification. Various event-mode levels were tested in order to determine the manufacturer's abilities to respond to a range of levels. The client was operated in "Auto" mode in the test DRAS. The OpenADR policy in the communication vendor's website was configured for the desired temperature offset. A DR test signal was sent from the test DRAS to the devices at the specified time and included the duration and event-start time. This information was received from the server by the PCT, which then changed the set point per the OpenADR policy and maintained this change until either the event was completed or the signal was overridden.

AC energy use is weather dependent, meaning any savings are influenced by the ambient conditions. For this project, the testing was conducted in the fall, so it stands to reason the demand reduction and energy savings would likely be different in the summer months. Summer testing should be scheduled in the future to determine more realistic demand reduction impacts. All computers, equipment, and loggers were intended to be synchronized to clocks on Pacific Time, as obtained from the National Institute of Standards and Testing (NIST)1 website.

[1] NIST web link: http://nist.time.gov/timezone.cgi?Pacific/d/-8/java

DATA ANALYSIS AND RESULTS

This section presents and discusses the data collected from monitoring PCTs at the three test sites. Data from each site were processed separately to identify tests that were successful in altering the thermostat set point and to determine demand reduction. This chapter presents a sample of the charts and data collected and used in the analysis. It also contains tables displaying the demand analysis results. Appendices A, B, and C contain charts for each of the test days and non-test comparison days.

DR TEMPERATURE OFFSET RELIABILITY

The data were processed site by site. Data for each AC unit were reviewed and verified. The data for each AC unit were inspected to identify whether the DR signal reached the thermostat and caused the cooling set point to change by the planned offset and period. Figures 5 through 7 each show one of the AC units at the Corona Magnolia site on November 5th. In Figure 5, the cooling set point for AC#1 rises eight degrees at 12:00 noon from 74°F to 82°F and lowers back to 74°F at 4:00 p.m. (16:00). This is a sign that the DR signal was successfully transmitted to the thermostat. In response to the change in set point, the AC turned off for approximately 45 minutes, turning back on once cooling was required. The gray band indicates the DR period.

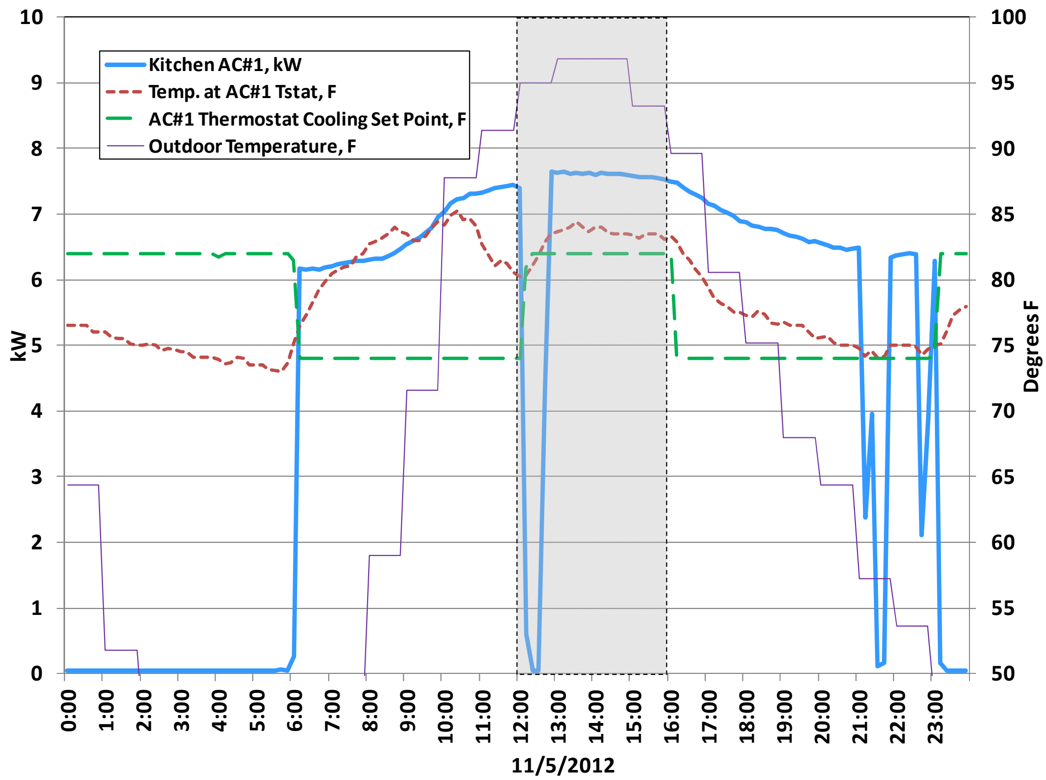

FIGURE 5. AC#1 PROFILES FOR DEMAND, COOLING SET POINT, INDOOR AND OUTDOOR TEMPERATURES

In Figure 6, the cooling set point for AC#2 rises eight degrees at 12:00 noon from 74°F to 82°F and lowers back to 74°F at approximately 2:45 p.m. This is a sign that the DR signal was successful in transmitting to the thermostat. The AC unit initially responded by turning off for more than an hour and then cycling until the cooling set point was prematurely reset by site personnel, at which time the AC unit ran for the remainder of the test period. This was the hottest of the test days, with outdoor temperatures reaching 97°F. From the figures for AC#1 and AC#2, it can be seen that the majority of the demand reduction occurred during the beginning of the DR period. This does not necessarily imply that the DR period should be short, as there is a rebound effect that will cause the AC unit to run at a higher duty cycle rate in order to decrease the temperature back down to the original cooling set point.

These charts present the 10-minute averages of the parameters displayed, with the exception of the outdoor temperature, which is presented as an hourly average. The charts depict data merged from three sources: monitored power data, data from the PCT, and weather station data.

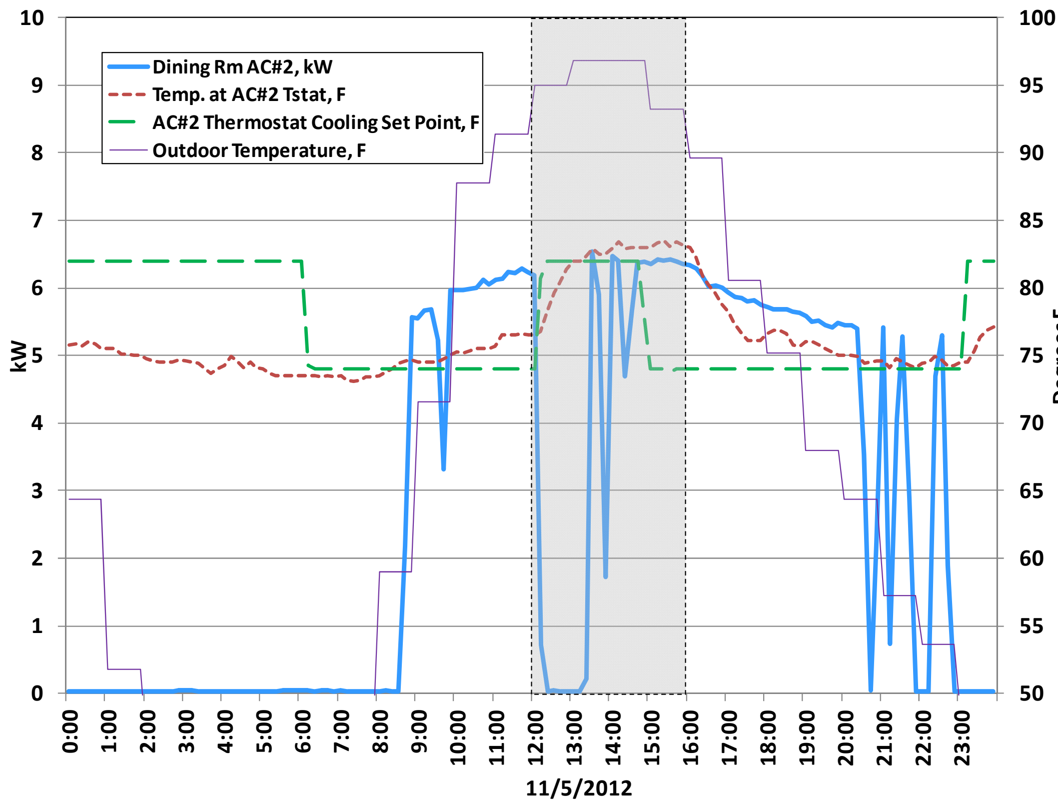

FIGURE 6. AC#2 PROFILES FOR DEMAND, COOLING SET POINT, INDOOR AND OUTDOOR TEMPERATURES

In Figure 7, the cooling set point for AC#3 rises eight degrees at 12:00 noon from 74°F to 82°F and lowers back to 74°F at 4:00 p.m. This is a sign that the DR signal was successfully transmitted to the thermostat. The AC unit was off for almost the entire four-hour DR test period, which may be due to a cross-over of cooling from the other zones.

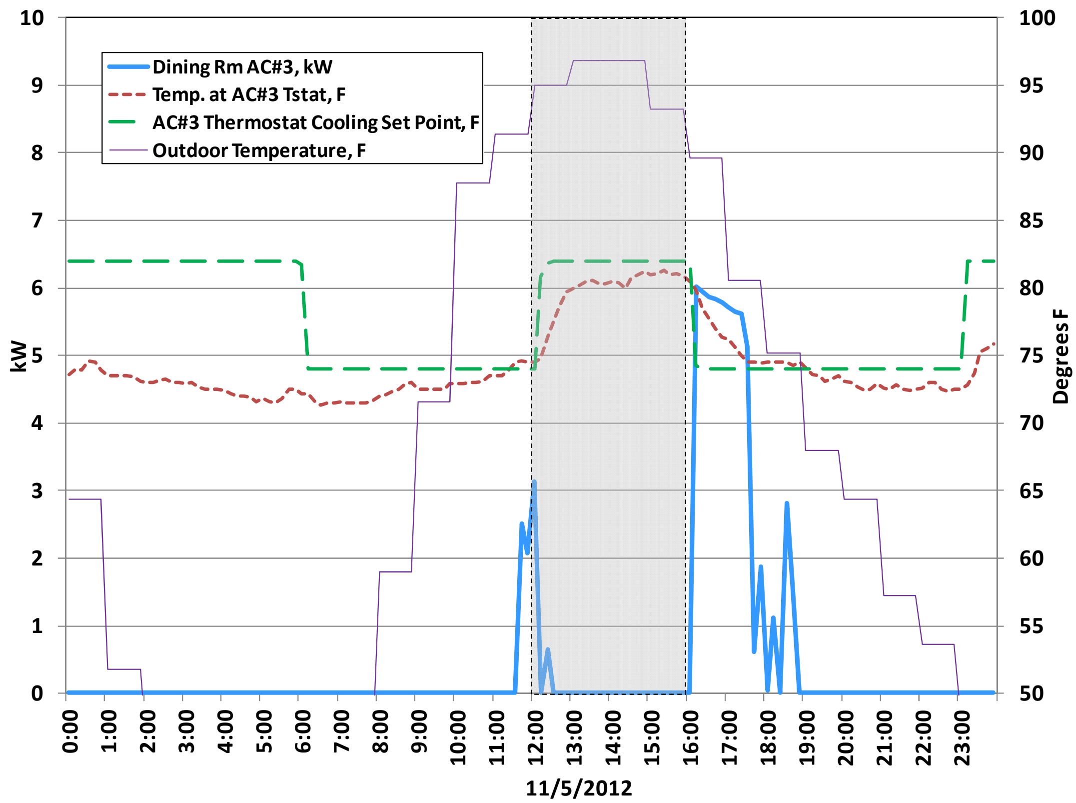

FIGURE 7. AC#3 PROFILES FOR DEMAND, COOLING SET POINT, INDOOR AND OUTDOOR TEMPERATURES

The data from each AC unit were reviewed for each DR test day. Cooling set point data from the PCTs were compared to the planned schedule of operation of the DR tests. A summary of the cooling set point observations is presented in Table 5~~Table 5~~. The notation "n/a" is used to signify that there was no DR test for that AC unit on that day. Some PCTs executed the DR planned schedule as intended; these are marked "As Planned". The issues observed in the data fall into four categories:

- Cooling set points that are for a different number of degrees than the planned offset
- Time duration of the cooling set point offset is different than the planned duration
- Unstable cooling offset during the DR period
- No data available from the PCT during all or part of the DR test period

Temperature offset differences from planned levels occurred in an even number of degrees. This may be an indication that a different temperature was entered for execution of the offset rather than the PCT arbitrarily using a different offset, although the latter must be considered a possibility unless otherwise documented. Although the starting time of the offset was always on time where there are data available, the ending time of the offset was often different than planned. The majority of time differences were minor;

however, one event extended a few hours past the expected reset time. Some of these occurrences may be due to a manual reset at the thermostat on the wall by the manager on duty. Another issue identified was an unstable temperature offset setting. This problem was traced back to a firmware issue, which has been corrected by the manufacturer for all of the thermostats. However, additional testing has not been conducted to confirm that the issue is resolved. The final issue is a lack of data or intermittent data, likely caused by problems with the cell service for the WiFi signal or the WiFi signal within the facility. The communication vendor addressed this issue by replacing the cellular service provider wireless devices with an alternative WiFi device. The replacement occurred after the DR test dates, and no additional testing has been conducted to confirm that the spotty WiFi signal issue has been corrected at these sites.

After the testing in early November was completed, one of the PCTs at the Rancho Cucamonga site was removed and replaced with a standard programmable thermostat by a HVAC technician unrelated to this project.

The observations in Table 5~~Table 5~~ indicate that approximately 68% of the DR test hours had cooling set point offsets that could result in demand reduction. As noted above, some of the issues reducing this percentage have been addressed. However, manual reset of the thermostat also contributes to a lower realization rate of DR hours. Although the reliability of the DR events is not as high as expected, additional testing may show improved reliability. It should be noted that the DR signal was received approximately 87% of the time.

TABLE 5. OBSERVATIONS ON COOLING SET POINTS LOGGED BY CLOUDBEAM DURING DR TESTS

DATE	AC#	CORONA – MAGNOLIA	CORONA –TEMESCAL	RANCHO CUCAMONGA
9/27	AC#1	n/a	n/a	n/a
9/27	AC#2	n/a	4°F Offset not 2°F	n/a
9/27	AC#3	n/a	4°F Offset not 2°F	n/a
9/28	AC#1	4°F Offset not 2°F	n/a	n/a
9/28	AC#2	4°F Offset not 2°F	n/a	n/a
9/28	AC#3	4°F Offset not 2°F	n/a	n/a
11/2	AC#1	No Offset	n/a	Offset Unstable
11/2	AC#2	No Offset	As Planned	Offset 1.25 hrs not 2 hrs
11/2	AC#3	No Offset	Offset 38 min not 2 hrs	No signal/data
11/5	AC#1	As Planned	n/a	Offset Unstable
11/5	AC#2	Offset 3 hrs not 4 hrs	As Planned	Offset Unstable

11/5	AC#3	As Planned	As Planned	Start OK, then no signal
11/6	AC#1	6°F Offset not 8°F, Did not reset at period end.	n/a	No signal/data
11/6	AC#2	Offset Unstable	Offset Unstable	Offset Unstable
11/6	AC#3	Offset Unstable	Offset Unstable	Offset Unstable
11/7	AC#1	Offset 2.25 hrs not 4 hrs	n/a	Offset Unstable
11/7	AC#2	As Planned	As Planned	Offset Unstable
11/7	AC#3	Offset 1.5 hrs not 4 hrs	Offset 3.25 hrs not 4 hrs	Offset Unstable, then no signal
11/8	AC#1	As Planned	n/a	8°F Offset not 6°F, Offset 6 hrs not 2 hrs
11/8	AC#2	As Planned	As Planned	8°F Offset not 6°F
11/8	AC#3	As Planned	As Planned	No signal/data

DR ANALYSIS RESULTS

Each site has two AC units for the public areas and one for the kitchen. The two public area zones are very well mixed, and even the kitchen zone is not isolated from the public zones. For this reason the metered demand levels for all three AC units at each site were summed together. The AC unit compressors are typically on or off because they do not have variable speed compressors. Therefore, an instantaneous peak measurement of power will not show a demand reduction over the test period if the unit turns on at all during the period. The analysis focused on the average demand during the entire DR test period, where the sum of the three AC units' metered kW was averaged over the two- or four-hour planned test windows. The average demand for a test day at a site was then compared to the average demand for a non-test day during the same time window on a day with a similar outdoor temperature. The comparison day was selected based on the closest peak daily temperature for a day within ten days of the test day. The largest temperature difference between any of the test and comparison days was 4°F. Although baseline data were collected throughout the summer months, these data were not usable because summer outdoor temperature profiles significantly differ from November temperature profiles.

