Laboratory Assessment of Demand Response Rooftop Unit (RTU) Controller

DR16.05 Report

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Acknowledgments

Southern California Edison's (SCE) Emerging Products (EP) group is responsible for this project. It was developed as part of SCE's Demand Response (DR) Program, under internal project number DR16.05. Rafik Sarhadian conducted this technology evaluation, with overall guidance and management from Jerine Ahmed. In addition, Bruce Coburn, Albert Nowakowski, and Alvaro Mendoza contributed tremendously with the test setup and data collection phase. Contact rafik.sarhadian@sce.com for more information on this project.

EXECUTIVE SUMMARY

The majority of California's electrical power demand and energy consumption is due to residential and commercial unitary air conditioners (A/Cs). The growing need for electrical power demand can have an adverse impact in grid reliability, especially when there is not enough electricity generation, and can result in power outages. To prevent such instances, utilities offer their customers economic incentives to reduce power demand and usage at certain times of day under DR programs. However, to fully take advantage of these programs, consumers need access to equipment and appliances that enable communication of rates and grid conditions, and offer integrated control capabilities to respond to the information received. These DR capabilities can be achieved either at the factory level, or by retrofitting and installing add-on devices to the existing equipment.

This laboratory project was initiated to evaluate the DR capabilities of an add-on retrofit controller on a five-ton rooftop unit. To communicate with the controller using OpenADR 2.0 protocol, the controller vendor chose a third-party central gateway, which received the OpenADR 2.0 signal and transferred that information to the controller, to perform pre-programmed demand-limiting control strategies. The manufacturer's certified contractor installed and set up the controller. The controller was set to vary the frequency from 40 Hertz (Hz) to 60 Hz in cooling mode. When the compressor cycles off, the indoor fan's frequency drops to 20 Hz.

This project was conducted at SCE's Technology Test Center's (TTC) controlled environment test chambers. This particular controller was pre-programmed with strategies to respond to two distinct DR events, namely "high" and "moderate" events. Testing was done to quantify the power demand reductions for each strategy under two indoor and two outdoor climatic conditions. The indoor conditions were Dry-Bulb Temperature (DBT) of 80 degrees Fahrenheit (°F) and Wet-Bulb Temperature (WBT) of 67°F, as well as DBT of 75°F and WBT of 63°F. The outdoor DBTs were 95°F and 105°F. A total of eight tests were conducted.

Results indicated the controller was capable of responding to both moderate and high DR signals through a central gateway. It also confirmed the pre-programmed strategy of the controller for each DR event. Additionally, results indicated that there is a potential for reducing demand. For moderate DR events, the average total power demand was reduced by up to 33%. For high DR events, the average total power can potentially be reduced by 60%. These DR events, however, resulted in a rise in indoor DBT, as expected. For moderate DR events, the rise in indoor DBT was 6°F to 9°F. The rise in indoor DBT was more evident for high DR events, with temperatures ranging between 14°F and 17°F.

Overall, gathered data suggests there is potential to reduce A/C power demand using DR-capable controllers. Thus, such devices are recommended for utility DR program consideration, since they can curtail power demand as needed. Future studies may consider evaluating similar technologies that may have different strategies for each DR event type.

ABBREVIATIONS AND ACRONYMS

A/C	Air Conditioner
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CS	Codes and Standards
DBT	Dry-Bulb Temperature
DR	Demand Response
EE	Energy Efficiency
FDD	Fault Detection and Diagnostic
Hz	Hertz
HTTC	HVAC Technology Test Center
HVAC	Heating, Ventilation, and Air Conditioning
IDSM	Integrated Demand-Side Management
kW	Kilowatt
NIST	National Institute of Standards and Technology
RTU	Rooftop Unit
SCE	Southern California Edison
SCFM	Standard Cubic Feet per Minute
SEER	Seasonal Energy Efficiency Ratio
TTC	Technology Test Centers
TXV	Thermostatic Expansion Valve
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
WBT	Wet-Bulb Temperature

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INTRODUCTION

Residential and commercial unitary A/Cs are one of the major sources of the growing electrical energy use and peak power demand in California.[1] For instance, in 2006, residential A/Cs accounted for about 24% of the peak power demand.[2] A large percentage of the A/Cs found in California's small- or light-commercial sector are packaged RTUs, with cooling capacities ranging between five and 10 tons. One of the most common A/C units within this capacity range is a five-ton packaged RTU.[3]

The growing need for electrical power demand can have an adverse impact in grid reliability when there is not enough electricity generation, and may trigger blackouts. To prevent such instances, utilities offer their customers economic incentives to reduce power demand and usage at certain times of day under DR programs. In essence, DR is a way for customers to reduce and manage their electricity consumption or power demand at certain times in a given day, while receiving economic benefits. To take full advantage of DR programs, however, consumers need access to equipment and appliances that enable communication of rates and grid conditions, and offer integrated control capabilities to respond to the information received. These DR capabilities can be achieved either at the factory level or by retrofitting and installing add-on devices to existing equipment.

This laboratory project evaluated the DR capabilities of an add-on retrofit controller for a five-ton RTU. This project was conducted at SCE's TTC controlled environment test chambers, which are described in Appendix A. The controller under test is also a Variable Frequency Drive (VFD) A/C controller, which modulates the speed of the A/C compressor and indoor fan simultaneously, according to cooling load requirements. This controller feature had been tested previously at the TTC.

The controller was pre-programmed with strategies to respond to two distinct DR events ("high" and "moderate"). Testing was done to quantify the power and energy reductions for each strategy under two indoor and two outdoor climatic conditions. The indoor conditions were DBT of 80 degrees Fahrenheit (°F) and WBT of 67°F, as well as DBT of 75°F and WBT of 63°F. The outdoor DBTs were 95°F and 105°F. A total of eight tests were run.

This laboratory assessment project quantified the Energy Efficiency (EE) benefits of a technology intended to match the cooling capacity of the A/C with the cooling load in the conditioned space. The technology under evaluation is an add-on VFD controller for commercial applications, which varies the frequency (and therefore the speed) of the compressor and indoor fan, to align the A/C capacity with the load in the conditioned space. The project compared the performance of a five-ton RTU with and without this VFD under controlled laboratory conditions at SCE's TTC controlled environment chambers, which are described in Appendix A. A total of 32 tests were run to reflect various cooling loads, outdoor ambient conditions, and indoor conditions.

ASSESSMENT OBJECTIVES

The primary objective of this laboratory assessment project was to establish the power demand impacts of two distinct DR events for a five-ton RTU. The power demand implications were obtained and evaluated for two outdoor and two indoor conditions.

TECHNOLOGY EVALUATION

The technology evaluated in this laboratory assessment project is an add-on VFD controller with embedded DR capabilities for A/Cs. To communicate with the controller using OpenADR 2.0 protocol, the controller vendor chose a third-party central gateway, which received the OpenADR 2.0 utility signal and transferred that information to the VFD controller, to perform demand-limiting control. For the most part, current models of this technology are designed for commercial A/Cs, and are not suitable for residential units.

Under normal operations, the controller modulates the speed of the A/C compressor and indoor fan simultaneously, according to the cooling load or thermostat setting. As part of the DR strategy, however, the controller modulates the speed of the compressor and indoor fan according to the DR signal. The controller's DR strategies for moderate and high event signals are:

- **Moderate Event (or low-load event):** limit the speed of the A/C compressor and indoor fan to no higher than 42 Hertz (Hz).
- **High Event (or high-load event):** run the A/C compressor and indoor fan at 40Hz for about nine minutes, then shut off the compressor for about six minutes. When the compressor is off, the indoor fan runs at 20Hz.

Figure 1 shows the VFD controller installed on the five-ton RTU, which represents the capacity of a typical A/C found in the field. It is a standard-efficiency heat pump unit. The test unit uses R-410A refrigerant and a Thermostatic Expansion Valve (TXV).

FIGURE 1. VARIABLE FREQUENCY DRIVE (LEFT) AND CONTROLLER (RIGHT)

The main components of this technology are a controller, programmable thermostat, supply and outside air temperature probe, return air carbon dioxide (CO_2) sensor, and the VFD. While the technology offers various control capabilities, this study focused mainly on the cooling mode. Its cooling control logic can turn on and simultaneously vary the frequency, and therefore speed, of both the compressor and indoor fan, to maintain the target thermostatic set point.

In general and under normal operation, the controller can vary the frequency from 40Hz to 60Hz. When there is no call for cooling or heating, the indoor fan is set to operate at the minimum frequency of 20Hz. Based on the measured return air CO_2 levels, however, the indoor fan speed, along with the outside air damper, can be adjusted to maintain the required CO_2 levels of 800 – 1,000 parts-per-million, as set by national standards.

