HVAC Capacity Controller

Final Report

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Executive Summary

There are millions of “fixed-capacity” or “fixed-speed” heating, ventilation, air conditioning, and refrigeration (HVACR) systems already installed throughout California that are a significant component of peak demand and summertime stress for the electric utility grid. These HVACR systems typically operate in two states, on or off, and utilize maximum power and energy whenever in the on state. Traditional fixed-capacity or fixed-speed HVACR systems do not regulate electrical power demand according to the cooling or heating requirements of the space to be cooled or heated, they simply turn fully on or fully off based on thermostat settings. These systems are often operating inefficiently because the electrical power and energy usage does not match the actual cooling or heating requirements. For example, on a relatively cool spring day at 80°F, the amount of power and energy required to cool a space is significantly less than that required for a hot summer day at 95°F. For residential and commercial consumers seeking to reduce their energy consumption and carbon footprint and to promote a more sustainable future for their local communities and economies, fixed-capacity or fixed-speed HVACR systems can be retrofitted with variable frequency drives (VFDs) to deliver significant efficiency improvements and a quick return on investment.

The custom-built HVAC capacity controller (HCC) studied in this project is a standalone device capable of interfacing with fixed-capacity or fixed-speed HVACR systems. The function of the HCC is to provide signal inputs to the VFD, so that the VFD’s output supplies the correct voltage and frequency to produce improved cooling load matching, less on and off cycling, soft start-ups, and faster temperature pulldowns of the HVACR system. The project team’s findings are broadly relevant for any HCC, however, at the time of this report, the custom-built HCC was the only one available that could work with a VFD to reduce HVACR power demand.

In this study, the project team installed custom-built HCCs to interface with the VFD, to retrofit various fixed-capacity or fixed-speed HVACR equipment that operates from 230 volts AC, 60 hertz single-phase power of 5 kilowatts maximum. Hereafter, we refer to the VFD as “the test unit” or “the VFD.” Participants in the study included several single- family residences, schools, and churches located within the Southern California Edison (SCE) service area. Data were gathered and evaluated to determine reductions in demand (peak kilowatts) and consumption (kilowatt-hours).

Site recruitment proved highly efficient, due primarily to a project team member with an extensive professional network in communities targeted. However, other aspects of project progress were significantly delayed by technical challenges related to VFDs and how they interface with HVACR equipment. The project team investigated and solved these challenges, but not on time to gather data during the most important season: Summer. Initial results from installed systems are positive: As frequency is reduced, power consumption is proportionally reduced, depending on power factor. Importantly, the team found very little difference in cooling capacity between 60 and 45 hertz, even though power consumption dropped up to 25 percent.

The project team recommends:

- Gather and publish 12 months of onboard energy/power data from the 24 installations, to include summer demand and energy consumption data. Due to initial technical challenges with the VFDs, this project could not gather the full year of data that would be critical for

understanding how well the HCC/VFD retrofits reduce demand and energy conservation, especially during high-demand times. An extension of this work should include comparisons of HCC site data with time-of-use data from SCE smart-utility meters for the same time, and for the same months in the previous year. Such comparisons would allow for a reliable estimate of reduced demand.

- If results continue to be positive, conduct a significantly larger study that includes 3-phase commercial ACs and heat pumps with voltages up to 480VAC and capacities up to 20 tons.
- IOUs should prioritize engagement with community-based businesses and organizations, including churches, to expand the reach of energy-efficiency programs and studies. In this field study, an energy consultant with extensive past experience with the local communities ensured that recruitment was extremely effective; these network connections allowed for extensive signups in a matter of weeks.

Abbreviations and Acronyms

Acronym	Meaning
ASC	acceleration stall current
DAC	disadvantaged communities
GSA	Go Solar America
HCC	HVAC capacity controller
HP	heat pump
HVAC	heating, ventilation, and air conditioning
HVACR	heating, ventilation, air conditioning, and refrigeration
HTR	hard-to-reach
IOU	investor-owned utility
kWh	kilowatt-hour
PPD	permanent passive device
RCB	relay control board
SCE	Southern California Edison
SFR	single family residence
SPD	switching passive device
SEER	seasonal energy efficiency rating
TPR	third-party retailers

Table of Contents

List of Tables

List of Figures

Background

There are many high-efficiency HVAC systems currently available for both residential and commercial applications in California; however, for the millions of fixed-capacity or fixed-speed systems already installed, there are not widely available, off-the-shelf, easy-to-install retrofits that provide the control inputs required by VFDs to produce the desired efficiency and environmental improvements. Therefore, retrofitting the HCC and a VFD to existing fixed-capacity or fixed-speed HVACR equipment allows owners and operators to implement a variable-capacity modulation strategy that reduces energy consumption while performing the same amount of work. Adding a VFD to a fixed-speed compressor motor can result in a 30 to 50 percent reduction in energy costs while enabling capacity modulation from 40 to 100 percent — without having to replace a compressor.