For comparison purposes, the outdoor temperature and the average indoor temperatures are provided for the test and comparison days in Table 6~~Table 6~~. The temperatures are only for the scheduled test periods. Some of the comparison days at Corona Magnolia did not have available thermostat temperature data.

TABLE 6. DR TEST AND COMPARISON DAY OUTDOOR AND AVERAGE INDOOR TEMPERATURES

	Outdoor Temperature, °F		Average Indoor Temperature, °F	
Test Day	Test Day	Comparison Day	Test Day	Comparison Day
Corona - Magnolia				
9/28	87.7	86.5	78.7	76.2
11/2	69.2	68.3	74.8	n/a
11/5	95.2	91.9	81.8	77.2
11/6	77.2	77.3	78.1	n/a
11/7	73.8	73.4	78.0	n/a
11/8	61.0	65.0	75.9	n/a
Corona – Temescal Canyon				
9/27	85.5	86.5	79.6	78.1
11/2	69.2	68.3	73.1	73.6
11/5	95.2	91.9	83.5	82.1
11/6	77.2	77.3	83.0	78.7
11/7	73.8	73.4	79.6	73.7
11/8	61.0	65.0	72.1	74.5
Rancho Cucamonga				
11/2	69.7	68.5	71.7	68.6
11/5	93.4	91.4	81.0	77.0
11/6	76.2	77.4	75.2	75.9
11/7	76.2	76.4	75.5	72.8
11/8	62.3	65.8	65.8	71.1

The difference in the demand between the comparison day and test day is the reported demand savings and only reflects the period from the start of the test to the end of the test.

The analysis of the DR test data from the Corona Magnolia site is presented in Table 7, which shows the average demand during the DR test period for each day and non-test comparison day. The demand savings percentage and total kW value are also presented. Due to the number of combinations of time and temperature within DR test periods, no conclusion can be drawn regarding which combination provides the best DR strategy for the utility. Although the two-hour time windows may show a higher average demand reduction, the savings will be short lived, and rebound will occur earlier.

Excluding the day when no offset was executed, the overall average demand reduction was 35% across all three AC units.

TABLE 7. DR TESTING DEMAND REDUCTION ANALYSIS FOR CORONA - MAGNOLIA

Test Day	Comparison Day	DR Test Hours	Offset, Deg F	Average Total AC Demand During DR Test Period, kW: Test Day	Comparison Day	Average Demand Savings, kW	Percent Savings, %
9/28	9/24	4	4	12.75	16.63	3.88	23%
11/2	11/1	2	4	11.82*	6.54*	-5.29*	-81%*
11/5	11/4	4	8	10.58	15.49	4.91	32%
11/6	10/29	2	8	6.63	13.98	7.35	53%
11/7	10/31	4	6	7.56	11.20	3.64	33%
11/8	11/1	2	6	0.19**	8.78**	8.59**	98%**
Average*				9.38	14.33	4.95	35%

* Not included in Average because no offset occurred on test day.

** Not included in Average due to lack of operation on test day.

Similar to Table 7, the analysis of the DR test data from the Corona Temescal Canyon site is presented in Table 8. Although the two-hour time windows may show a higher average demand reduction the savings will be short lived, and rebound will occur earlier. The overall average demand reduction resulted in a 25% savings across all three AC units. Only two of the three AC units at this site have PCTs, but the AC demand is across all three units. The negative savings for two days can be attributed to the cooler temperatures of the comparison days. In order to do more analysis on this issue, more test- and comparison-day data would be needed.

TABLE 8. DR TESTING DEMAND REDUCTION ANALYSIS FOR CORONA – TEMESCAL CANYON

Test Day	Comparison Day	DR Test Hours	Offset, Deg F	Average Total AC Demand During DR Test Period, kW: Test Day	Comparison Day	Average Demand Savings, kW	Percent Savings, %
9/27	9/24	4	4	12.33	14.59	2.25	15%

				Average Total AC Demand During DR Test Period, kW			
Test Day	Comparison Day	DR Test Hours	Offset, Deg F	Test Day	Comparison Day	Average Demand Savings, kW	Percent Savings, %
11/2	11/1	2	4	7.56	6.95	-0.61	-9%
11/5	11/4	4	8	7.05	6.88	-0.17	-2%
11/6	10/29	2	8	6.24	12.27	6.03	49%
11/7	10/31	4	6	6.39	8.39	2.01	24%
11/8	11/1	2	6	2.52	7.02	4.50	64%
Average				7.02	9.35	2.33	25%

Finally, the analysis of the DR test data from the Rancho Cucamonga site is presented in Table 9. The overall average demand reduction resulted in a 28% savings across all three AC units. The negative savings for one of the test days for this site can be attributed to the cooler temperature of the comparison day. In order to do more analysis on this issue, more test- and comparison-day data would be needed.

Table 9. DR Testing Demand Reduction Analysis for Rancho Cucamonga

				Average Total AC Demand During DR Test Period, kW			
Test Day	Comparison Day	DR Test Hours	Offset, Deg F	Test Day	Comparison Day	Average Demand Savings, kW	Percent Savings, %
11/2	11/1	2	4	5.02	6.19	1.17	19%
11/5	11/4	4	8	13.67	11.72	-1.96	-17%
11/6	10/29	2	8	6.86	12.80	5.94	46%
11/7	10/31	4	6	6.30	11.05	4.76	43%
11/8	11/1	2	6	1.42	4.19	2.78	66%
Average				6.65	9.19	2.54	28%

The overall average demand savings across all three sites for all the test days was 3.5 kW during the DR test period, representing a 32% savings.

More consistent results would be expected if the DR signals were reliably received and executed by the PCTs. Also, additional baseline comparison days within similar outdoor temperature profiles could be leveraged to provide a more stable baseline assessment of demand. Testing during the summer would provide results that are more closely representative of actual DR event conditions.

ENERGY SAVINGS ANALYSIS RESULTS

Energy savings were also considered during the data analysis. As compared to demand savings analysis, analyzing energy savings involves consideration of additional issues. Thermostat offsets increase overall AC activity after the DR period ends and the set point is returned to the original setting; this is called a rebound effect. To account for the rebound, the energy use for the hour following the DR period was also included in the data aggregation. Another factor is that the outdoor temperatures on the comparison days are not identical to the test days. In order to address this, the analysis included a normalizing factor for the temperature. The total AC energy use during the period was divided by the difference between the average outdoor temperature during the period and the cooling balance point temperature. The cooling balance point temperature was estimated by charting the demand versus outdoor temperature and projecting the outdoor temperature at which AC use is typically no longer needed (as shown in Figure 8). The cooling balance point temperature for Corona Magnolia is 45°F. The cooling balance point temperatures for Corona Temescal Canyon and Rancho Cucamonga are 45°F and 50°F, respectively.

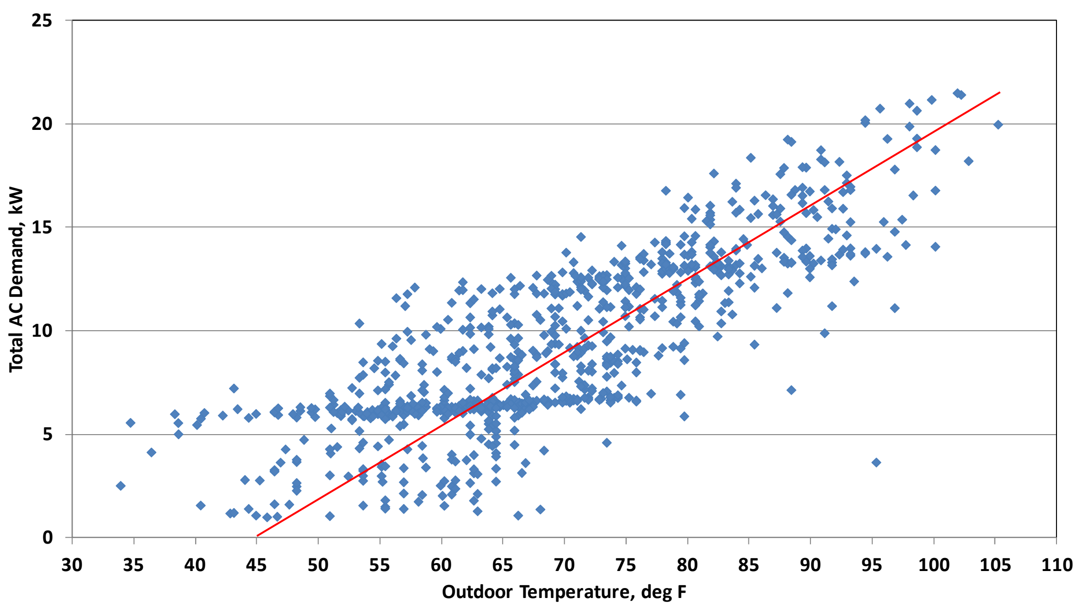

FIGURE 8. SCATTER PLOT OF TOTAL AC DEMAND VS. OUTDOOR TEMPERATURE, CORONA MAGNOLIA

The analysis of the energy savings for each of the three sites is presented in Table 10~~Table 10~~. The total AC energy use for the test period plus the hour immediately following are presented for the test and comparison days in the second and third columns of the table. The normalized energy use is provided in the fourth and fifth columns of the table. The normalizing temperature is the outdoor temperature for the period minus the cooling balance point temperature for the site. The normalized energy savings for the test period plus the subsequent hour are listed in the sixth column, and the overall average is 0.095 kWh/hr/°F. The overall average normalized energy savings is 25%. For example, if a four-hour DR event occurred in Corona when the average outdoor temperature during the event was 100°F, the energy savings would be 20.9 kWh [(100°F - 45°F) * 4hr * 0.095 kWh/hr/°F], and the average demand savings for the event would be 5.2kW (20.9kWh/4hr).

TABLE 10. TOTAL AC ENERGY USE AND NORMALIZED SAVINGS BY SITE FOR TEST AND COMPARISON DAYS

	Total AC Energy Use for Test Period + Next Hour, kWh		Normalized Total AC Energy Use, kWh/hr/F		Normalized Savings,	Percent Savings,
Test Day	Test Day	Comparison Day	Test Day	Comparison Day	kWh/hr/F	%
Corona – Magnolia						
9/28	67.8	79.8	0.340	0.401	0.061	15%
11/2	35.6	21.0	0.475	0.294	-0.181*	-62%*
11/5	61.6	77.8	0.258	0.334	0.076	23%
11/6	24.5	40.2	0.281	0.439	0.158	36%
11/7	43.6	59.4	0.314	0.426	0.112	26%
11/8	10.2	23.8	0.247	0.413	0.165	40%
Site Average*			0.288	0.403	0.115	28%
Corona – Temescal Canyon						
9/27	49.3	58.3	0.332	0.347	0.015	4%
11/2	22.9	21.4	0.306	0.299	-0.007	-2%
11/5	34.9	34.1	0.144	0.146	0.003	2%
11/6	18.4	33.5	0.205	0.363	0.158	43%
11/7	32.8	42.6	0.234	0.305	0.071	23%
11/8	10.8	20.1	0.244	0.351	0.107	30%

Site Average			0.244	0.302	0.058	19%
Rancho Cucamonga						
11/2	17.7	21.4	0.291	0.361	0.071	20%
11/5	72.3	58.0	0.349	0.283	-0.066	-23%
11/6	19.9	36.1	0.306	0.512	0.206	40%
11/7	32.6	55.1	0.257	0.429	0.172	40%
11/8	4.3	11.8	0.126	0.297	0.171	58%
Site Average			0.266	0.376	0.111	29%
Overall Average					0.095	25%

* Not included in Average because no offset occurred on test day.

ECONOMICS

The hardware costs for the PCT were $270 per unit. The installation of the hardware and providing dedicated WiFi service came to $1,462 per unit, for a total of $1,732 per unit. The installation and WiFi costs could be substantially reduced if the site has existing, accessible WiFi, 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. The hardware costs of this system align well with other PCTs in the market (on average $250), but the cost of install and wireless service drive up the total cost for bringing, and keeping, the system online.

DISCUSSION

This project implemented new technology to enable DR capability and provide savings to a few sites participating in a field study. Fast food restaurants typically have AC load for a wide range of hours, making them ideal candidates for DR opportunities.

In order to capitalize on the opportunity for DR, HVAC units should be properly sized. Improperly sized units will not be able to efficiently meet the load, causing the HVAC unit to either run continuously (undersized) or have wider temperature swings (oversized). In either case, the savings attributable to a DR event will be negatively impacted. Improperly working HVAC units may also encounter issues with realizing DR savings. They may be non-functional, in which case no load can be reduced, or are inefficient, resulting in their capacity being reduced below the nameplate. This could cause the unit to be unable to meet the load, similar to an undersized unit.

Some test and comparison days in this study were compromised because of non-functioning units. Although they are included in the average, the result may not provide the best savings estimate. Better savings estimates would be obtained when the HVAC units are consistently maintained and operated.

Demand savings estimates for realistic summer conditions should be monitored. Although the fall test days were useful in testing the DR signal reliability, the savings may not be representative of an actual DR event.

There were several issues that reduced the effectiveness of the PCTs. The PCTs require a constant wireless network connection to perform to their intended capabilities. Although the thermostat will continue to operate without wireless communication, the ability to log activity or remotely change settings is lost. Therefore, it is important to install the PCTs where they will have a reliable wireless network connection. During the study, a cellular service provider hotspot device was installed along with the PCTs, but there were some intermittent connection issues. In response, the communication vendor replaced the original hotspots with an alternative vendor's hotspot devices. In addition, the communication vendor updated the communication module firmware to correct a problem that had resulted in an unstable temperature offset. Unfortunately, due to project time constraints, no tests were performed with the updated equipment and software. However, the original suite of tests provided sufficient information. Additionally, customers had a manual override option in the event that temperatures rose above the needs for the site during a DR event; however, there is no available log of manual overrides to confirm the extent of this type of activity. One site had an HVAC unit without a PCT. Because the zones are open to each other, an HVAC unit without a PCT could use more power to try and maintain the temperature in the space and thus counteract the savings the other unit may provide. All of these factors contribute to lowering the realization rate of the demand reduction capacity at a site.