For this project, the manufacturer's certified contractor installed and set up the controller, which was capable of responding to high and moderate DR events. The evaluation captured key data points for a five-ton RTU operating under two sets of indoor and two sets of outdoor DBTs, before and after initiating DR events within the TTC's environment test chambers. This enabled tight control and maintenance of key test parameters. After data collection was completed, the performance data of the RTU before and after each DR event was compared, to evaluate the response of the technology to DR signals, and to quantify the power demand reductions for each test scenario.

TEST DESIGN

This section provides information on the test unit and protocols. It also addresses the testing performed, and key monitoring points.

TEST UNIT

The test unit was a standard-efficiency heat pump (13 SEER), five-ton nominal RTU (Figure 2). It used R-410A refrigerant and a TXV. The original test unit was equipped with a single-phase scroll compressor. However, since the VFD controller was capable of modulating the speed of a three-phase compressor, the original compressor was changed to a three-phase unit, with the same cooling capacity.

FIGURE 2. TEST UNIT (5-TON RTU)

TEST METHODOLOGY

For all tests, cooling capacities and performance characteristics were determined in accordance with the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standard 210/240.[4] This standard adopts Test Standard 37, developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).[5]

Instrumentation was installed at locations required by test procedures, and measurements were taken as follows:

- The air- and refrigerant-enthalpy methods set by the test standards were followed, to measure air and refrigerant properties.
- An airflow measurement apparatus, as specified in the ASHRAE protocols, was used to measure the volumetric airflow rates, in Standard Cubic Feet per Minute (SCFM) across the evaporator coil.
- A Coriolis mass flow meter was installed in the liquid line, to measure refrigerant mass flow rates.

- Electric power and frequency measurements included input to the compressor, condenser, evaporator fan, controls, and other items required as part of the system for normal operation.
- The air and refrigerant properties, flow rates, and total input power data were used to obtain cooling capacities and efficiencies.

TEST SCENARIOS

A set of eight tests was designed, to compare the performance of the five-ton RTU during normal operations and during DR events. The tests were run for two DR signal types: high and moderate events. These tests were done for the following two sets of indoor conditions, at outdoor DBTs of 95°F and 105°F:

Set 1: DBT of 75°F and WBT of 63°F, to characterize a typical temperature setting with a moderate humidity level.

Set 2: DBT of 80°F and WBT of 67°F, to replicate standard A/C rating conditions.

Table 1 summarizes all test scenarios, which were run for the typical DR duration of 60 minutes. For test runs with DBT of 75°F and WBT of 63°F, the imposed cooling load was kept at around 4.2-ton, while for test runs with DBT of 95°F and WBT of 67°F, it was kept at around 4.5-ton. These cooling load values were used to ensure the unit operated at maximum power. To impose the indoor test chamber's cooling load, the air-handling unit's electric heaters were used.

TABLE 1. TEST SCENARIOS

SCENARIOS	OUTDOOR DBT	DR SIGNAL TYPE	DR DURATION	COOLING LOAD
Indoor DBT of 75°F and WBT of 63°F	95°F	Moderate	60 minutes	4.2-ton
	95°F	High	60 minutes	4.2-ton
	105°F	Moderate	60 minutes	4.2-ton
	105°F	High	60 minutes	4.2-ton
Indoor DBT of 80°F and WBT of 67°F	95°F	Moderate	60 minutes	4.5-ton
	95°F	High	60 minutes	4.5-ton
	105°F	Moderate	60 minutes	4.5-ton
	105°F	High	60 minutes	4.5-ton

MONITORING POINTS

The following list includes the core monitoring points. The schematic diagram of all sensor locations used for testing the five-ton packaged RTU is in Appendix B.

- Refrigeration side:
  - Compressor discharge temperature and pressure
  - Compressor suction temperature and pressure
  - Liquid line temperature and pressure before and after the mass flow meter
  - Refrigerant mass flow rate
- Air side:
  - Air DBT and WBT in the supply duct
  - Air DBT and WBT in the return duct
  - Airflow rates across the evaporator coil
  - Air DBT entering the condenser coil
- Indoor test chamber (indoor air) DBT and WBT
- Outdoor test chamber DBT
- Condensate mass
- Electrical data:
  - Compressor power
  - Indoor fan power
  - Condenser fan power
  - Total unit power, amperage, and voltage

DATA ACQUISITION

National Instruments' SCXI data acquisition system was used to log test data. The data acquisition system was set up to scan and log 79 data channels in 20-second intervals.

Screening the collected data ensured the key control parameters were within the acceptable ranges. When any of the control parameters fell outside the acceptable limits, a series of diagnostic inspections was carried out. Corrections were then made and tests were repeated, as necessary.

After the data passed the initial screening process, it was imported to a customized refrigeration analysis model that enabled detailed calculations to be performed. Appendix B provides a comparative list of the specifications required by the ASHRAE standard, and the specifications for the instruments used in this project.

RESULTS

This section presents key results of testing a DR-capable controller for A/Cs. The results include 20-second power profiles, as well as indoor DBT before and during each DR event, at two outdoor and two indoor DBTs.

INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 95°F

Figure 3 depicts 20-second power profiles before and during a moderate DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 95°F. The power profiles are for indoor fan, outdoor fan (condenser fan), compressor, and total unit. The event duration was 60 minutes, and it is marked in Figure 3. Clearly, the compressor was the main contributor to total power. During normal operation (prior to a DR event), the system was running at full speed, or 60Hz. During this period, the total power was around 5.4 kilowatts (kW). When the event was initiated, however, the controller unexpectedly shut the unit off for about three minutes, then ramped up the speed (or frequency) to 40Hz, and stayed there until the end of the event. During the event, the total power was dropped from 5.4 kW to 3.6 kW, which is a 33% reduction in power. Once the event ended, the unit operated normally.

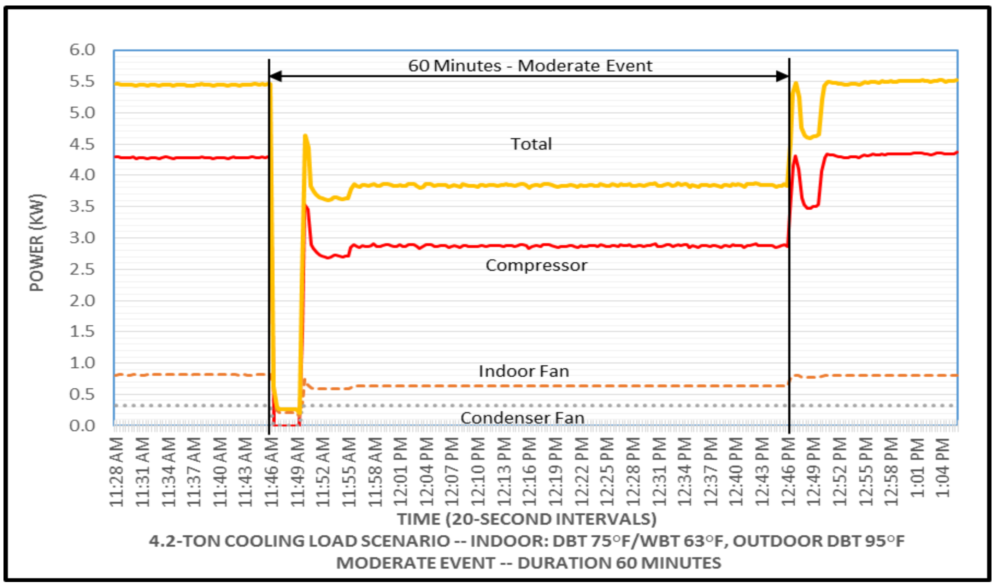

FIGURE 3. 20-SECOND POWER PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 95°F

Figure 4 shows 20-second total power and indoor DBT profiles before and during a moderate DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 95°F. Figure 4 shows that before the event, the indoor DBT was 75°F. Once the event started, however, the indoor DBT started to rise, and by the end of the event, it was about 82°F. This 7°F increase in DBT was due to running the unit at low speed, causing a reduction in the unit's cooling capacity.