HVACR equipment such as mini-splits or inverter-type air conditioners and heat pumps (HPs) are well established technologies capable of matching the power and energy requirements to the actual cooling and heating demand, reducing energy consumption and electrical power demand. Unfortunately, such variable-capacity HVACR systems are a very small fraction of the HVACR systems currently installed in California. HCCs, if widely installed, can help the state of California meet its future decarbonization goals.

The function of the HCC is to provide the signal inputs to the VFD so that the VFD's output supplies the correct voltage and frequency to produce improved load matching, less on and off cycling, soft start-ups, and faster temperature pulldowns of the HVACR system. The two main inputs required by the VFD to control the HVACR compressor's speed are temperature and remote start. A temperature probe or sensor is installed in the return air duct to sample the temperature in the space to be cooled. The probe produces a small voltage that is directly proportional to the return air duct temperature and is fed into a temperature transducer. The temperature transducer converts the small voltage to a 0- to 10-volt signal that the VFD requires to vary the frequency and the speed of the HVACR compressor automatically. The VFD requires a dry contact input (switch) to remotely start the VFD. The thermostat in the space to be cooled starts the cooling or heating process by sending a signal to the HCC which in turn sends out the dry contact signal to the VFD, starting the HVACR compressor.

Objectives

The objectives of the study were to:

- Select the best VFDs to be interfaced with HCCs and the best HVACR equipment to be retrofitted.
- Determine net reductions in energy consumption and demand.
- Estimate operating cost savings of retrofitting existing HVACR equipment.
- Determine the short-term reliability of the interfaced HCC, VFD, and HVACR equipment. The short-term reliability describes how often the HCC/VFD upgrades or HVACR equipment malfunction within the first six months of service installation dates.

- Determine system operating procedures, settings, and parameters, such as minimum and maximum frequencies, temperature, starting torque, ramp up time, and more.

The project team was unable to meet all objectives in the limited time frame of this study. Initial data collected from 24 installations shows that the VFD studied can be used effectively on a variety of HVAC equipment, but a compressed project timeline, associated with technical challenges with the VFDs tested meant there was not time to document seasonal or annual net reductions in energy consumption and demand nor estimated operating cost savings. Because units were installed for less than six months, the team could not test the short-term reliability of the interconnected HCC-VFD-HVACR equipment systems.

Methodology and Approach

Participant Sites

The Project Plan indicated that the intended participants shall include a school in a disadvantaged community (DAC) with at least 20 packaged or split room air conditioners and one or more walk-in refrigerators, and 15 single family residences with split or rooftop packaged air conditioners, all rated for three to five tons (30 to 35 HCC/VFD units). Although any type of fixed-capacity or fixed-speed HVACR equipment containing a compressor can benefit from the HCC/VFD retrofit upgrade, the study only addresses HVACR equipment that operates from 208/230 volts AC, 60 hertz single-phase power. Many commercial buildings under 20 years of age have 208/230 volts, 60 hertz three phase power.

Site participant recruitment, which began with a single church in a DAC, was extremely efficient. It became clear this was primarily because of decision makers' familiarity with one of the project team members — an energy consultant who has long worked professionally with churches, schools, and individuals in the community. Decision makers at each site were eager to support the study and the work, and eager to understand potential energy and money savings because of his work motivating a high degree of interest in the technology. Applicants had to be turned away because time did not allow for more sites to be included. Importantly, the requirement of single-phase power turned out to be a barrier to participation.

The project team determined that the VFD chosen for this project has difficulty starting and operating four- and five-ton ACs and heat pumps (HPs). Mitigating the starting difficulties required modifications to the HCCs, which are detailed in the Findings section of this report. These unexpected modifications cut into the project funds already allocated to acquire more site participants, so the number of HCC/VFD units to be installed was reduced to 25; the project team ended up installing 24 due to technical and time challenges detailed below. We focused on single family residences and churches in Southern California Edison service territory, in designated disadvantaged communities, and which had ACs or HPs of three tons. We enrolled two schools, three churches, and 10 single family residences, all of which have signed the Emerging Technologies Program Customer Agreement. The site participants are described in Table 1; at a few sites, we installed several systems for a total of 24 units installed.