Due to the large number of settings tested, it is not possible to identify savings associated with each combination of parameters. In order for only one test to be run for each setting, the baseline conditions must be very stable and repeatable. The typical approach would be to increase the number of sample points in order to account for variability of the load. The temperatures at the thermostats were not stable even when the AC units were operating. Although a temperature rise could be seen in the data during the DR event, it was not possible to quantify the temperature rise in a reliable manner. No customer feedback on comfort level was conducted during the DR testing.

The technology tested in this study can also be used to control HVAC units in other business types.

CONCLUSIONS

The main objectives of the project were to:

1. *Determine whether the PCTs reliably receive the DR signal:* The DR signal was received in approximately 87% of the tests. The WiFi signal is suspect in some of the cases where the signal was not received, which indicates that a strong reliable wireless signal at the PCTs is an important part of the communication chain.
2. *Determine whether the PCTs reduce AC demand when receiving a DR signal:* The PCTs were able to reduce demand after receiving a DR signal. AC demand was reduced when the PCTs received the DR signal and increased the cooling temperature set point above the temperature at the thermostat. Generally, this is the case for properly sized AC units. If the AC unit does not meet the load before the DR signal is received, and if the temperature has drifted above the new set point, then the demand cannot be reduced.
3. *Determine how much AC demand is dropped for each setting tested:* The overall average demand savings across all three sites for all the test days was 3.3 kW during the DR test period which is a 29% savings. There are insufficient data to develop a demand savings estimate for each setting.

The energy savings for the DR events was approximately 25%.

There were many factors influencing the demand savings results. These include communication module firmware issues, manual override of set points during DR tests, occasionally intermittent WiFi at the site, non-optimal test conditions, AC units that were turned off, and AC units that may not be 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 would have on an actual DR event.

This evaluation consisted 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 PCTs responding to a DR request. As with some new technologies, there are compatibility issues that need to be addressed during specification of equipment prior to installation. One of the specifications is that the PCT is not compatible with thermostats using remote temperature sensors.

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

The DR period for AC units should not be set too short or much of the savings will be lost during the period immediately afterward, 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 initiation of DR periods are staggered.

Because these are new technologies, HVAC installation technicians must be trained on how to pair the units with any wireless networks that already exist at customer facilities.

Further study of these installations could be conducted during summer conditions in order to determine how much savings are achievable during conditions similar to actual DR events.

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APPENDIX A – CORONA MAGNOLIA CHARTS

This appendix contains data charts for all the test and comparison days for the Corona Magnolia site.

Figure 9~~Figure 9~~ shows a scatter plot of the Total AC hourly demand versus outdoor temperature. The cooling balance point temperature is projected to be approximately 45°F.

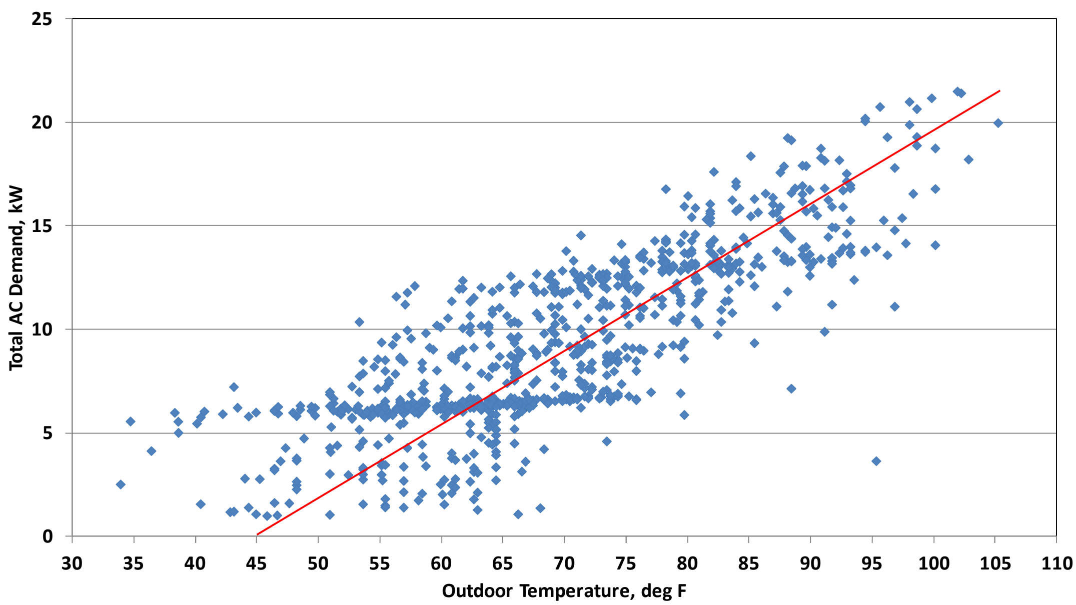

FIGURE 9. SCATTER PLOT OF TOTAL AC DEMAND VS. OUTDOOR TEMPERATURE, CORONA MAGNOLIA

Figure 10 shows four charts of the AC loads on test day September 28. The upper left chart shows only the AC demand profile for each of the three AC units. The other three charts on the page show one AC unit per chart and the temperatures associated with that AC unit. The following test day figures follow the same layout.

Figure 11 shows four charts of the AC loads on test day November 2.

Figure 12 shows four charts of the AC loads on test day November 5.

Figure 13 shows four charts of the AC loads on test day November 6.

Figure 14 shows four charts of the AC loads on test day November 7.

Figure 15 shows four charts of the AC loads on test day November 8.

Figure 16 shows four charts of the AC loads on comparison days September 24, October 29, October 31, and November 1.

Figure 17 shows the last chart of the AC loads on a comparison day November 4.

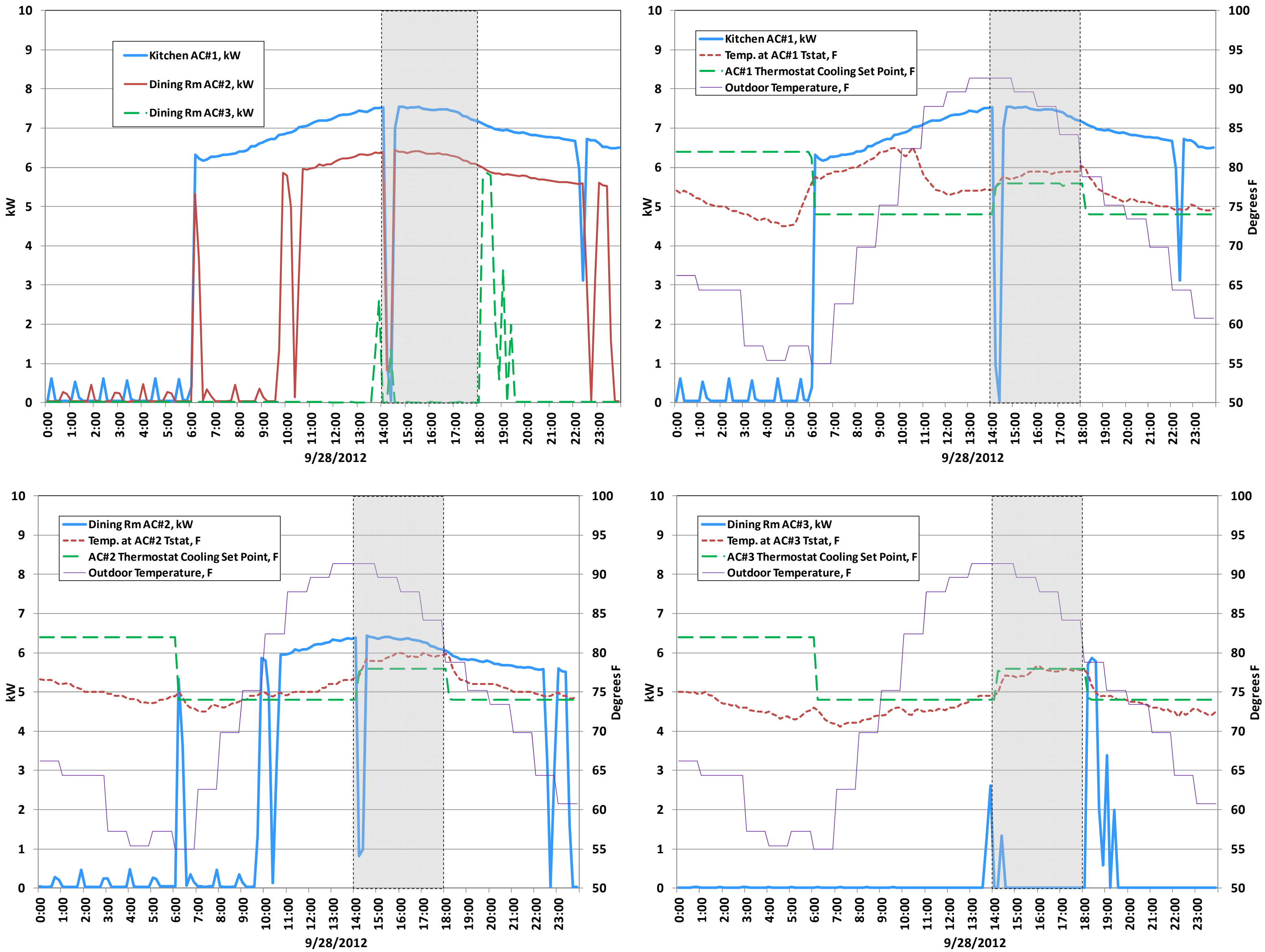

FIGURE 10. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON TEST DAY SEPTEMBER 28

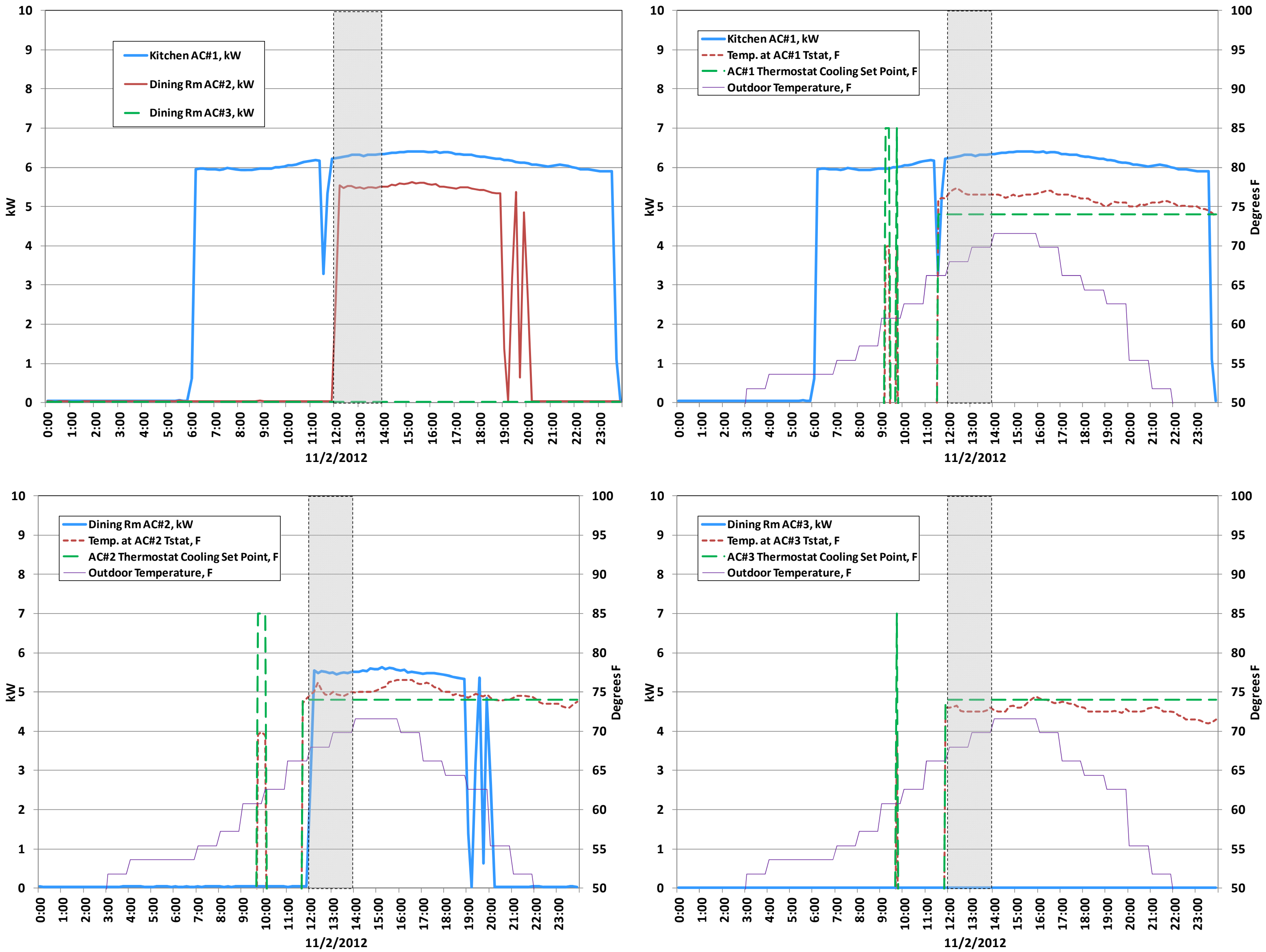

FIGURE 11. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON TEST DAY NOVEMBER 2

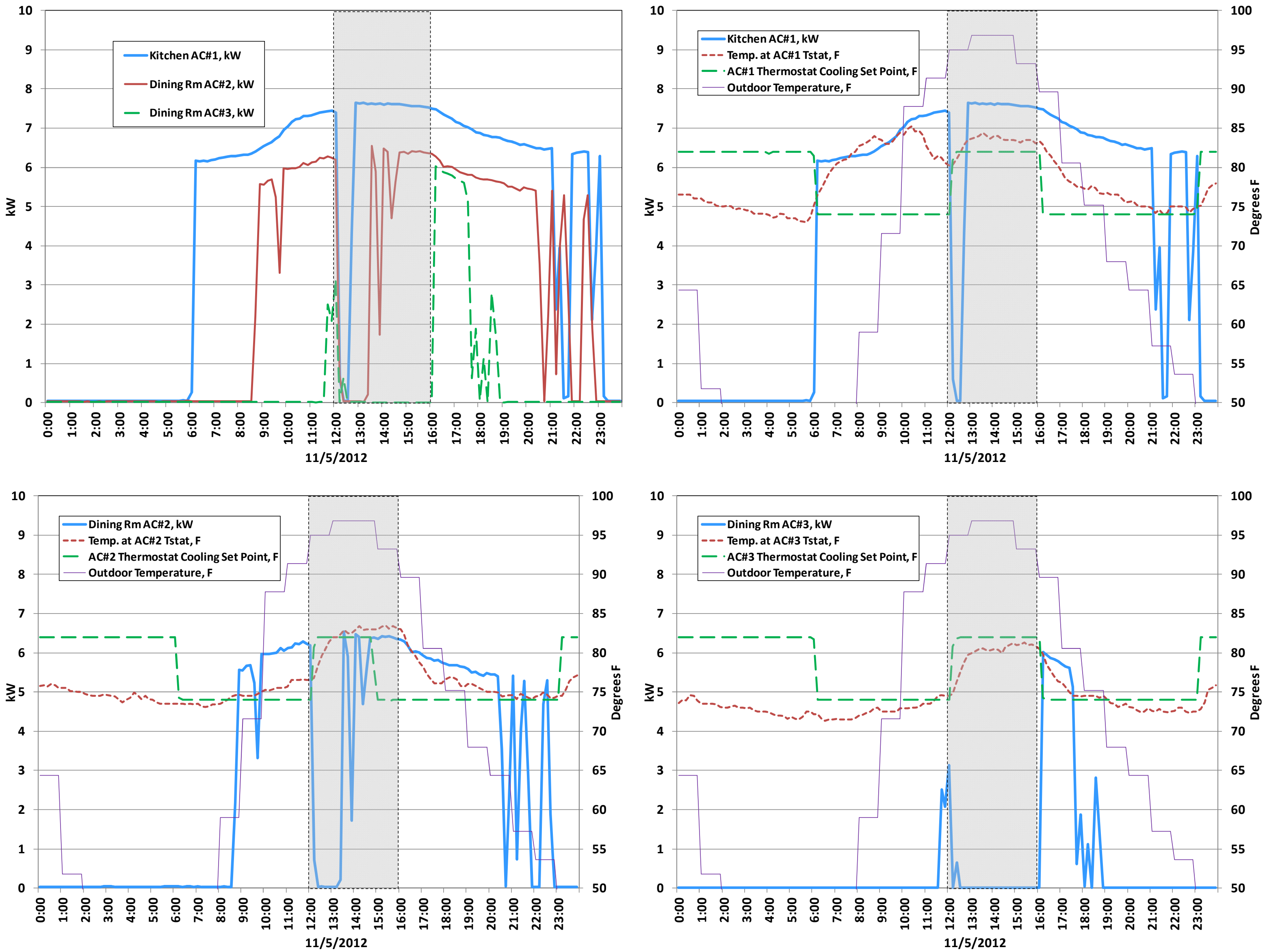

FIGURE 12. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON TEST DAY NOVEMBER 5