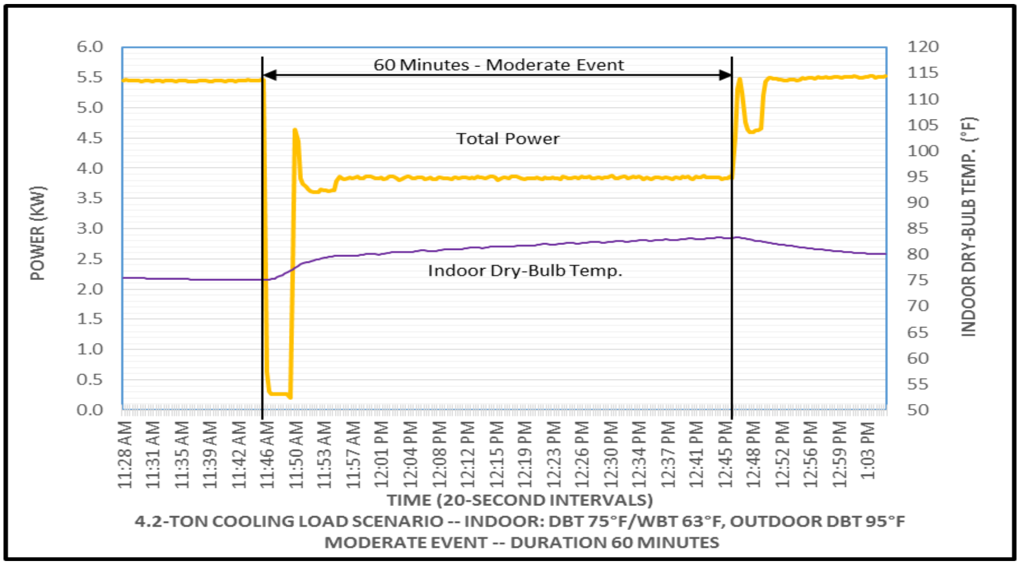

FIGURE 4. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 95°F

Figure 5 shows the 20-second power profiles before and during a high DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 95°F. Prior to the event (normal operation), the unit ran at full speed (60Hz) with an average total power of 5.5 kW. Once the event was initiated, the controller shut the compressor off for six minutes, then ran it for nine minutes at 40Hz before shutting it off again, as intended (the controller cycled the compressor on and off during a 15-minute interval). This cycle continued until the end of the event. When the compressor was operating, the total power was around 3.6 kW. Averaging the total power during a 15-minute or 60-minute interval, however, resulted in an average total power of 2.2 kW. In other words, the average total power dropped from 5.5 kW to 2.2 kW, which is a 60% reduction in power. Once the event ended, the unit operated normally.

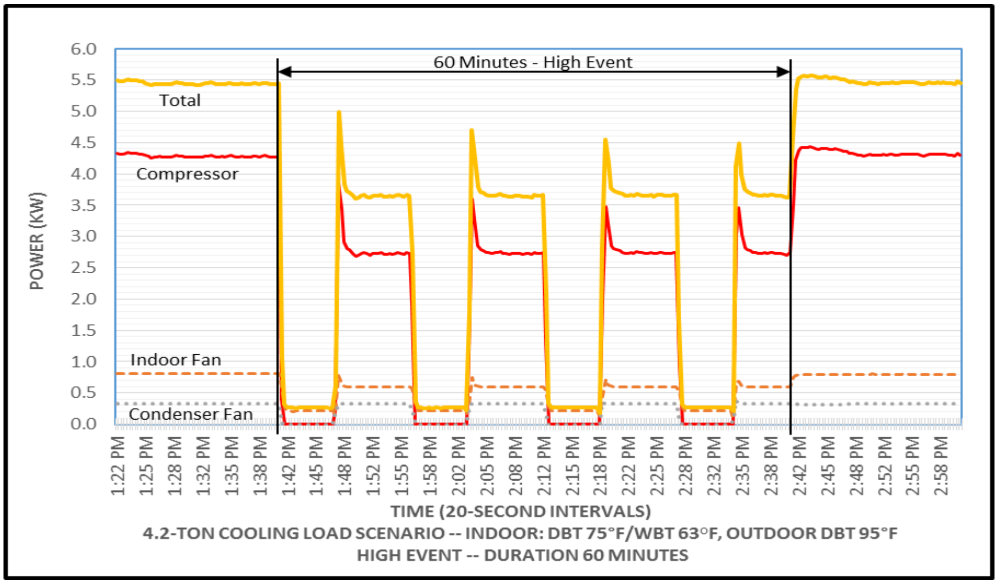

FIGURE 5. 20-SECOND POWER PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 95°F

Figure 6 shows 20-second total power and indoor DBT profiles before and during a high DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 95°F. Prior to the event, the indoor DBT was at 75°F. However, the indoor DBT reached approximately 92°F by the end of the event.

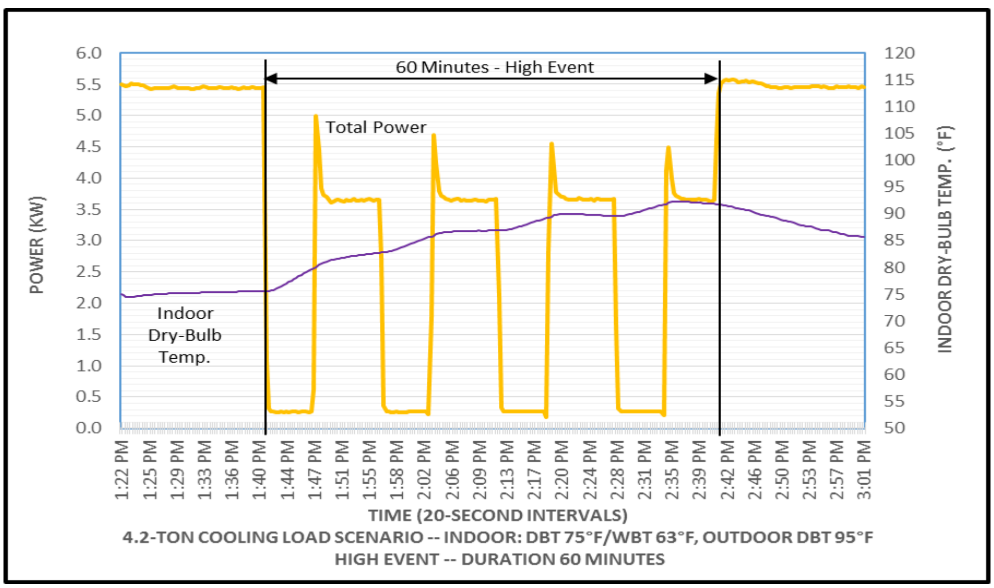

FIGURE 6. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 95°F

INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 105°F

Figure 7 shows 20-second power profiles before and during a moderate DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 105°F. As shown, before the event, the system was running at full speed (60Hz) with an average total power of 6.0 kW. After initiating the event, the speed (or frequency) was reduced to 42Hz, with an average total power of 4.8 kW for the entire 60 minutes of the event. This was a 20% reduction in average total power.

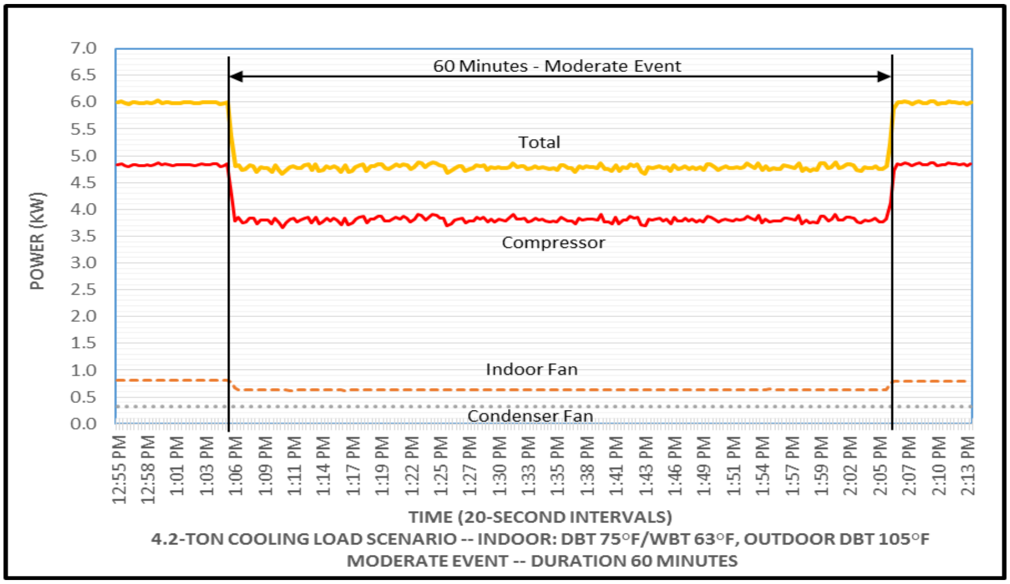

FIGURE 7. 20-SECOND POWER PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 105°F

Figure 8 shows 20-second total power and indoor DBT profiles before and during a moderate DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 105°F. Before the event, the indoor DBT was at 75°F, but it rose to about 82°F by the end of the event.