Table 1: Participant Site Summary

Site	Date	Signed	Type of Facility	ACs	Date Installed
1	2/22/24	Y	Church	2	10/11/24
2	4/11/24	Y	Church	2	10/19/24
3	4/11/24	Y	Church	4	10/8/24
4	2/19/24	Y	School	2	5/1/24_Site Visit
5	3/13/24	Y	Single family residence	2	10/29/24
6	4/3/24	Y	Single family residence	1	10/21/24
7	2/19/24	Y	Single family residence	1	10/22/24
8	6/24/24	Y	School	4	10/16/24
9	6/24/24	Y	Single family residence	1	10/18/24
10	10/15/24	Y	Single family residence	2	11/6/24
11	10/27/24	Y	Single family residence	1	10/27/24
12	11/8/24	Y	Single family residence	1	11/8/24
13	11/8/24	Y	Single family residence	1	11/21/24
14	N/A	N	Church	6	7/16/24_Site Visit
15	11/22/24	Y	Single family residence	1	11/22/24
16	11/24/24	Y	Single family residence	1	11/24/24

Variable Frequency Drive Selection and Testing

In researching available VFDs, the project team identified several that met the technical specifications (7.5kW, 220VAC, 0–400Hz, single-phase input, single-phase output, 0–10V frequency control and remote start) required by this project. However, only one — the unit tested, shown in Figure 1 and Figure 2 — was selected. The cost for this unit ranges from $160 to $350, depending on whether it is refurbished or new. Other VFDs available and considered here were too costly for this project's budget with an average cost of $2,500 per unit. It is important to note here that such costs would also make them prohibitively expensive for many homeowners, churches, schools, and other institutions considering retrofits.

Figure 1: Variable frequency drive (VFD).

Figure 2: VFD internal wiring.

The drives were bench tested using a 220VAC, 2,000-watt power supply and a 220VAC, 2-horsepower, capacitor start, capacitor run, single-phase induction motor. For testing, the drives were initially set in manual mode and operated from the panel run/stop buttons. The induction motor was mechanically unloaded and the VFD parameter settings were adjusted accordingly.

There are a number of parameter settings — including acceleration, deceleration, motor rated frequency, maximum frequency, minimum frequency, start frequency, and torque offset — that are specific to each air conditioner or HP. These parameters can only be set during site installation.

HVAC Capacity Controller Manufacturing and Testing

The HCC custom built for this study was composed of several peripheral devices, including a temperature controller, temperature probe, on/off switch, and a power/energy meter. The on/off switch powers the HCC on/off and provides an override so that the AC or HP can operate in case there is a fault with the HCC. The HCC is essentially a customized junction box containing electrical controls, 220VAC power, 120VAC power, 24VAC power, VFD inputs and outputs, an HVAC compressor, and an indoor thermostat. The HCC is built with components that include a printed circuit board, wire (10, 14, and 20 gauges), a terminal block, time delay relays, a current transformer, power relays or contactors, and various connectors as shown in Figure 3.

Figure 3: HVAC capacity controller components.

The project team began by assembling the HCC's relay control board (RCB) shown in Figure 4. The functions of the RCB are to provide override in case there is an HCC fault and to protect the HVACR compressor and VFD from "short-cycling," i.e., the rapid on/off cycling of a HVACR system. The RCB was bench tested by connecting it to 220VAC power, 120VAC power, and 24VAC power. The 24VAC power is generated at the air handler control board of the HVAC equipment and passes through the thermostat. All power sources were connected to the printed circuit board and routed to the peripheral devices, VFD, and an induction motor as shown in the HCC Electrical Block Diagram Figure 8. The temperature controller was set with minimum and maximum settings, and the minimum operating frequency was set for the VFD. The VFD operates the load (induction motor) at 60 hertz or maximum power for all temperatures greater than or equal to the maximum temperature setting and will turn off the load when the minimum temperature is reached. When the temperature starts to rise from the minimum, the VFD is not allowed to turn the load back on for at least three minutes, which gives the temperature a chance to settle, thereby preventing short-cycling. The power drawn by the load will increase as temperature increases and decrease as temperature decreases. Under normal operating conditions, the thermostat determines when the HVACR systems cycles on or off. The operator of the HVACR system determines the thermostat temperature setting. The temperature controller's maximum and minimum settings are plus or minus two or three degrees of the thermostat setting. Once the space to be cooled or heated reaches the thermostat setting, the load will be drawing 50 to 60 percent of maximum power (operating between 30 and 36 hertz).

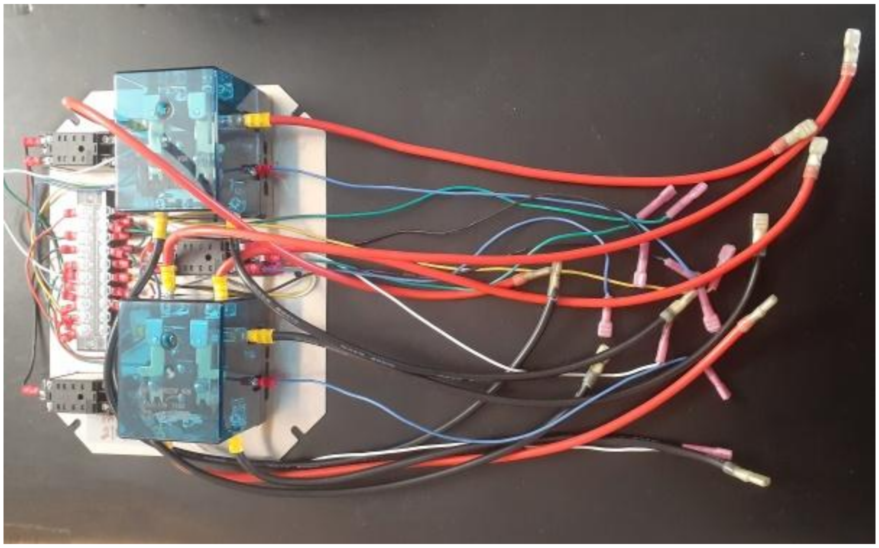

Figure 4: HVAC capacity controller relay control board (RCB).