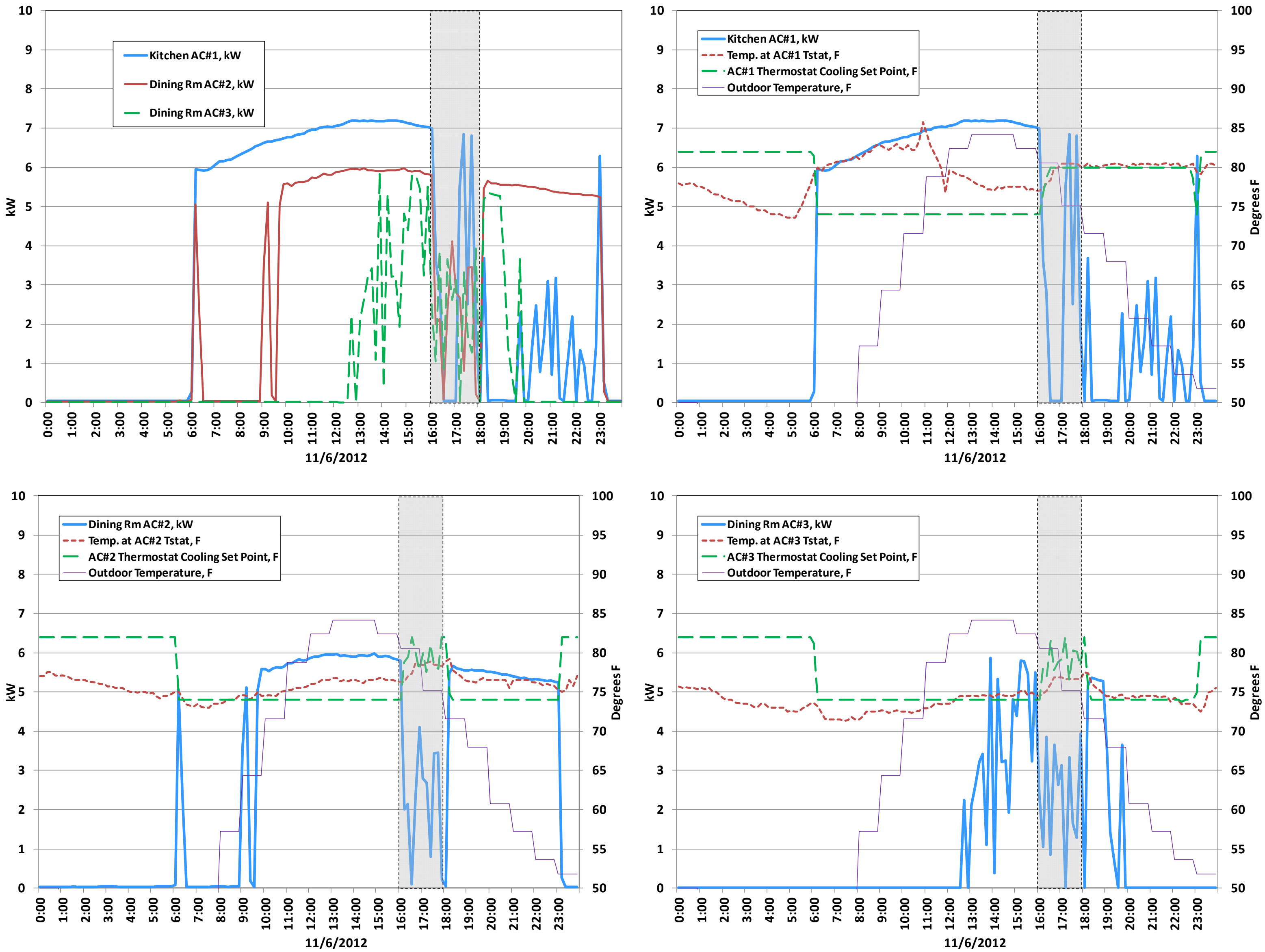

FIGURE 13. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON TEST DAY NOVEMBER 6

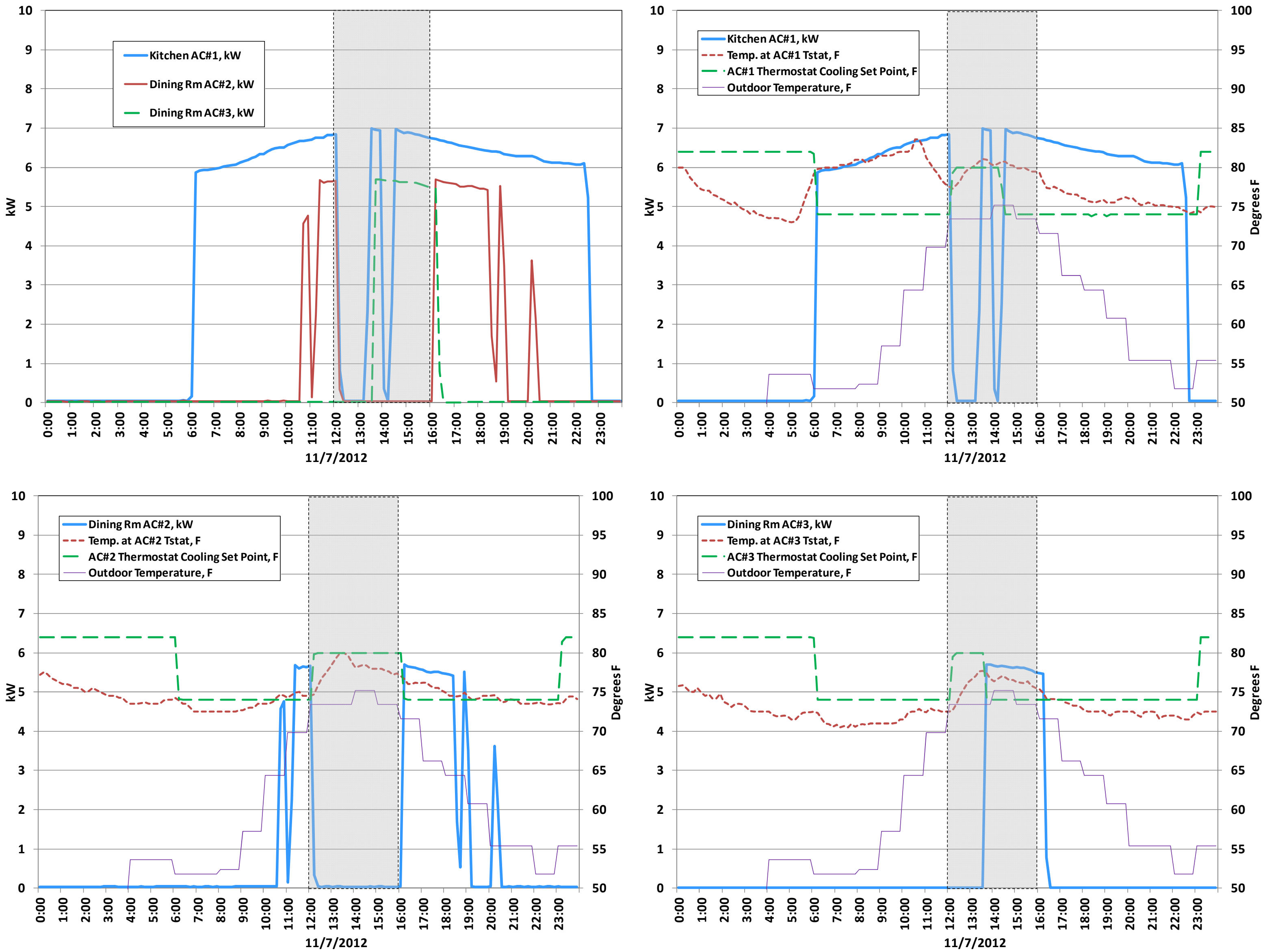

FIGURE 14. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON TEST DAY NOVEMBER 7

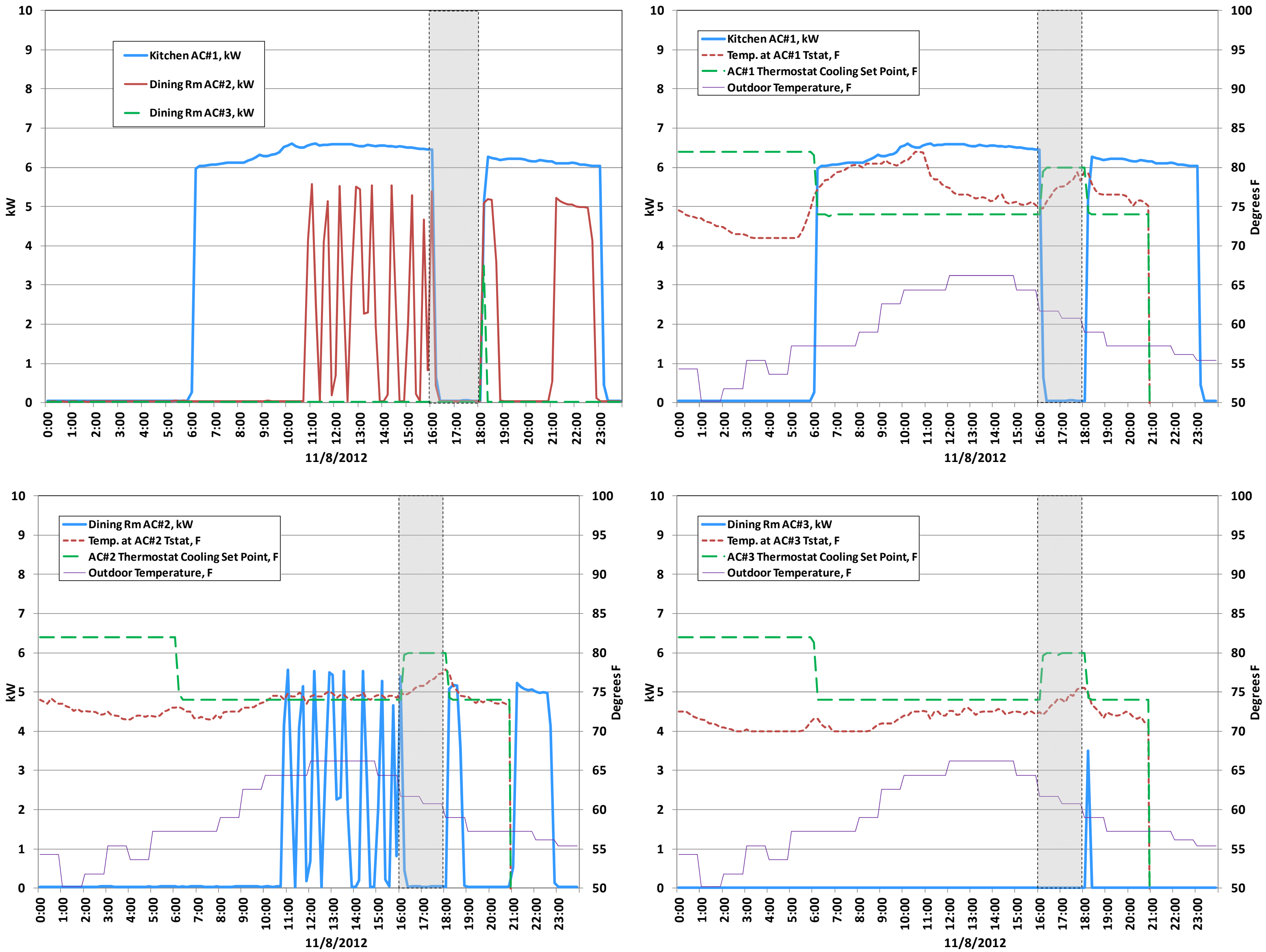

FIGURE 15. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON TEST DAY NOVEMBER 8

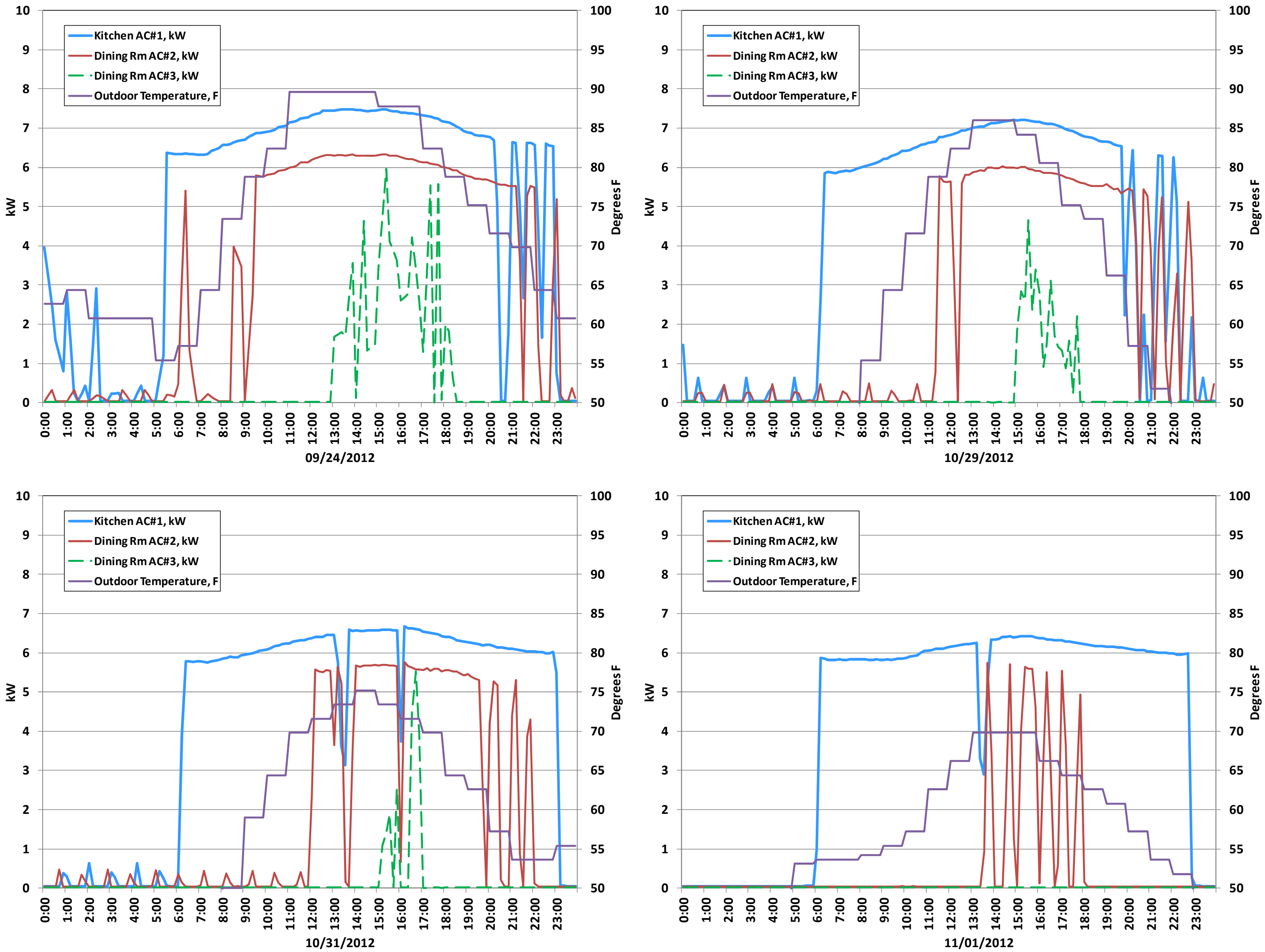

FIGURE 16. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON COMPARISON DAYS