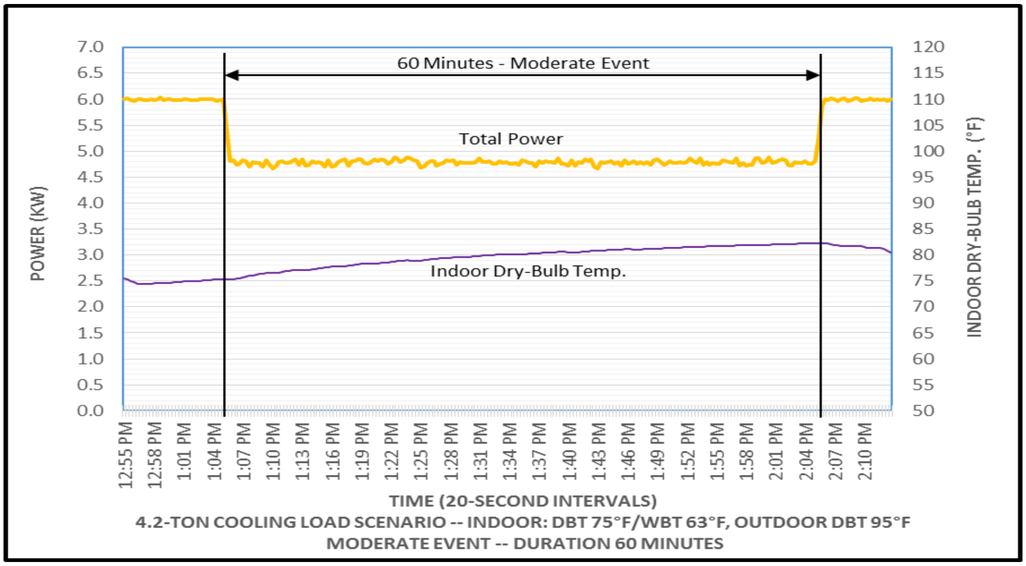

FIGURE 8. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 105°F

Figure 9 illustrates the 20-second power profiles before and during a high DR event, for indoor DBT of 75°F and WBT of 63°F, at an outdoor DBT of 105°F. Prior to the event (normal operation), the unit was running at full speed (60Hz) with an average total power of 6.0 kW. After initiating the event, the controller shut the compressor off for six minutes, then ran it for nine minutes at 40Hz before shutting it off again. When the compressor was operating during the event, the total power was around 3.9 kW. However, averaging the total power during a 15- or 60-minute time interval resulted in an average total power of 2.4 kW, a 60% reduction in average total power in relation to the unit's normal operation.

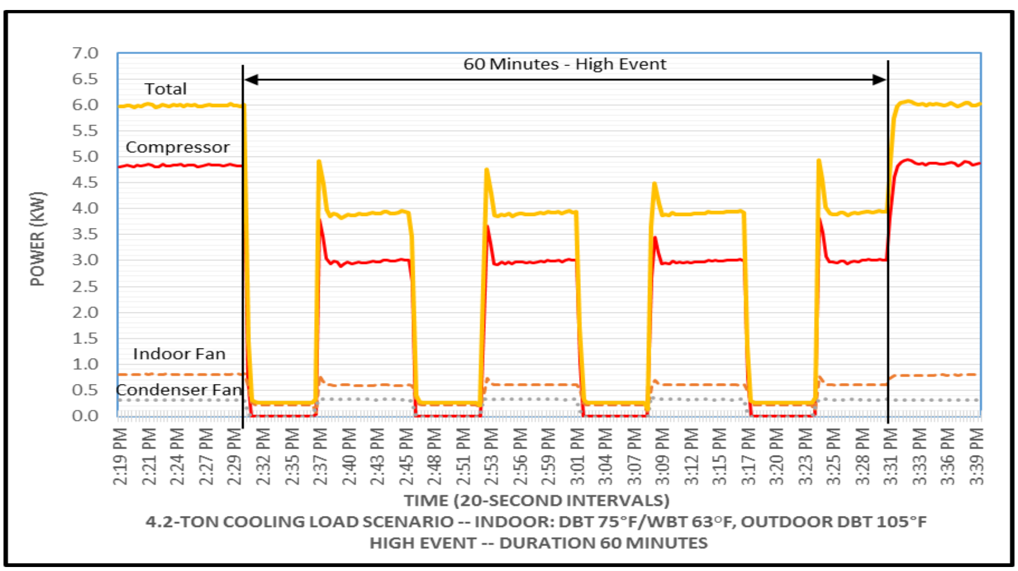

FIGURE 9. 20-SECOND POWER PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 105°F

Clearly, as the "on" and "off" cycling takes place during the DR event, the indoor DBT increases (Figure 9). The average indoor DBT increased from 76°F to 90°F.

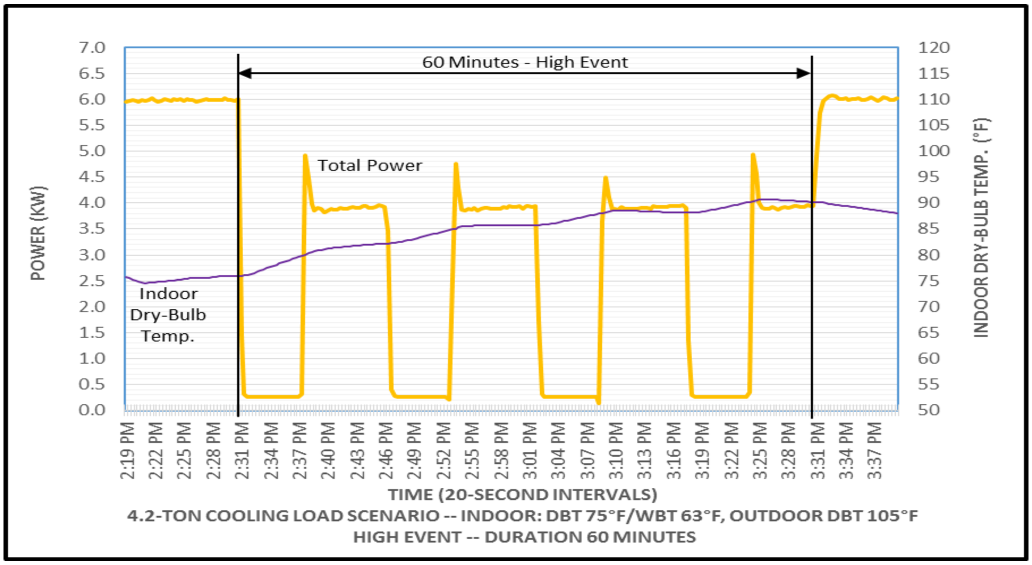

FIGURE 10. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 75°F AND WBT OF 63°F AT OUTDOOR DBT OF 105°F

INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 95°F

Figure 11 shows the 20-second power profiles before and during a moderate DR event, for indoor DBT of 80°F and WBT of 67°F, at an outdoor DBT of 95°F. As shown, before the event, the system was running at full speed (60Hz) with an average total power of 5.4 kW. After initiating the event, the speed (or frequency) was reduced to 42Hz, with an average total power of 4.4 kW for the entire 60 minutes of the event. This was an 18% reduction in average total power.