After the RCB was assembled and tested, the next step was to assemble and test the HCC. All peripheral devices, printed circuit, RCB, and external wiring connectors were installed in the HCC enclosure (junction box). Images of the fully assembled HCC are shown in Figure 5, Figure 6, and Figure 7. The HCC was bench tested by connecting the 220VAC power source, 120VAC power source, 24VAC power source, thermostat, VFD, and electrical load (induction motor) to the output wiring via the external connectors. The testing process was the same as that used to test the RCB.

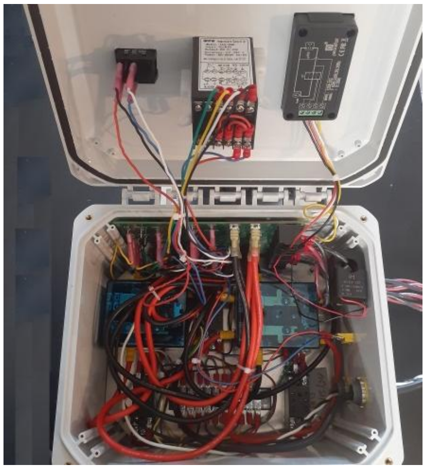

Figure 5: HCC internal wiring.

Figure 6: Assembled HCC.

Figure 7: Assembled HCC upright.

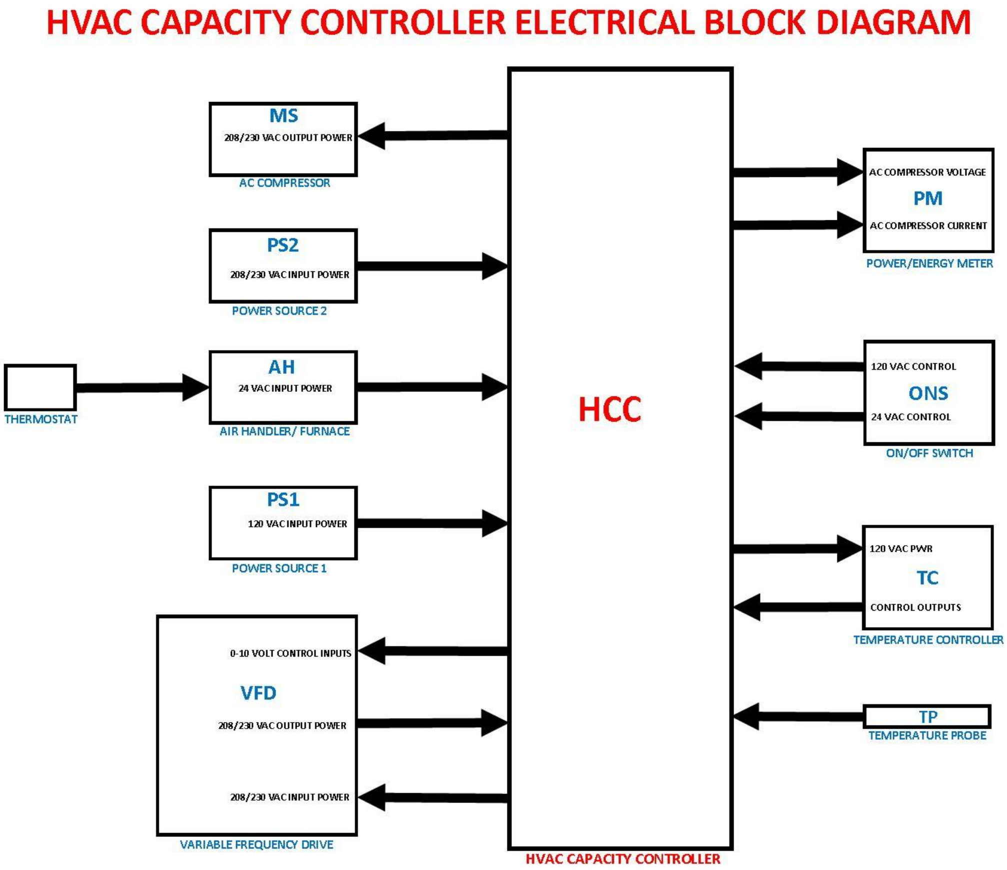

Figure 8: HCC electrical block diagram.