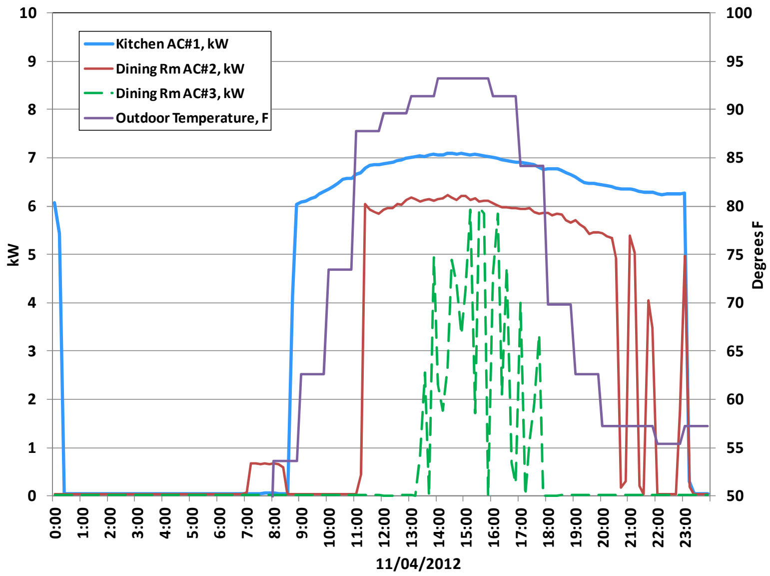

FIGURE 17. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA MAGNOLIA ON COMPARISON DAYS

APPENDIX B – TEMESCAL CANYON CHARTS

This appendix contains data charts for all the test and comparison days for the Corona Temescal Canyon site.

Figure 18~~Figure 18~~ shows a scatter plot of the Total AC hourly demand versus outdoor temperature. The cooling balance point temperature is projected to be approximately 45°F.

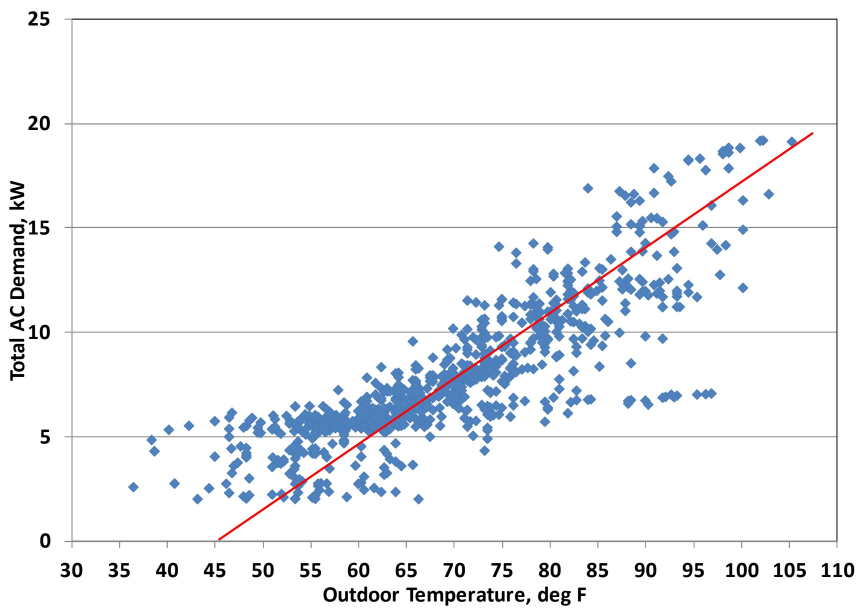

FIGURE 18. SCATTER PLOT OF TOTAL AC DEMAND VS. OUTDOOR TEMPERATURE, CORONA TEMESCAL CANYON

Figure 19 shows four charts of the AC loads on test day September 27. The upper left chart shows only the AC demand profile for each of the three AC units. The other three charts on the page show one AC unit per chart and the temperatures associated with that AC unit. Note that AC#1 does not have a PCT so there are no temperatures to plot. The following test day figures follow the same layout.

Figure 20 shows four charts of the AC loads on test day November 2.

Figure 21 shows four charts of the AC loads on test day November 5.

Figure 22 shows four charts of the AC loads on test day November 6.

Figure 23 shows four charts of the AC loads on test day November 7.

Figure 24 shows four charts of the AC loads on test day November 8.

Figure 25 shows four charts of the AC loads on comparison days September 24, October 29, October 31, and November 1.

Figure 26 shows the last chart of the AC loads on a comparison day November 4.

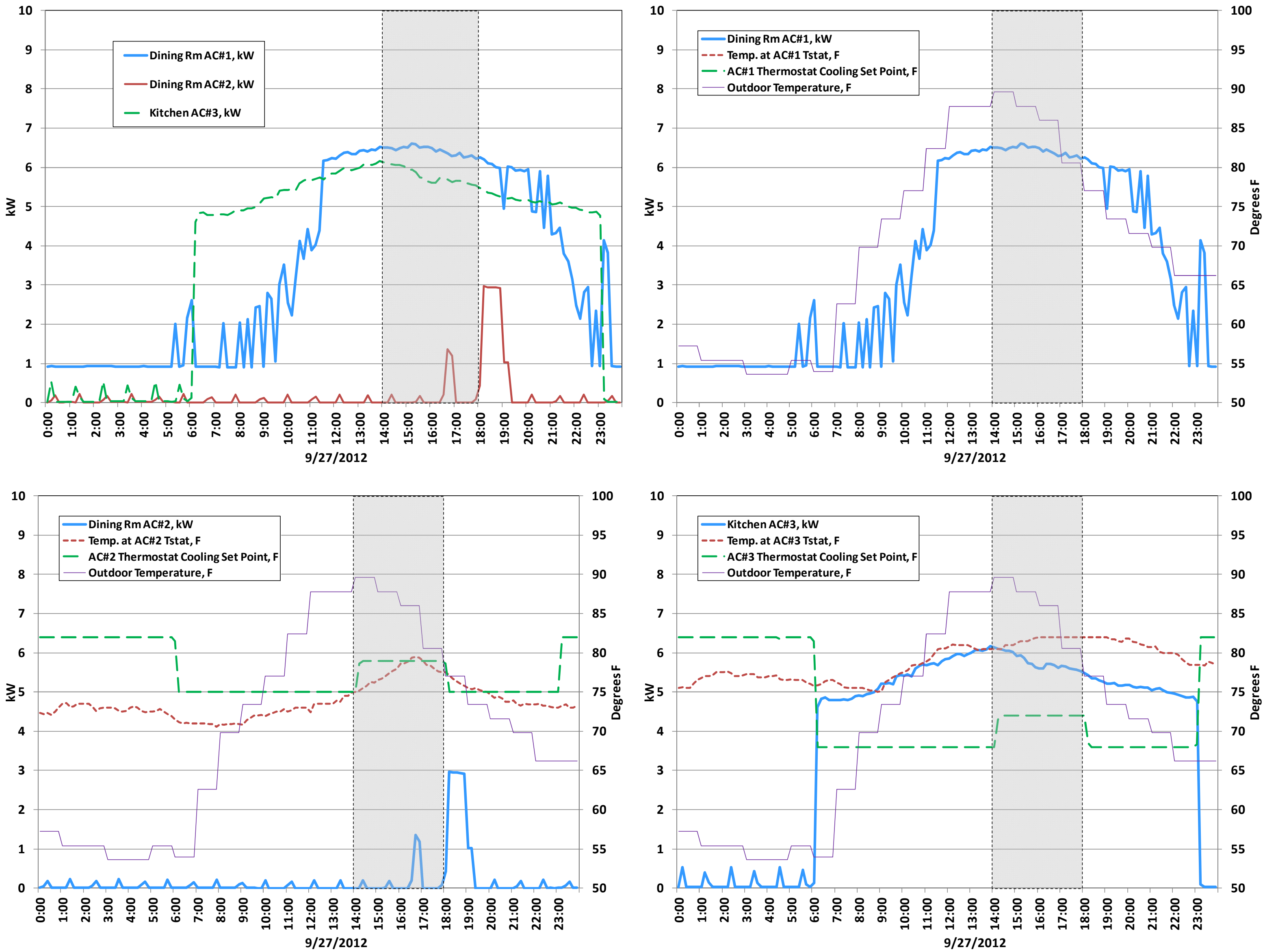

FIGURE 19. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON TEST DAY SEPTEMBER 27

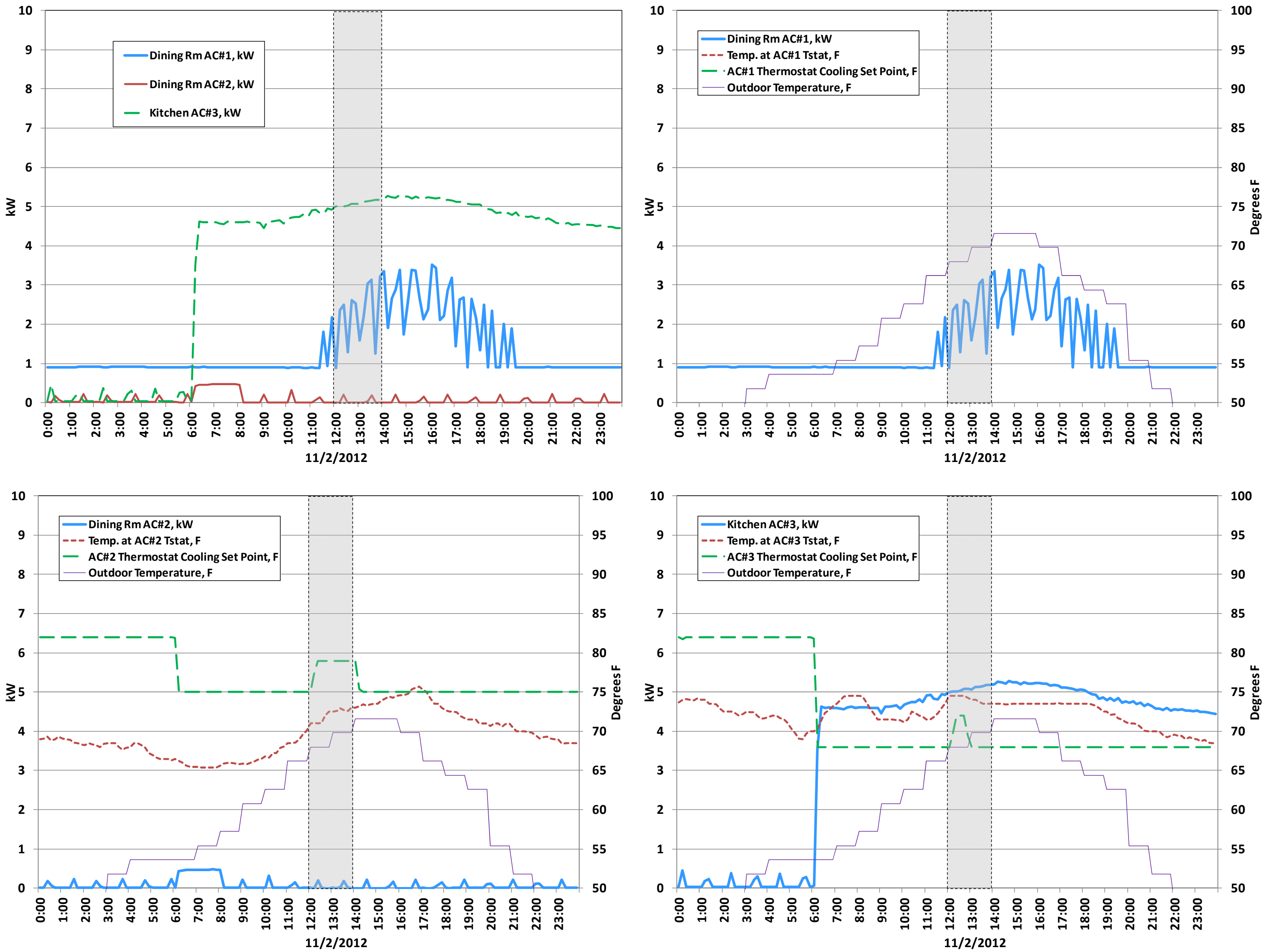

FIGURE 20. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON TEST DAY NOVEMBER 2