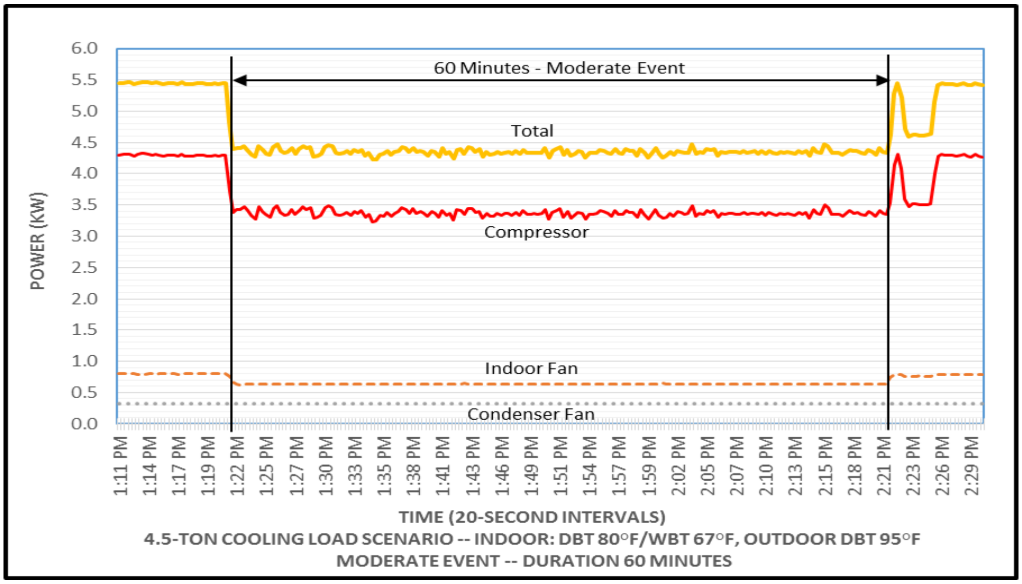

FIGURE 11. 20-SECOND POWER PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 95°F

Figure 12 shows 20-second total power and indoor DBT profiles before and during a moderate DR event, for indoor DBT of 75°F and WBT of 67°F, at an outdoor DBT of 95°F. As shown, the average indoor DBT increased from 80°F to 89°F.

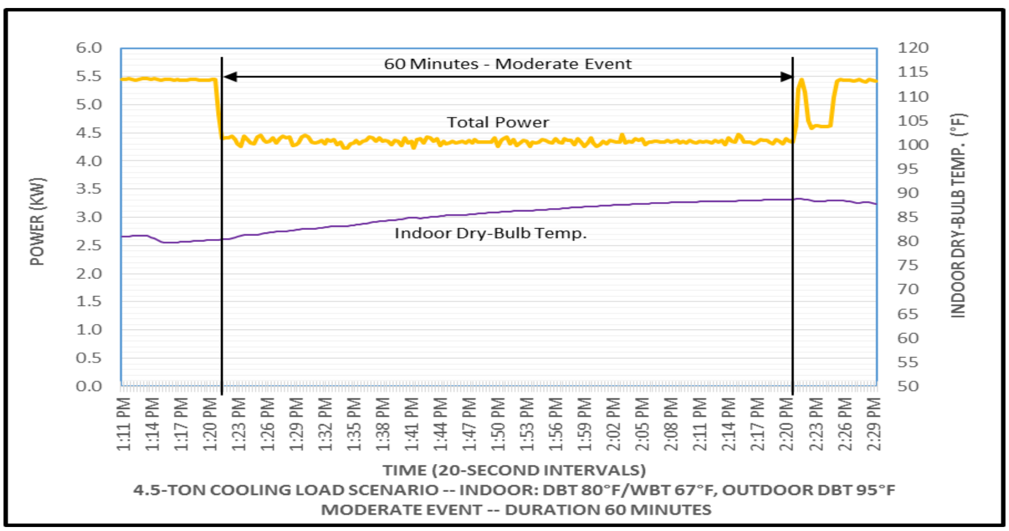

FIGURE 12. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 95°F

As expected, during a high DR event (Figure 13), the controller cycled the compressor on and off every 15 minutes over the entire DR event. During normal operations, the average total power was 5.4 kW. The average total power was reduced to 2.2 kW during either a 15-minute or 60-minute interval, or 60% reduction in power.

Similar to previous test runs, there was an increase in indoor DBT due to DR periods (Figure 14). The average indoor DBT increased from 81°F to 98°F.

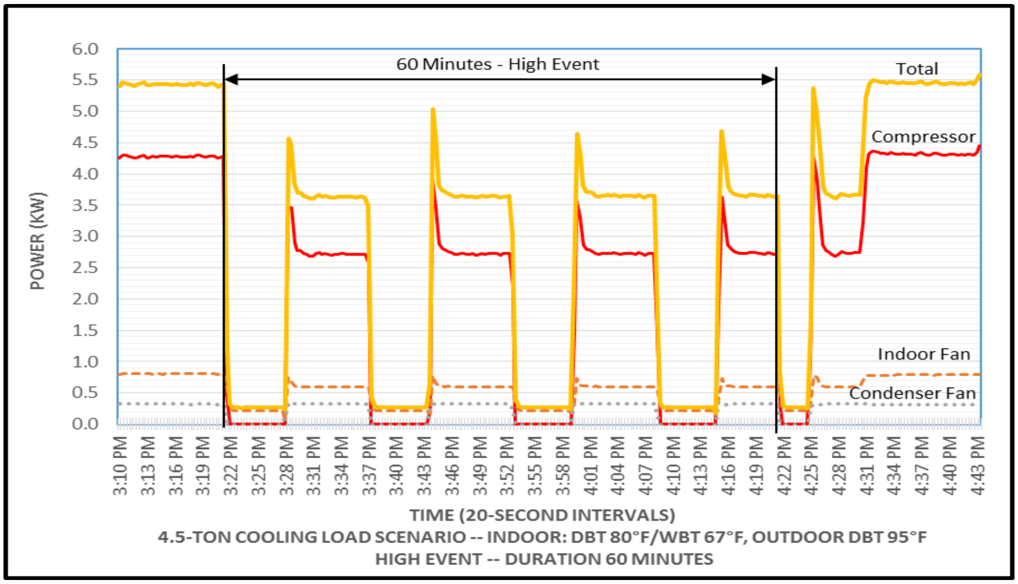

FIGURE 13. 20-SECOND POWER PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 95°F

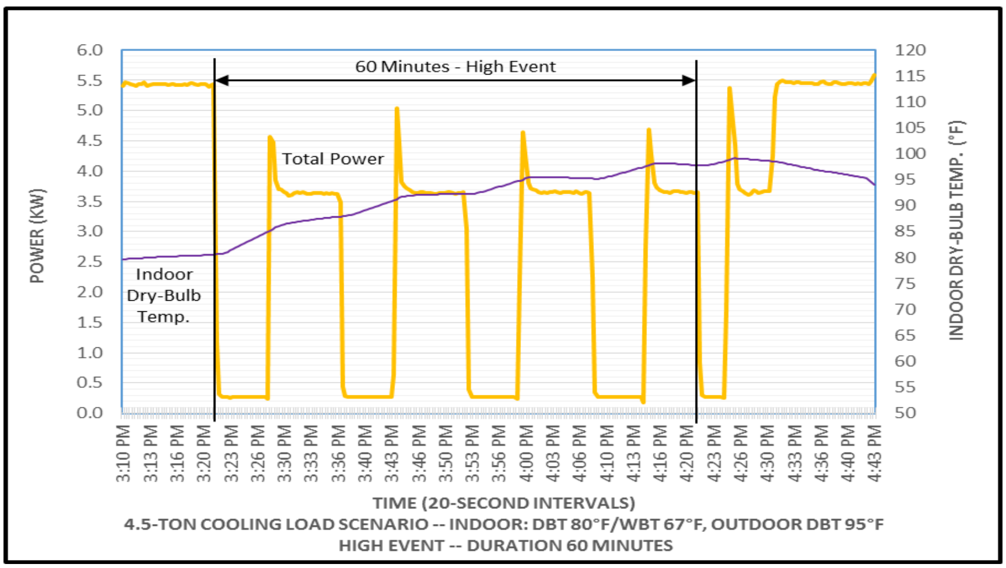

FIGURE 14. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 95°F

INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 105°F

Figure 15 depicts 20-second power profiles before and during a moderate DR event, for indoor DBT of 80°F and WBT of 67°F, at an outdoor DBT of 105°F. Prior to the event, the system was running at full speed (60Hz) with an average total power of 6.0 kW. After initiating the event, the speed (or frequency) was reduced to 42Hz, with an average total power of 4.7 kW for the entire 60 minutes of the event. This was a 22% reduction in average total power.