Figure 9: Sample HCC AC Install

Operating Parameters and Settings

Once a participating site was selected that met the guidelines of the HCC field study, a site visit was scheduled to confirm that HVACR equipment could be retrofitted with the HCC/VFD upgrades. During the site visit, the HVAC technician determined where the HCC and VFD would be installed, how the power sources (230VAC, 120VAC, and 24VAC) and HVAC compressor wiring would be routed to the HCC, and where the temperature probe would be installed. The HCC and VFD were always installed where there was easy access to the equipment, such as in an attic or utility closet. On the installation date, a tailboard meeting was held prior to beginning work, to discuss the details of the project, supervision, and safety. After locating the service panels, power to the HVACR equipment was turned off and all disconnects were removed at the HVACR equipment. After all wiring was routed and installed, the HCC/VFD was temporarily wired but not physically mounted and installed. Each VFD and HCC arrived at the install site with parameters (acceleration, deceleration, motor rated frequency, maximum frequency, minimum frequency, start frequency and torque offset, and minimum temperature and maximum temperature) preset based on previous knowledge and the make and model of HVACR equipment, as shown in Table 2 below.

Table 2: Preset Operating Parameters

PN3 Freq Control Mode	PN4 Start Control Mode	PN8 Acceleration	PN9 Deceleration	PN10 Max frequency	PN11 Min frequency	PN12 Rated frequency
2: Manual	1: Manual	10 seconds	10 seconds	60 hertz	32 hertz	60 hertz

PN3 Freq Control Mode	PN4 Start Control Mode	PN8 Acceleration	PN9 Deceleration	PN10 Max frequency	PN11 Min frequency	PN12 Rated frequency
4: Auto	2: Auto	10 seconds	10 seconds	60 hertz	32 hertz	60 hertz

All wiring was checked and double checked to confirm all components were properly wired according to Articles 430 and 725 of the National Electrical Code (NEC). The VFD was placed in manual mode and the HCC initially set to override or turned off. Power was restored at the service panel and disconnects reinstalled. The thermostat was set and the HVACR equipment was turned on at the thermostat.

Next, the site owner or operator determined the desired operating temperature and the thermostat setting. The power/energy meter on the HCC booted up and began displaying readings and the HVACR equipment was checked to ensure it was operating normally, as if the HCC/VFD upgrades were not connected. After it was confirmed that the HVACR equipment was functioning properly, the thermostat was turned off and the HCC turned on, at which point the temperature controller and the VFD booted up and the power/energy meter turned off. Then, the thermostat was turned on, the VFD set to 60 hertz, and the run button (green) on the VFD activated to start the HVACR equipment.

If the HVACR equipment started, the VFD parameters were fine-tuned to determine the lowest frequency where the equipment could consistently start without faulting out. If the HVACR equipment did not start, the VFD parameters were adjusted until the equipment could consistently operate at 60 hertz. The fine-tuning process was completed to determine the lowest frequency where the equipment could consistently start without faulting out. After the operating parameters of the VFD were determined, the thermostat was turned off and the VFD placed in auto mode. To ensure the HVACR equipment could be operated within the required temperature range, the temperature probe was artificially heated significantly above the maximum temperature setting of the temperature controller, which caused the VFD to display 60 hertz. The thermostat was then turned on and, following a 10 second delay, the VFD, power/energy meter, and HVACR equipment turned on and ramped up to full power or 60 hertz. If the temperature probe was artificially cooled e.g., by spraying water on the probe, the VFD began to reduce the frequency, reducing the power consumed by the HVACR equipment.

Once it was confirmed that the HVACR equipment could be operated from varying temperatures, the thermostat was turned off, VFD placed in manual mode, all power removed, and the HCC and the VFD mounted and permanently installed. After the HCC/VFD was permanently installed, all power was restored and both electrical and HVACR operating characteristic data were taken with the VFD operating in the manual mode. Once all the data was collected, the VFD was placed in auto mode and the system placed in service and ready to operate at the discretion of the owner or operator. The owner or operator did not interface with the VFD or HCC and only operated the HVACR equipment from the thermostat. The data collection matrix template is shown in Table 3; data from each site are detailed in Appendix A.