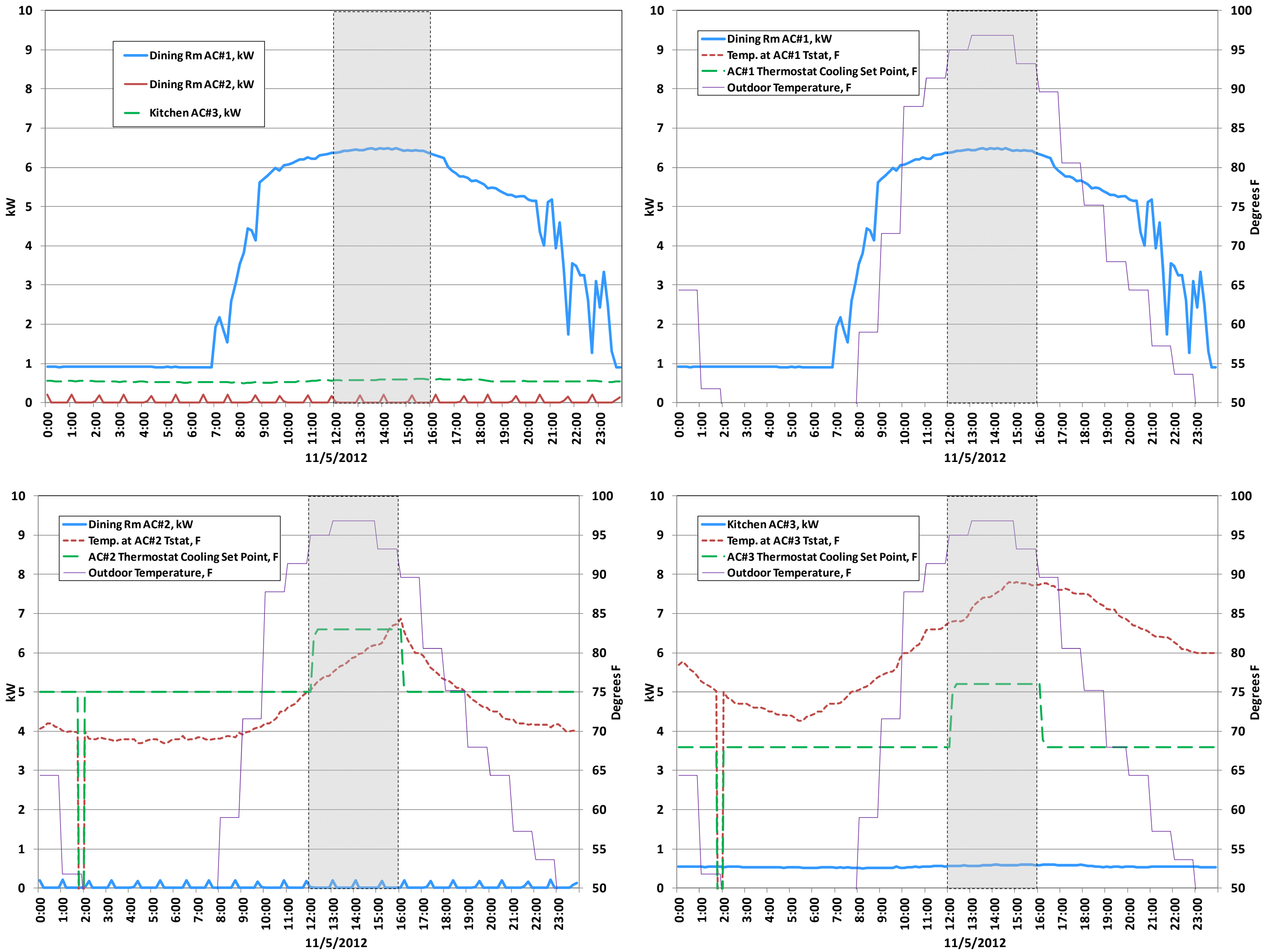

FIGURE 21. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON TEST DAY NOVEMBER 5

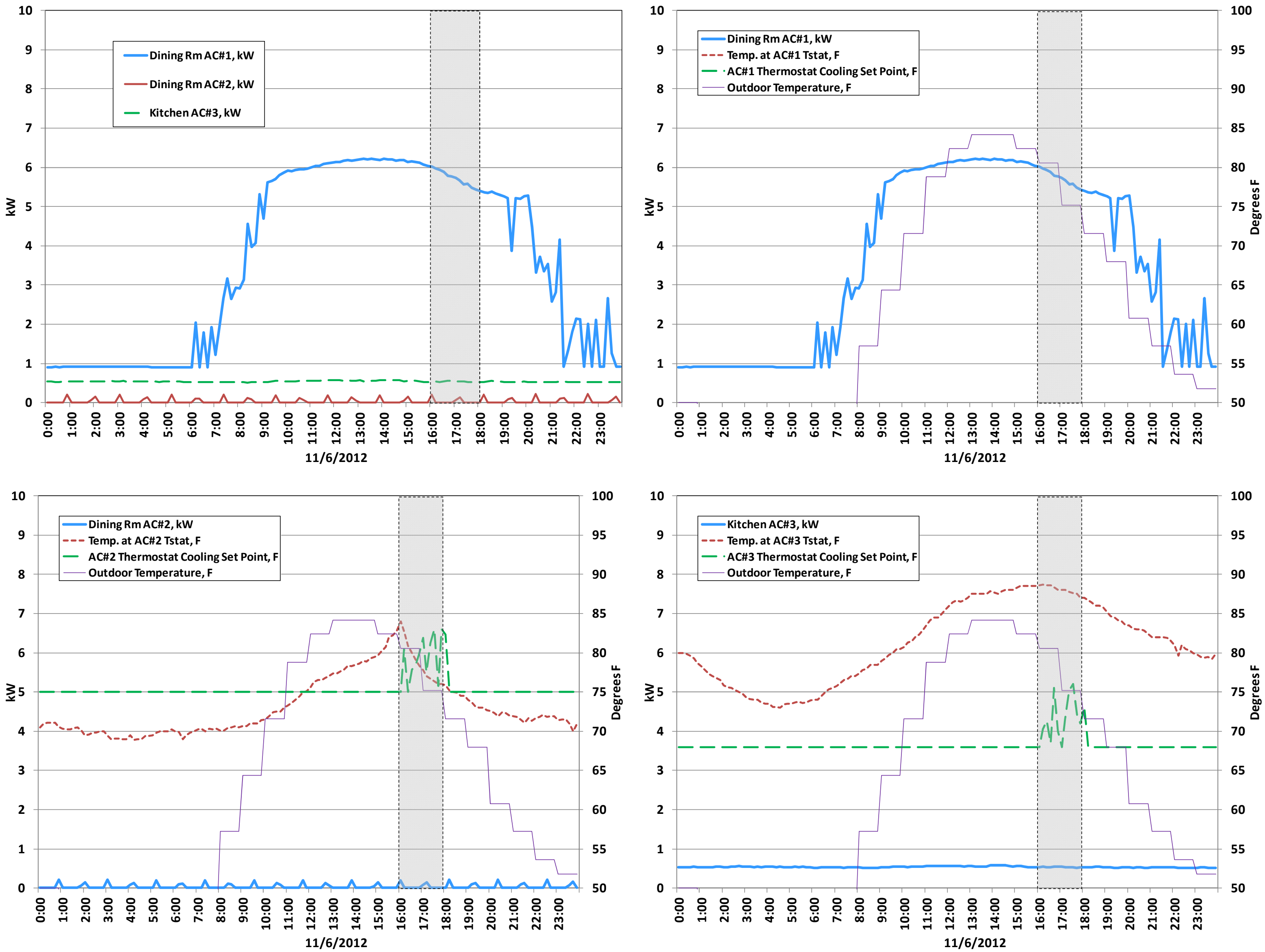

FIGURE 22. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON TEST DAY NOVEMBER 6

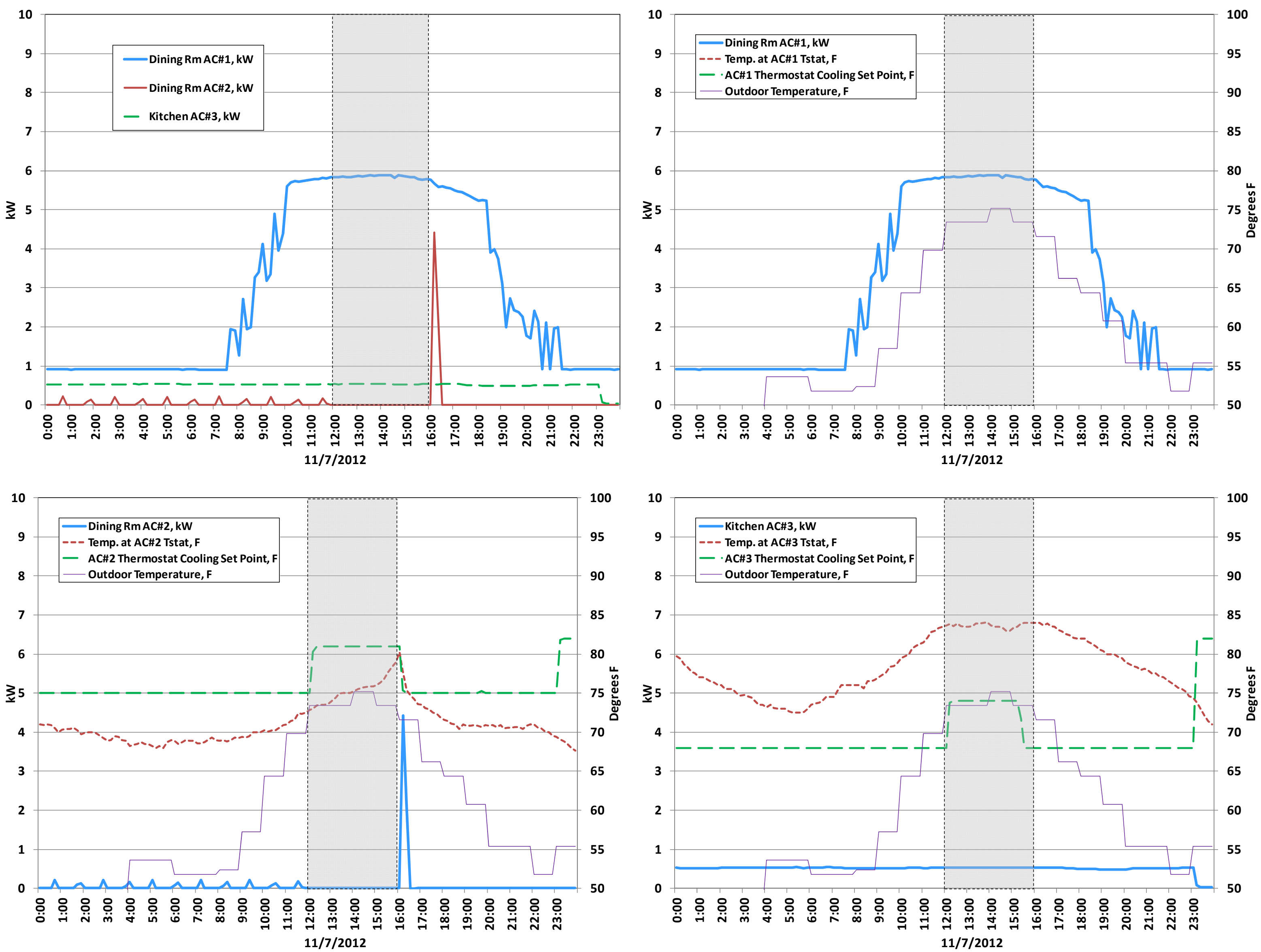

FIGURE 23. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON TEST DAY NOVEMBER 7

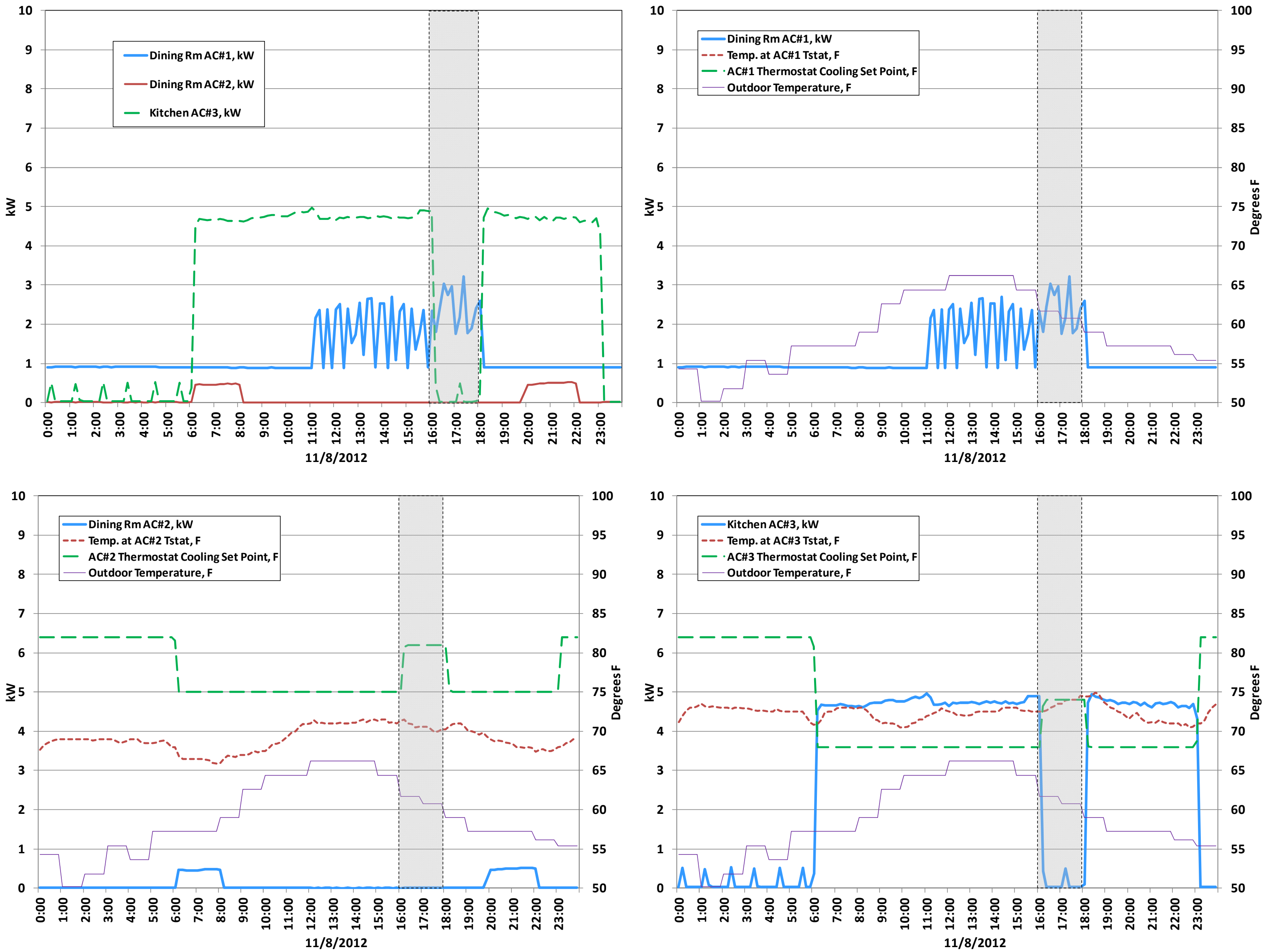

FIGURE 24. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON TEST DAY NOVEMBER 8