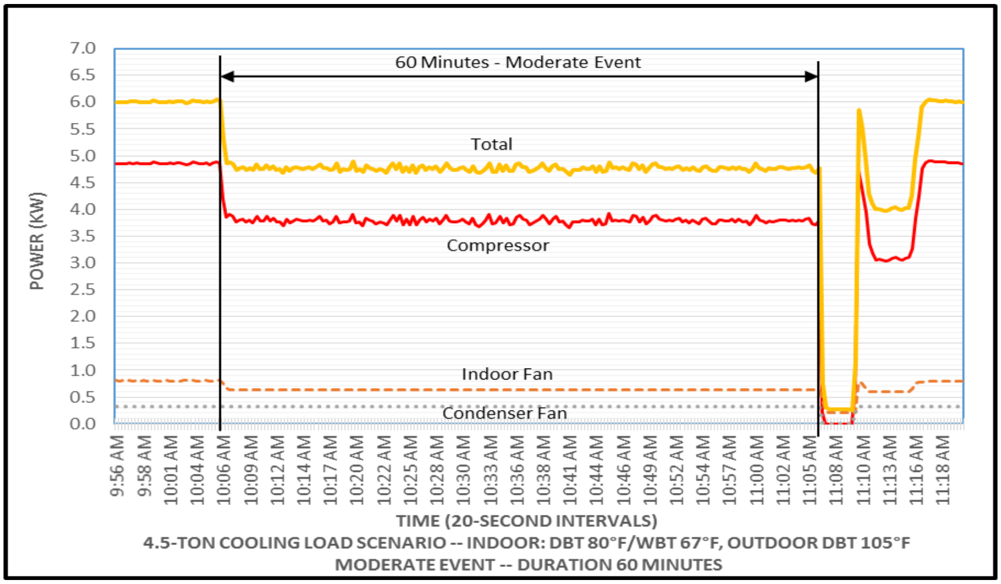

FIGURE 15. 20-SECOND POWER PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 105°F

Figure 16 depicts 20-second total power and indoor DBT profiles before and during a moderate DR event, for indoor DBT of 80°F and WBT of 67°F, at an outdoor DBT of 105°F. As depicted, the average indoor DBT increased, from 80°F to 86°F.

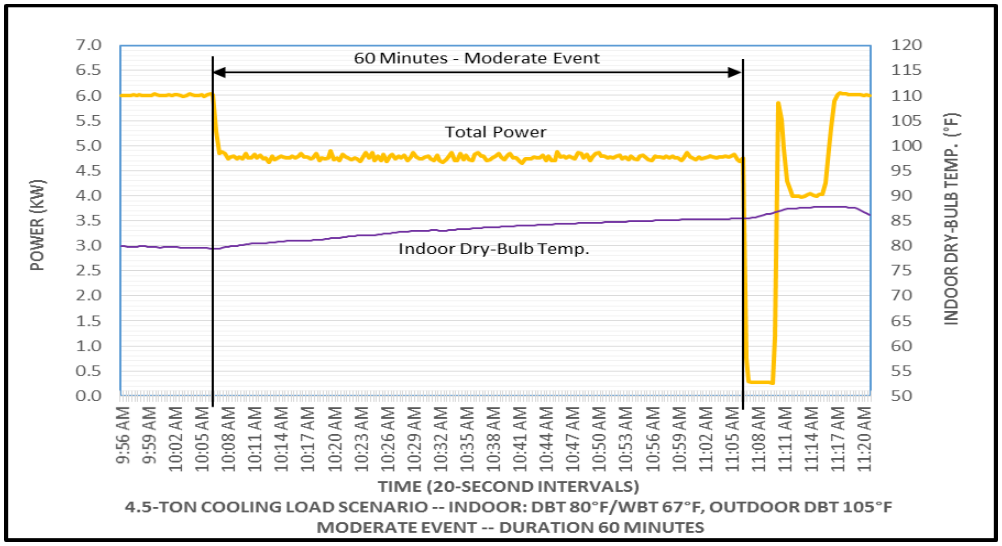

FIGURE 16. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR MODERATE DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 105°F

Again, during a high DR event (Figure 17), the controller cycled the compressor on and off every 15 minutes over the entire event. During normal operations, the average total power was 6.0 kW. The average total power was reduced to 2.4 kW during either a 15-minute or 60-minute interval, or 60% reduction in power.

For this test scenario, there was also an increase in indoor DBT due to DR periods (Figure 18**Error! Reference source not found.**). The average indoor DBT increased from 80°F to 95°F.

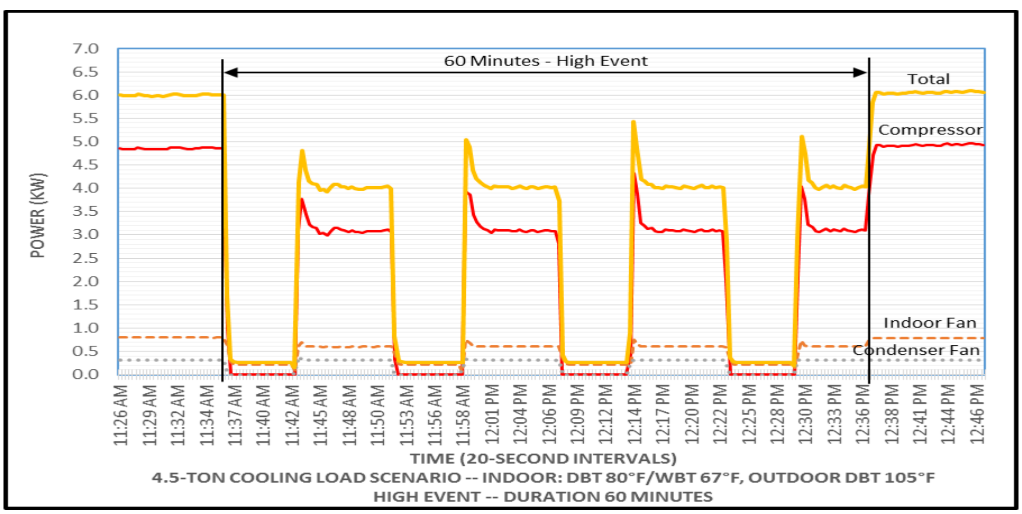

FIGURE 17. 20-SECOND POWER PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 105°F

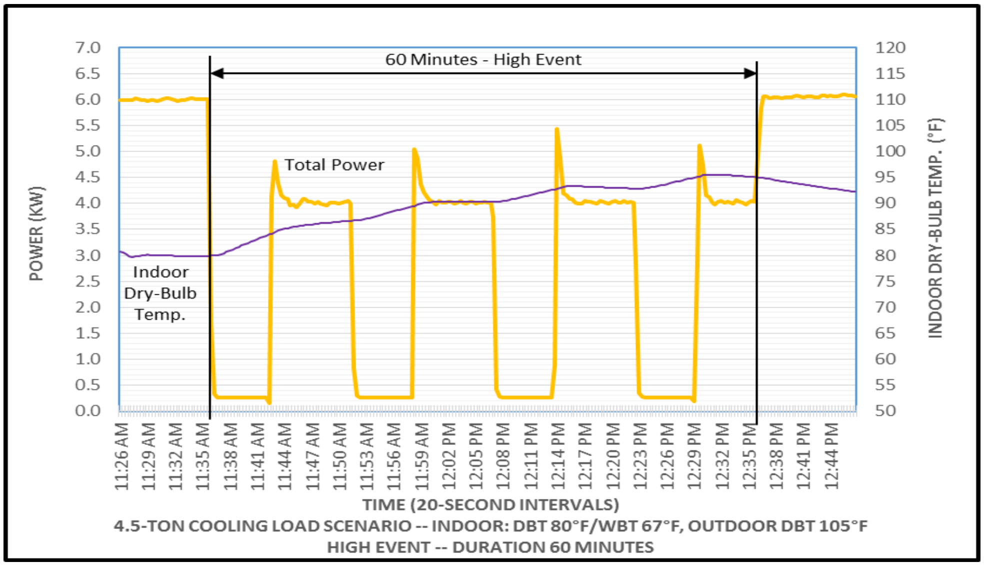

FIGURE 18. 20-SECOND TOTAL POWER AND INDOOR DBT PROFILES FOR HIGH DEMAND RESPONSE EVENT -- INDOOR DBT OF 80°F AND WBT OF 67°F AT OUTDOOR DBT OF 105°F

Table 2 summarizes key test control parameters, as well as the results of all test runs. Key control parameters include indoor DBT and WBT, as well as outdoor DBT. The results presented in Table 2 are average power data gathered for each test run.