Table 3: HCC Site-Install Data Collected from Each Site Template

HVAC Capacity Controller Site-Install Measurements									
Site Information:									
Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS									
60									
55									
50									
45									
40									
35									
30									

Findings

Between September (when the challenges described below were overcome) and November, the project team had working systems installed on 24 units at 14 sites, allowing for brief but detailed data collection. When the team solved these challenges, recruitment re-started, however there was not sufficient time to complete 25 system installations or to collect data for a full year, as planned. Work completed did, however, produce meaningful insights into the operation of HCCs, detailed in the Recommendations section below

Data collected from 14 sites clearly shows that as frequency is reduced power consumption is proportionally reduced depending on power factor. For example; if the frequency is reduced by 10%, power consumption is reduced by 10%. If the power factor is low (0.75) additional power will be lost internally in the HVAC equipment where a 10% reduction in frequency leads to a 7% reduction in net power consumption. The data also shows that there is very little difference in cooling capacity between 60 and 45 hertz; however, there are reductions in power consumption up to 25 percent over this range. Over the entire frequency spectrum of 60 to 30 hertz there are reductions in power consumption up to 50 percent, depending on power factor. Each HCC/VFD retrofit must be tuned to the specific HVAC equipment and is expected to operate at approximately 38 hertz. Within these parameters, average reductions in demand and energy consumption are 37 percent.

Variable Frequency Drive Selection

We selected the VFD tested for the following reasons:

1. It is cost-effective and fit within the budget for the study.
2. The rated output power of 7.5 kilowatts is more than adequate to operate single-phase, 60 hertz, 220VAC HPs and ACs up to five tons.
3. There has been previous successful experience with this VFD (3 to 3.5-ton ACs).
4. The VFD interfaces well with the HCC.
5. The VFD has been rugged and reliable.
6. The team has experience setting and adjusting parameters that allowed HVAC equipment to operate.

Only one VFD model was evaluated in the study primarily due to budget restrictions and compatibility to the HCC. The HVAC equipment evaluated includes: 3 Trane ACs, 3-Carrier ACs, 1 Carrier HP, 1 Goodman HP, 4 Goodman ACs, 5 Rheem ACs, 3 Rudd ACs and 4 Bard HPs. All of the HP are package units. There were a total of five package units and 19 split units installed. The capacity was evenly divided; 8–5- ton units, 8–4- ton units and 8–3-ton units.

As recruitment efforts quickly produced willing participants in the study, installations of the HCC/VFD HVAC system upgrades began April 26, 2024, with two five-ton ACs. The project team immediately began having problems with the internal circuit breakers of the VFDs tripping or faulting out when attempting to operate the ACs off of the VFDs. The VFDs were producing a fault described as "OC – u." The OC –u fault means that the output current of the VFD has exceeded 50 amps. The five-ton ACs we were attempting to operate have a seasonal energy efficiency rating (SEER) of 14, which means they operate at approximately 4.3 kilowatts of power, 220VAC, and 20 amps under full cooling load capacity, well within the power output capability of the VFD chosen for the study. Over the past six years, GSA (Go Solar America) has successfully operated the test unit on 3 to 3.5 ACs without the VFD consistently faulting out once the parameter settings of PN8-Acceleration (seconds), PN11-Minimum Frequency (hertz), PN10-Maximum Frequency (hertz), and PN12-Rated Frequency (hertz) were properly determined. These values vary based on the individual AC or HP operating characteristics, including minimum and maximum operating voltages, locked rotor current, and high and low side operating pressures.

The majority of the site participants enrolled in the study have five-ton ACs or HPs. As we continued with scheduled installations, we were able to get five three-ton units to operate from the VFDs, although the typical parameter settings were significantly different from those experienced six years prior. By the end of the study, we had working systems installed on 24 units in 14 sites, allowing for brief but detailed data collection (Appendix A).

OC –u Fault

All of the ACs and HPs enrolled in the study had a minimum SEER rating of 12. This means the maximum output current the VFDs can be expected to supply ranges from 13.5 amps for three-ton HVAC units up to 22.5 amps for five-ton HVAC units. The VFD tested can produce an output current of 31.8 amps when operating at its maximum output rating of 7.5 kilowatts; given this fact, the OC –u fault should not be preventing the five-ton HVAC units from operating because the operating current of 22.5 amps is significantly less than the maximum output current of 31.8 amps that the VFD can safely deliver. The OC –u fault means that the output current of the VFD has exceeded 50 amps. Although the expected operating current for a typical single-phase, 220VAC, 60 hertz, SEER 12, five-ton HVAC unit operating at full cooling capacity is 22.5 amps, the units operated so far have clearly exceeded 50 amps of current, resulting in the OC –u faults.

Causes of the OC –u Fault

The project team determined the primary causes of the OC –u fault to be as follows:

- **Factory Settings:** Although we have successfully operated 220VAC, single-phase, 60 hertz, three-ton ACs with the VFD test unit, the parameter settings (PN8, PN11, and PN12) are significantly different than those used on the exact same VFD six years ago. The seemingly identical VFDs purchased six years ago operated with parameter settings of PN8 (5 seconds), PN11 (32 hertz), and PN12 (60 hertz) and could operate a three-ton AC consistently without experiencing the OC –u fault. The tested VFDs are sold through third-party retailers (TPRs) and do not come directly from the manufacturer. The series VFDs being sold by the TPRs are arriving with operating characteristics that can only be adjusted at the factory. These VFDs require parameter settings of PN8 (180 seconds), PN11 (20 hertz), and PN12 (65 hertz) to operate a three-ton AC consistently without experiencing the OC –u fault. It took several months to determine that the VFDs purchased for the study did not function as those purchased six years ago.
- **Inrush or Locked Rotor Current**: The HVAC equipment compressor has an induction motor that draws a very large starting current of 70 to 160 amps. VFDs are designed to operate with induction motors and are configured to withstand large inrush currents without tripping internal circuit breakers. The VFDs purchased for the study arrived with factory set circuit breakers that can withstand current of approximately 85 amps for up to two seconds without faulting out. Most of the SEER 12, three-ton HVAC units produce inrush current less than 80 amps, allowing the test units to start the compressor without faulting out. Most of the SEER 12, four to five-ton HVAC units produce inrush current greater than 130 amps and immediately trip the circuit breakers of the VFD test units.
- **Acceleration Stall Current (ASC):** The tested VFD can initially start without immediately faulting out depending on the parameter settings of PN8, PN11, and PN12. The ASC is initially less than the inrush current and increases as the frequency of the VFD increases. The ASC attempts to rise to the inrush current because the rotor is locked, and the compressor is not pumping refrigerant although current is flowing in the compressor

motor. PN8–Acceleration (seconds) determines how long it takes for the VFD to accelerate from PN11-Minimum Frequency (hertz) to PN10-Maximum Frequency (hertz). This means that the tested VFD can attempt to start the HVAC compressor for as much as 60 seconds before the current exceeds 50 amps and trips the VFD circuit breakers. During the 60 seconds the VFD is accelerating, the condenser fan will be spinning, giving the illusion that the compressor has actually engaged; this fact delayed our understanding and therefore solutions to mitigate the VFD faults.

- **Inductive Kick:** There is a sudden voltage spike across an inductive element when its supply current is suddenly reduced or interrupted. Initially, we believed that the inrush or locked rotor current was the only factor causing the OC –u fault. The early attempts to reduce the inrush current involved switching passive devices (resistors and inductors) in series with the HVAC compressor motor, allowing the VFD test units to start the HVAC compressor and then bypass the passive devices after the HVAC equipment is fully functioning. Unfortunately, when we tried to bypass or switch the passive devices out of the electrical circuit of the HVAC compressor, the VFD tested would generate an OC –u fault, where a current greater than 50 amps attempted to flow after the VFD was up and running, because the inductive kick of the stator windings induces a large current greater than 50 amps.

OC –u Fault Mitigation

Installations of the HCC/VFD HVAC system upgrades began April 26, 2024, and continued until it was determined that the OC –u fault was a barrier to the full implementation of the study. The following measures were considered or tested to mitigate the OC –u fault:

- **Upgrade to a Higher Powered VFD:** We considered upgrading the 7.5-kilowatt VFD to a 15-kilowatt VFD. This plan assumed that inrush current was the only factor causing the OC –u fault. There was insufficient information regarding the amount of inrush current that actually caused the VFD circuit breakers to trip or whether a VFD rated for a higher power output would mitigate the fault. We ultimately ruled out this option because the cost to upgrade the VFDs did not fit the budget.
- **Soft Starter:** A soft starter is a type of motor starter that uses voltage reduction techniques during the starting of a motor by gradually increasing voltage, allowing the motor to slowly accelerate to its rated speed and reducing inrush current by as much as 70 percent. Although a soft starter can reduce inrush current, it must be supplied with constant line voltage and frequency (220VAC, 60 hertz). The output voltage and frequency of the VFD is variable and therefore cannot supply the soft starter with a constant voltage and frequency. A soft starter was ruled out as OC –u fault mitigation.
- **Switching Passive Devices (SPDs):** The early attempts to reduce the inrush current involved switching passive devices (resistors, inductors, and thermistors) in series with the HVAC compressor motor, allowing the VFD test unit to start the HVAC compressor and then bypass the passive devices after the HVAC equipment is fully functioning. Unfortunately, when we tried to bypass or switch the passive devices out of the electrical circuit of the HVAC compressor, the test unit would generate an OC –r fault, where a current greater than 50 amps attempted to flow after the VFD was up and running, because the inductive kick of the stator windings induces current greater than 50 amps.

Serval circuit configurations were attempted over a two-month period, and all configurations produced the OC –r fault.

- **Permanent Passive Devices (PPDs):** Inserting PPDs (inductors and thermistors) in series with the HVAC compressor motor allowed the VFD test unit to start and run the HVAC compressor inconsistently. The parameter settings, outside temperature, operating pressures, and amount of inductance determined if the VFD could run the HVAC unit. PPDs allow the HVAC unit to start and run 70 percent of the time. The inconsistent operation of the HVAC unit is related to the ASC. If the starting characteristics of the HVAC compressor can be improved, the addition of PPDs can consistently allow the HVAC unit to be operated by the tested VFD unit.