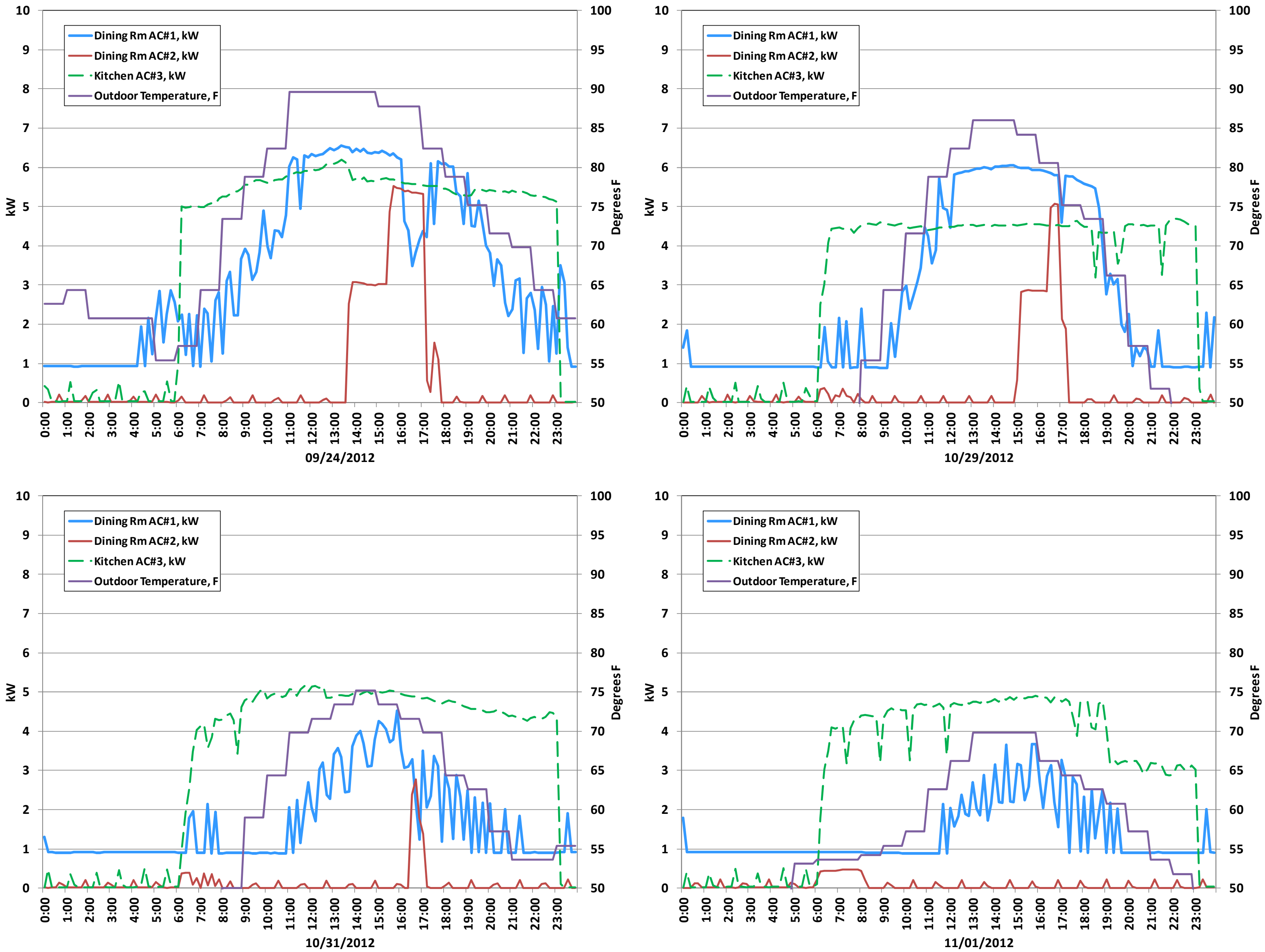

FIGURE 25. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON COMPARISON DAYS

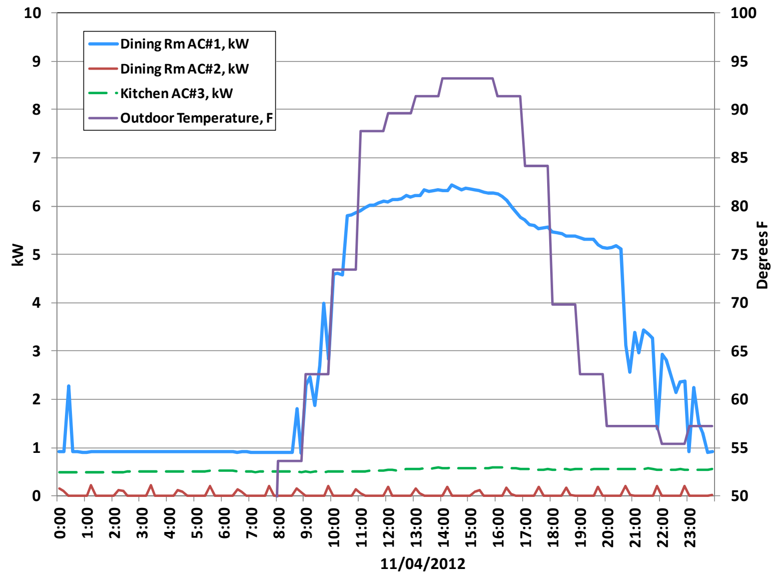

FIGURE 26. CHARTS OF AC DEMAND AND TEMPERATURES FOR CORONA TEMESCAL CANYON ON COMPARISON DAYS

APPENDIX C – RANCHO CUCAMONGA CHARTS

This appendix contains data charts for all the test and comparison days for the Rancho Cucamonga site.

Figure 27 shows a scatter plot of the Total AC hourly demand versus outdoor temperature. The cooling balance point temperature is projected to be approximately 50°F.

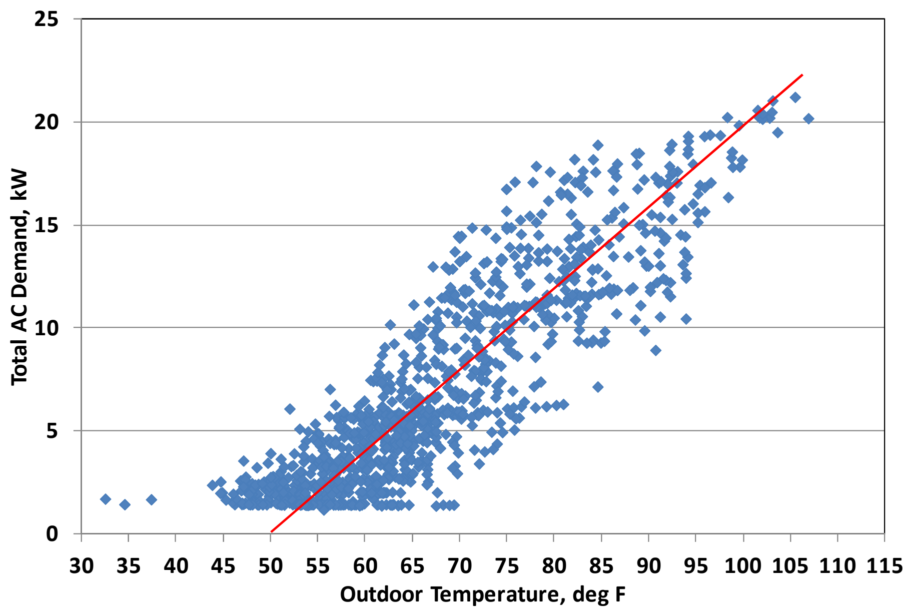

FIGURE 27. SCATTER PLOT OF TOTAL AC DEMAND VS. OUTDOOR TEMPERATURE, RANCHO CUCAMONGA

Figure 28 shows four charts of the AC loads on test day November 2. The upper left chart shows only the AC demand profile for each of the three AC units. The other three charts on the page show one AC unit per chart and the temperatures associated with that AC unit. The following test day figures follow the same layout.

Figure 29 shows four charts of the AC loads on test day November 5.

Figure 30 shows four charts of the AC loads on test day November 6.

Figure 31 shows four charts of the AC loads on test day November 7.

Figure 32 shows four charts of the AC loads on test day November 8.

Figure 33 shows four charts of the AC loads on comparison days October 29, October 31, November 1, and November 4.

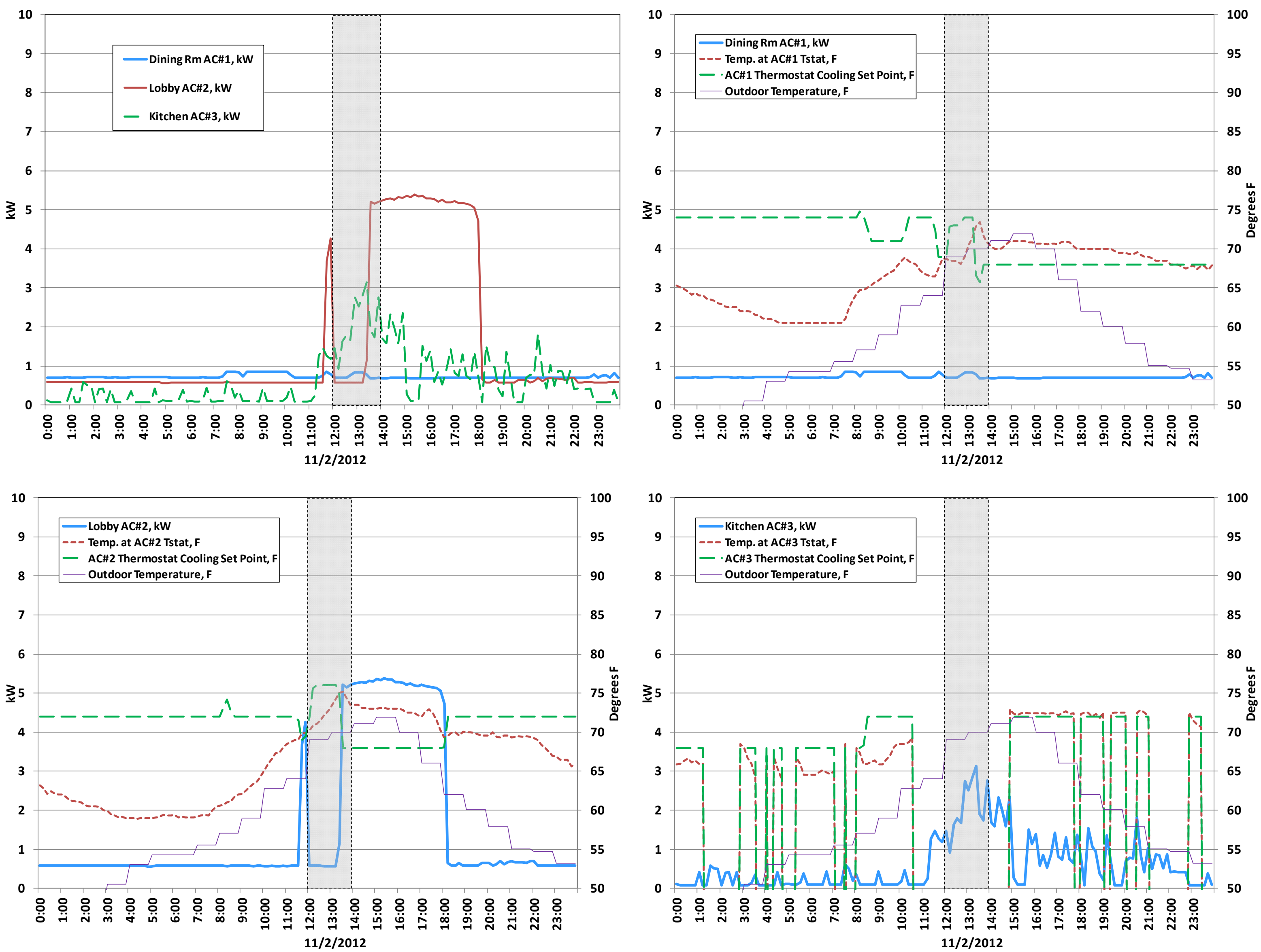

Figure 28. Charts of AC Demand and Temperatures for Rancho Cucamonga on Test Day November 2