TABLE 2. SUMMARY OF KEY TEST CONTROL PARAMETERS AND RESULTS

Test Scenarios	Parameters	Moderate Demand Response (DR) Event Scenario			High Demand Response (DR) Event Scenario		
		Before DR Event	Entire 60-minute of DR Period	First 15-minutes of DR Period	Before DR Event	Entire 60-minute of DR Period	First 15-minutes of DR Period
Indoor DBT of 75°F and WBT of 63°F Outdoor DBT of 95°F	Indoor DBT(°F)	75.3	81.1	78.5	75.2	86.3	79.9
	Indoor WBT (°F)	63.1	66.8	67.0	63.1	72.1	69.1
	Outdoor DBT(°F)	95.2	95.0	94.7	95.3	94.8	94.6
	Compressor kW	4.3	2.7	2.2	4.3	1.6	1.6
	Indoor Fan kW	0.8	0.6	0.5	0.8	0.4	0.4
	Outdoor Fan kW	0.3	0.3	0.3	0.3	0.2	0.2
	Total kW	5.4	3.6	3.0	5.5	2.2	2.2
Indoor DBT of 75°F and WBT of 63°F Outdoor DBT of 105°F	Indoor DBT(°F)	74.9	79.8	77.1	75.3	85.3	79.8
	Indoor WBT (°F)	62.8	64.7	63.7	62.9	71.4	68.8
	Outdoor DBT(°F)	105.1	105.1	105.1	105.1	99.0	99.1
	Compressor kW	4.8	3.8	3.8	4.8	1.7	1.7
	Indoor Fan kW	0.8	0.6	0.6	0.8	0.4	0.4
	Outdoor Fan kW	0.3	0.3	0.3	0.3	0.2	0.2
	Total kW	6.0	4.8	4.8	6.0	2.4	2.3
Indoor DBT of 80°F and WBT of 67°F Outdoor DBT of 95°F	Indoor DBT(°F)	80.4	85.7	82.2	80.2	91.7	85.0
	Indoor WBT (°F)	66.8	68.0	67.6	65.4	75.2	72.0
	Outdoor DBT(°F)	95.2	95.0	95.0	95.1	94.7	94.6
	Compressor kW	4.3	3.4	3.4	4.3	1.6	1.6
	Indoor Fan kW	0.8	0.6	0.6	0.8	0.4	0.4
	Outdoor Fan kW	0.3	0.3	0.3	0.3	0.2	0.2
	Total kW	5.4	4.4	4.4	5.4	2.2	2.2
Indoor DBT of 80°F and WBT of 67°F Outdoor DBT of 105°F	Indoor DBT(°F)	79.7	83.2	80.8	80.0	89.9	84.0
	Indoor WBT (°F)	66.9	67.4	67.3	66.2	75.0	72.5
	Outdoor DBT(°F)	105.1	105.0	105.0	105.1	104.2	104.0
	Compressor kW	4.8	3.8	3.8	4.9	1.8	1.8
	Indoor Fan kW	0.8	0.6	0.6	0.8	0.4	0.4
	Outdoor Fan kW	0.3	0.3	0.3	0.3	0.2	0.2
	Total kW	6.0	4.7	4.8	6.0	2.4	2.4

CONCLUSIONS

This assessment involved conducting a set of eight test runs, to quantify the power demand reductions for high and moderate DR events under two indoor and two outdoor climatic conditions, using a five-ton RTU. The indoor conditions were DBT of 75°F and WBT of 63°F, as well as DBT of 80°F and WBT of 67°F. The outdoor DBTs were 95°F and 105°F.

Results indicated the controller was capable of responding to both moderate and high DR signals through a central gateway. It also verified the pre-programmed strategy of the controller for each DR event.

Results also indicated that there is a potential for moderate DR events to reduce average total power demand by 20%, and up to 33%, depending on the operating conditions. For high DR events, the average total power can potentially be reduced by 60%. In addition, these DR events resulted in a rise in indoor DBT, as expected. For moderate DR events, the rise in indoor DBT was 6°F to 9°F. The rise in indoor DBT was more noticeable for high DR events, with temperatures ranging between 14°F and 17°F.

RECOMMENDATIONS

Gathered data suggests there is a potential to reduce A/C power demand using DR-capable controllers. The potential to reduce power demand was more noticeable for high DR event scenarios compared to moderate DR events. Therefore, such devices are recommended for consideration in utility DR programs, since they can curtail power demand as needed. Future studies may consider evaluating similar technologies that may have different strategies for each DR event type.

APPENDIX A. TECHNOLOGY TEST CENTERS

SCE's TTCs are technology assessment laboratories specializing in testing the performance of Integrated Demand-Side Management (IDSM) strategies for SCE's EE, DR, and Codes and Standards programs. Located in Irwindale, California, the TTCs are various centers focused on distinct energy end uses.

By conducting independent lab testing and analysis, the TTC widens the scope of available IDSM solutions with verified performance and efficiency. TTC tests are thorough and repeatable, and conducted in realistic, impartial, and consistent laboratory environments, to ensure the best-quality results and recommendations.

Heating, Ventilation, and Air Conditioning Technology Test Center

The Heating, Ventilation, and Air Conditioning Technology Test Center (HTTC) evaluates the latest residential and commercial Heating, Ventilation, and Air Conditioning (HVAC) equipment. By testing systems and strategies in controlled environment chambers capable of surpassing industry standards and producing realistic climatic conditions, the HTTC can help EE program designers and customers, as well as the industry, make informed HVAC design and specification decisions.

Responsibilities

Key responsibilities include:

- **Testing:** The HTTC tests HVAC equipment in support of California's statewide ET, Codes and Standards, and DR. Testing capabilities include:
  - Packaged units (up to 7.5 tons)
  - Split systems
  - Control systems
  - Fault Detection and Diagnostic (FDD) systems
- **Evaluation:** The HTTC evaluates the latest residential and commercial HVAC equipment, to provide customers with the information necessary to make informed equipment purchasing decisions.
- **Equipment Efficiency Enhancement:** With funding support from statewide programs and research grants, the HTTC works with manufacturers, and state and federal agencies, to improve EE HVAC equipment regulations.

Test Chambers and Equipment

Test chambers and equipment include:

- **HVAC Indoor Test Chamber:** This 292-square-foot test chamber provides thermal conditions typically found in residential and commercial building air conditioned spaces, where maintaining desirable human comfort is critical. It is used to collect precise data on temperature, airflow, and humidity, to test various cooling strategies.
- **HVAC Outdoor Test Chamber:** This 250-square-foot test chamber is used to replicate outdoor weather conditions, and to examine how A/C units respond under realistic climatic conditions. Temperatures can be maintained as high as 130°F.

APPENDIX B. INSTRUMENTATION AND TEST SETUP DIAGRAM

Table 3 lists the specifications required by the ASHRAE standard and specifications for the instruments used in testing the five-ton RTU at SCE's TTC. As shown, accuracy relied on National Institute of Standards and Technology (NIST) standards. All the sensors were calibrated in-house prior to installing them on the test equipment and conducting testing.

TABLE 3. LIST OF SPECIFICATIONS REQUIRED AND USED FOR INSTRUMENTATION

MEASUREMENT	MAKE/MODEL	ACCURACY (NIST TRACEABLE)	ASHRAE STANDARD REQUIRED ACCURACY
Dry-bulb	Masy Systems, (type-T thermocouples)	± 0.18°F	± 0.2°F (range of -20 to 140°F)
Dew Point	Edgetech, Dew Prime DF Dew Point Hygrometer	± 0.36°F	± 0.4°F
Pressure	Setra, C207 (0-1,000 psi)	± 0.13% of full scale	± 2.5% of reading
Pressure	Setra, C207 (0-500 psi)		
Power	Ohio Semitronics, GW5-002C	± 0.2% of reading ± 0.04% of full scale	± 2.0% of reading
Power	HIOKI 3169-21	± 0.5% of reading	
Power	HIOKI 3390	± 0.1% of reading	
Power	YOKOGAWA WT1800	± 0.1% of reading	
Refrigerant Mass Flow Rate	Endress-Hauser, (Coriolis meter) 80F08-AFTSAAACB4AA	For liquids, ± 0.15% of reading For gases, ± 0.35% of reading	± 1.0% of reading
Condensate Mass (using a scale)	HP-30K	± 0.1 gram (± 0.0035 ounces)	± 1.0% of reading

Figure 19 through Figure 21 illustrate the measurement state points on the air-side and refrigerant-side circuits, respectively. The test setup uses a two-chamber configuration for the indoor and outdoor areas. The addition of piping and the refrigerant mass flow meter increased the system's refrigerant charge. The RTU charge protocol was followed, and the total charge increased to a total of 11 lbs (from the original 10 lbs). The manufacturer's vacuum specifications were followed prior to establishing charge levels.