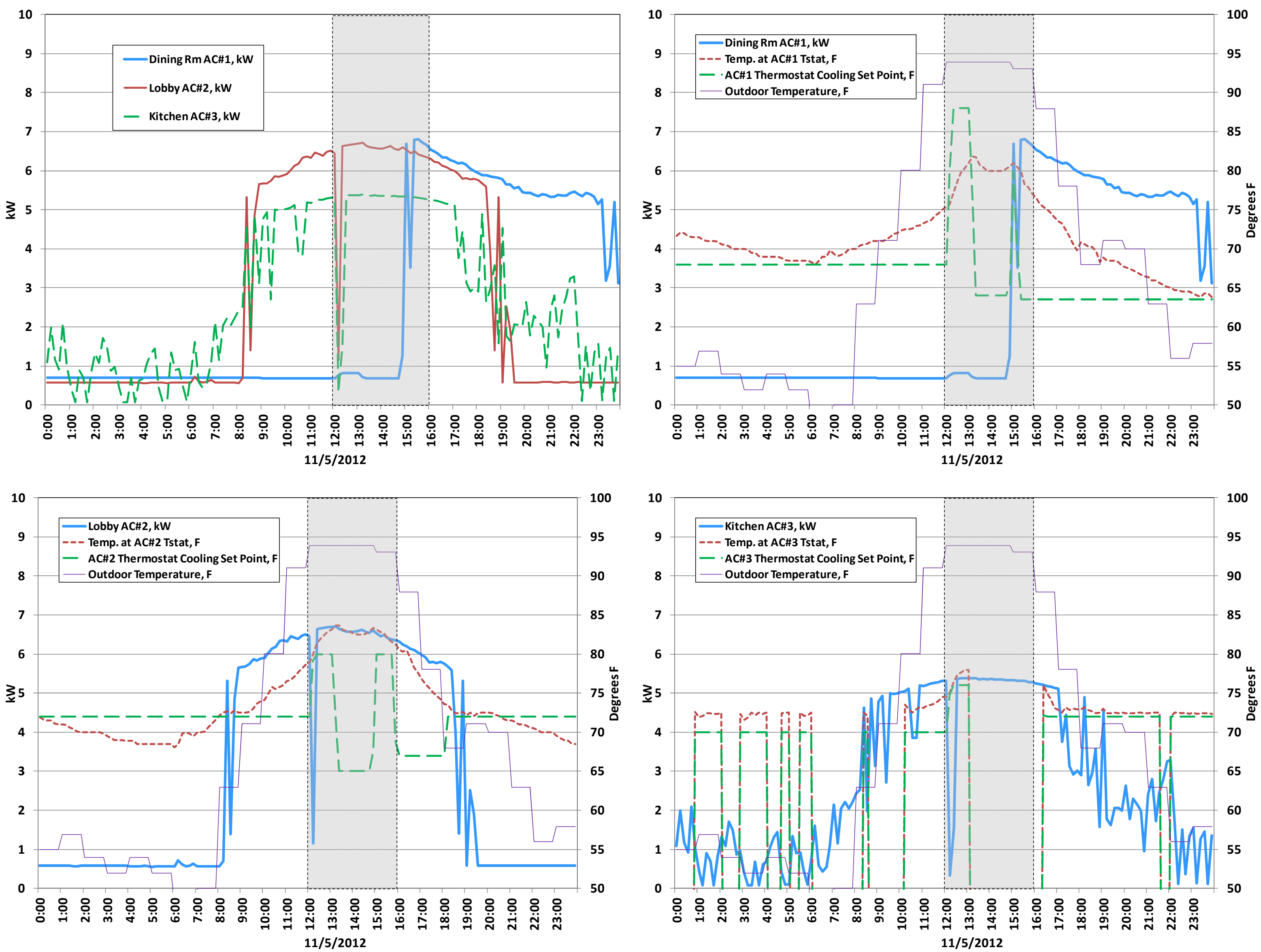

FIGURE 29. CHARTS OF AC DEMAND AND TEMPERATURES FOR RANCHO CUCAMONGA ON TEST DAY NOVEMBER 5

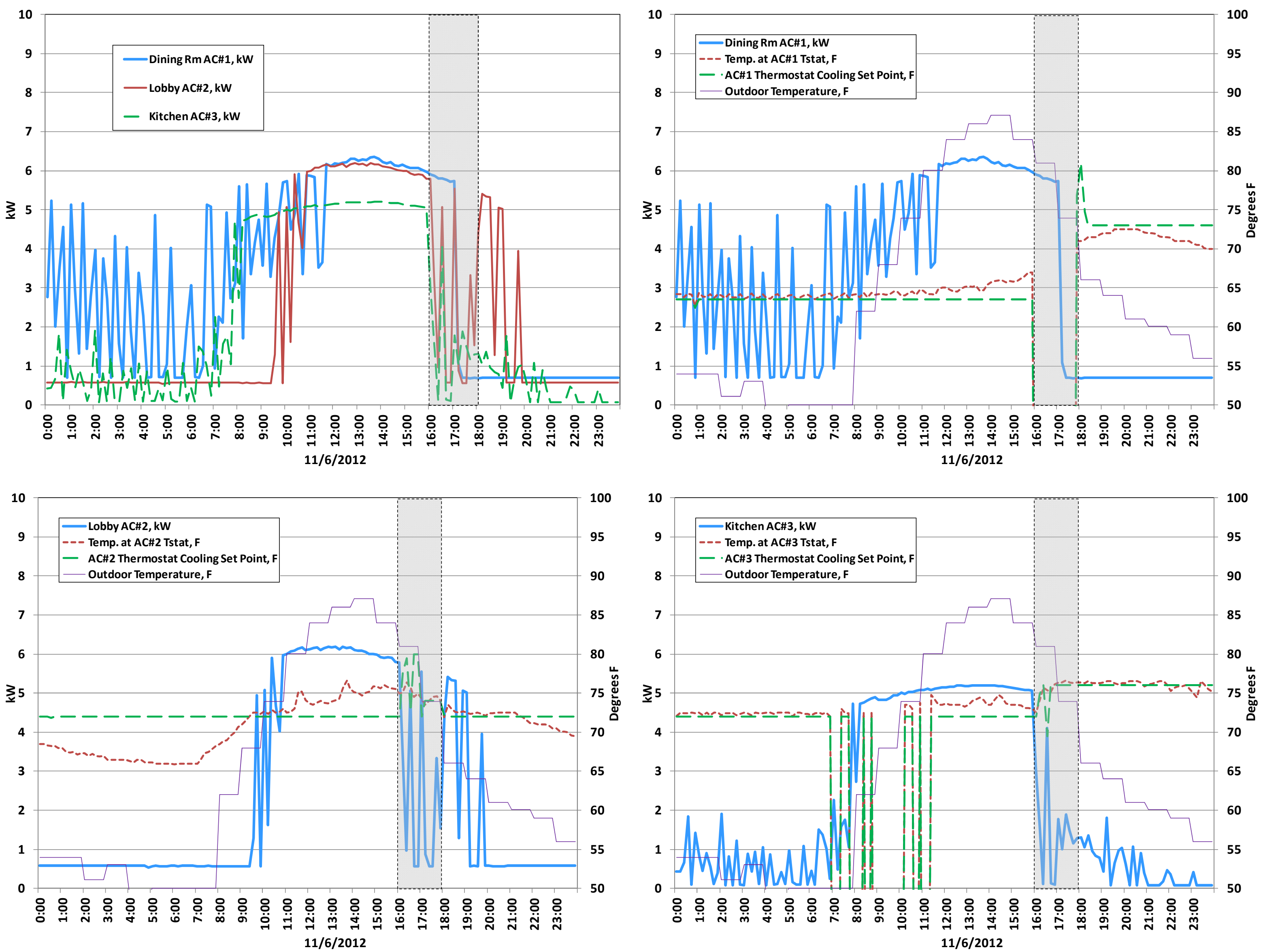

FIGURE 30. CHARTS OF AC DEMAND AND TEMPERATURES FOR RANCHO CUCAMONGA ON TEST DAY NOVEMBER 6

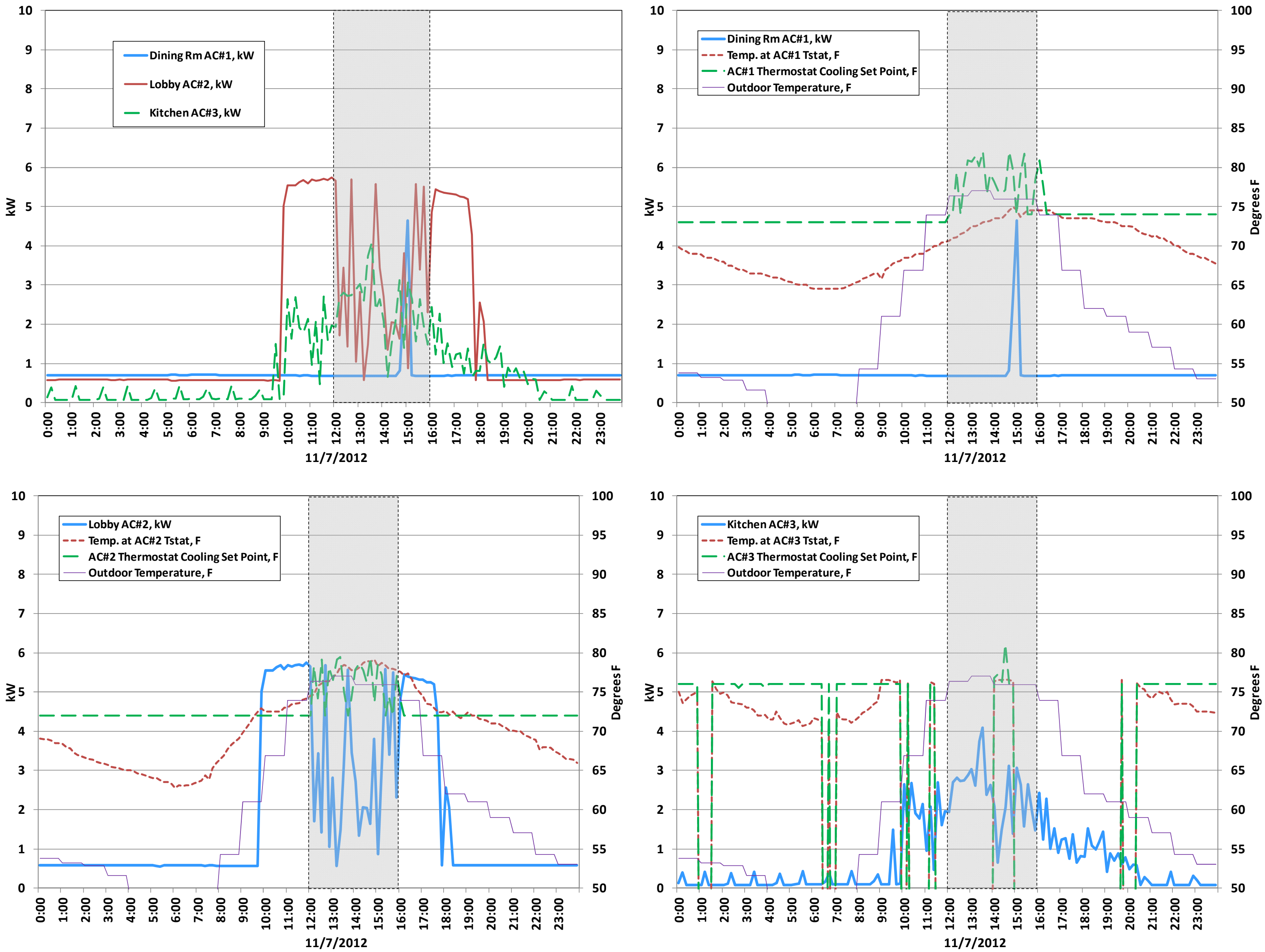

FIGURE 31. CHARTS OF AC DEMAND AND TEMPERATURES FOR RANCHO CUCAMONGA ON TEST DAY NOVEMBER 7

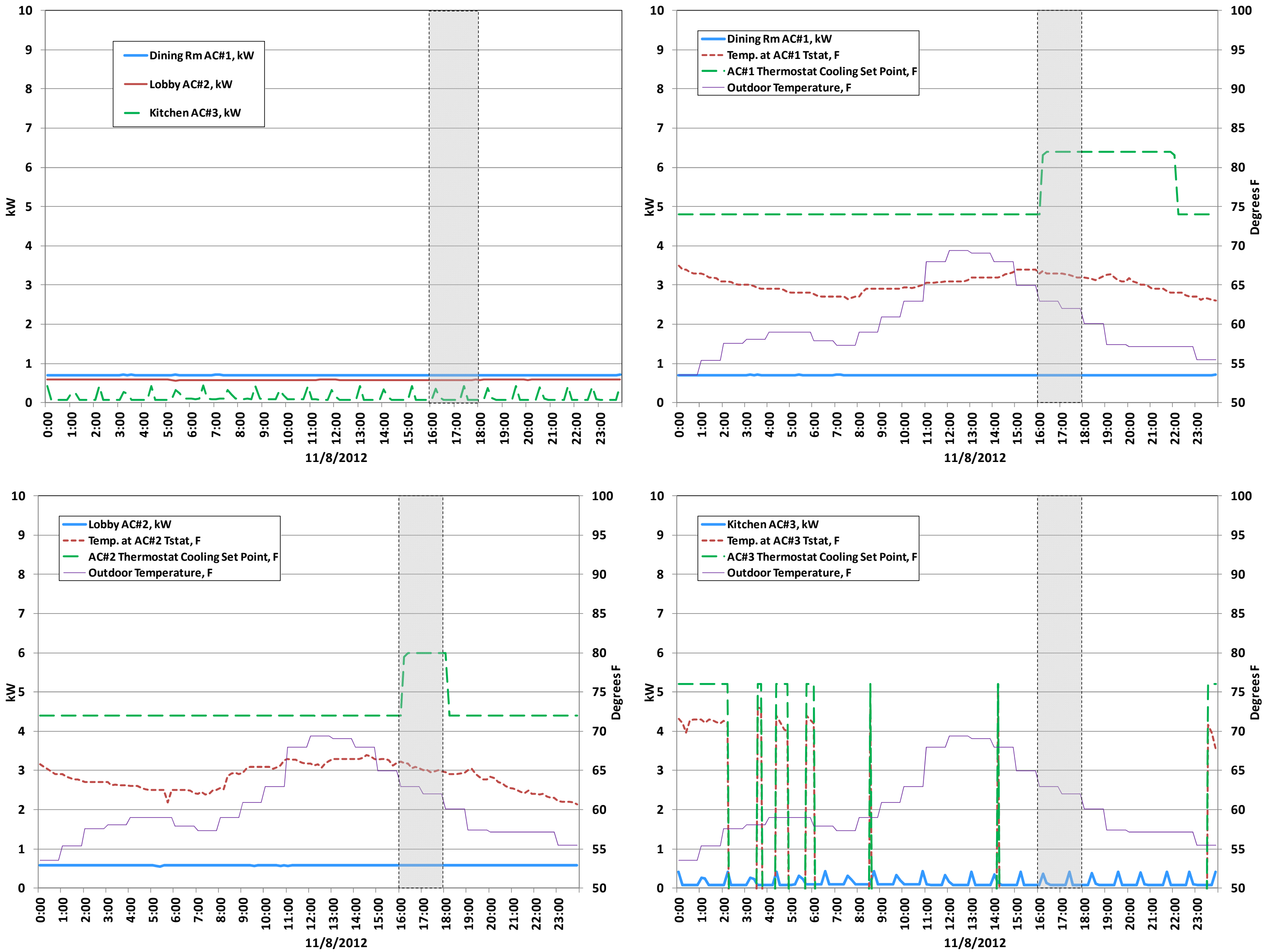

FIGURE 32. CHARTS OF AC DEMAND AND TEMPERATURES FOR RANCHO CUCAMONGA ON TEST DAY NOVEMBER 8

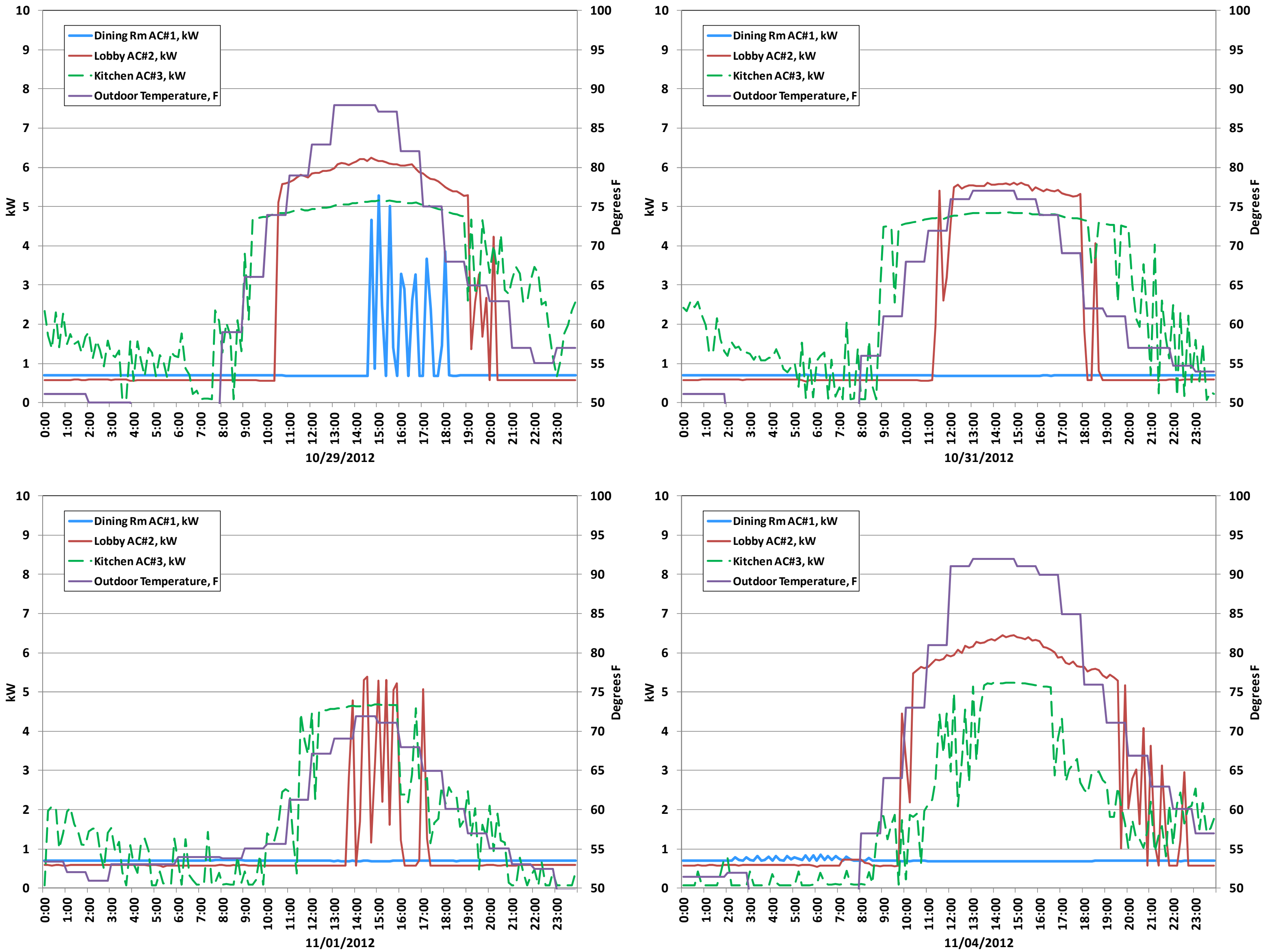

FIGURE 33. CHARTS OF AC DEMAND AND TEMPERATURES FOR RANCHO CUCAMONGA ON COMPARISON DAYS

APPENDIX D – EMBEDDED DATA FILES

Raw and processed data collected for the evaluation of this project can be found in the embedded Excel files. There is one file for each of the three HVAC control sites tested. The files contain the charts used in this report in the event that they need to be reformatted.

CJMG ACall.xlsx CJRC ACall.xlsx CJTC ACall.xlsx