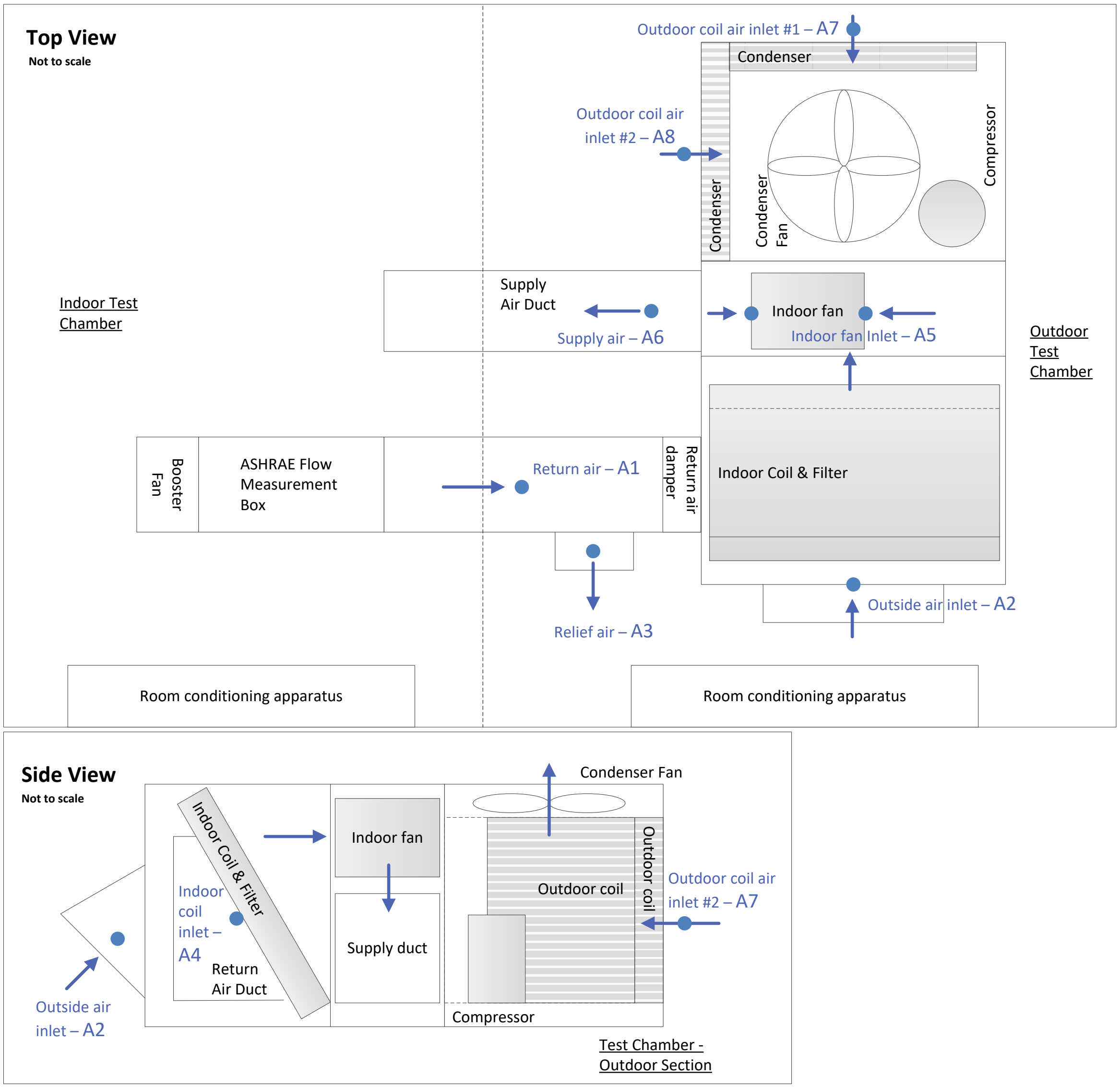

FIGURE 19. AIR-SIDE STATE POINTS

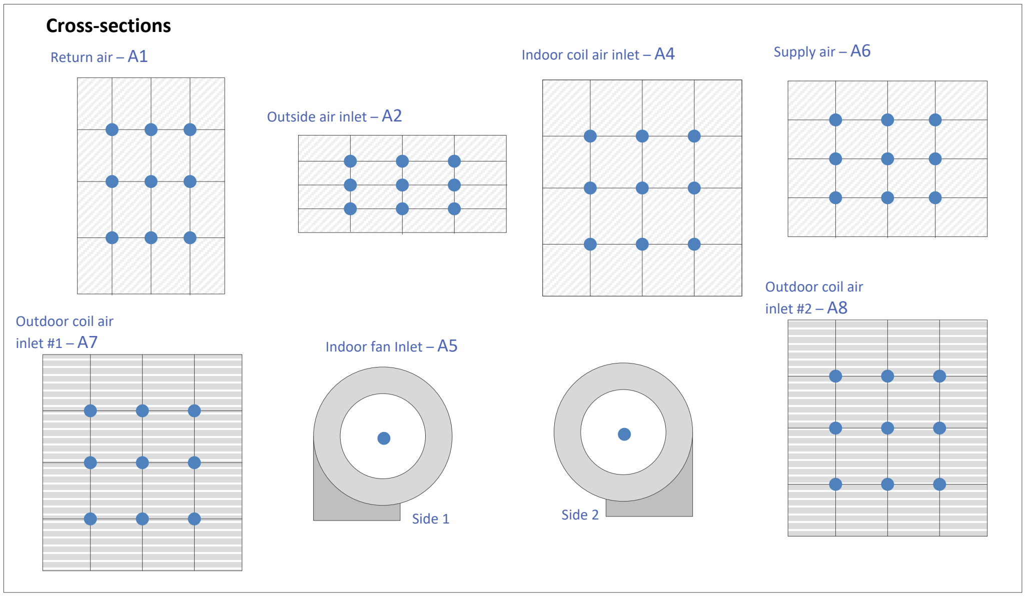

FIGURE 20. AIR-SIDE STATE POINTS (CROSS SECTIONS)

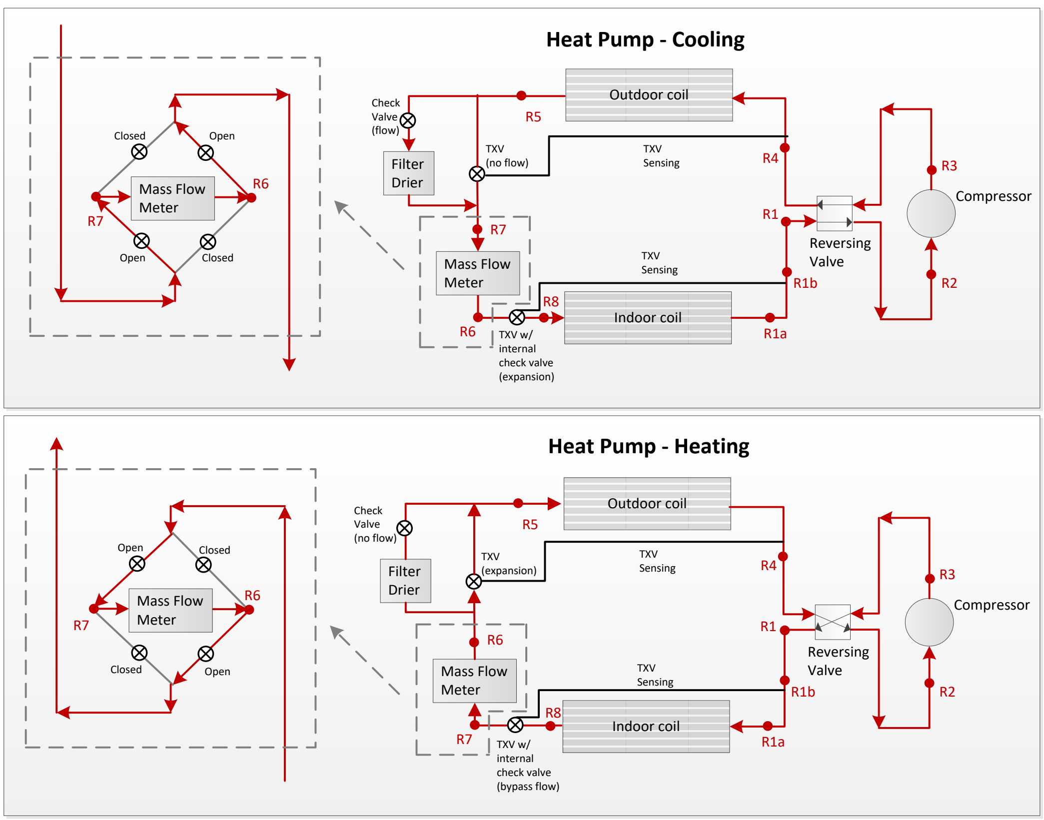

FIGURE 21. REFRIGERANT-SIDE STATE POINTS

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