Demand Reduction and Energy Reduction

HVACR systems typically operate in two states, on or off, and utilize maximum power and energy whenever in the on state. Retrofitting VFDs to fixed-capacity or fixed-speed HVACR systems can deliver significant efficiency improvements. The function of the HCC is to provide signal inputs to the VFD, so that the VFD's output supplies the correct voltage and frequency to produce improved cooling load matching, reduced peak power (demand), and reduced energy consumption (kilowatt-hours).

Adding a VFD to a fixed-speed compressor motor can result in a 30 to 50 percent reduction in energy costs while enabling capacity modulation from 40 to 100 percent without having to replace a compressor.

One of the primary objectives of the study was to determine net reductions in energy consumption and demand. The original plan was to get 30 to 35 HCC/VFD units installed by May 15, 2024, to ensure that all summertime data was captured. Installations did not begin until April 26, 2024, and were immediately derailed because the internal circuit breakers of the VFDs selected for the study were tripping (OC –u fault) for all four to five-ton HVAC units. The study's participating HCC/VFD units were later reduced to 25 to accommodate modifications to the HCCs required to get the VFDs functional while simultaneously retaining the original budget allocated for the study.

A solution to the OC –u fault was developed September 19, 2024. The HCC power/energy meters are permanently affixed to the HCC and accumulatively store kilowatt-hour data that could later be retrieved and compared to data taken from the SCE smart utility meters if further data comparison is desired. By early November, the project team had installed 24 units, collecting detailed data at 20 of them; at four sites, data could not be collected on time for this report, generally because AC systems needed servicing before reliable data could be collected. The significantly shortened time frame for data collection did not allow for seasonal or annual net reductions in energy consumption or demand nor estimated operating costs savings; however, initial data collection resulted in positive findings.

Regardless of the tonnage or manufacturer of the HVAC equipment, all HCC/VFD retrofits showed that as frequency is reduced there is an approximate 1:1 linear reduction in power consumption. The average power consumption (demand) measured across all units at 60 hertz was 2.46 kW and 1.81 kW at 45 hertz. This represents a 26.69% reduction in demand when HVAC systems are operated at 45 hertz instead of 60 hertz.

The HCC/VFD retrofit does not involve the indoor fan; therefore, the CFM of air flowing over the evaporator coil is the same. We primarily evaluated cooling capacity based on the differential between the supply and return temperatures. We also paid close attention to the high and low operating pressures. The temperature differential is between 15 and 22 degrees when the HVAC system is functioning properly. As frequency was decreased, we expected to see a corresponding decrease in the temperature differential between the supply and return. For example, 60 hertz to 45 hertz should have resulted in a 25% reduction in temperature differential; however, we measured an average temperature differential reduction of 12.43%. In some cases, the temperature differential at 45 hertz was higher than 60 hertz. These results led to the conclusion that the average 3-to-5-ton HVAC system can comfortably operate at 45 hertz without sacrificing cooling while simultaneously reducing demand by 26.69%.

The overall HVAC system efficiency decreases as outdoor temperatures rise because the temperature difference between the outdoor air and the condenser is lower which means it's harder for heat to be released to the outdoor air. The HCC operating in auto-mode causes the power consumption to vary with the cooling load. As the temperature of the space-to-be cooled drops, the frequency and power consumption also drop. The Site-Install-Data shows reductions in demand as frequency is reduced reached 51%. Auto-mode should be engaged if the objective of the "End-User" is maximum comfort for the least amount of energy. Alternatively, the "End-User could choose to operate the HCC/VFD system at 45 hertz and achieve a 26.69% reduction in demand and energy consumption without sacrificing comfort.

Data collected from 14 sites shows that as frequency is reduced power consumption is proportionally reduced depending on power factor. Over the entire frequency spectrum of 60 to 30 hertz there are reductions in power consumption up to 51 percent, depending on the power factor. Each HCC/VFD retrofit must be tuned to the specific HVAC equipment and is expected to operate at approximately 38 hertz. Within these parameters, average reductions in demand and energy consumption are 37 percent.

Recommendations

- Gather and publish 12 months of onboard energy/power data from the 24 installations, to include summer demand and energy consumption data. Due to initial technical challenges with the VFDs, this project could not gather the full year of data that would be critical for understanding how well the HCC/VFD retrofits reduce demand and energy consumption, especially during high-demand times. An extension of this work should include comparisons of HCC site data with time-of-use data from SCE smart-utility meters for the same time, and for the same months in the previous year. Such comparisons would allow for a reliable estimate of reduced demand.
- If results continue to be positive, conduct a significantly larger study that includes 3-phase commercial ACs and heat pumps with voltages up to 480VAC and capacities up to 20 tons.
- IOUs should prioritize engagement with community-based businesses and organizations, including churches, to expand the reach of energy-efficiency programs and studies. In this field study, an energy consultant with extensive past experience with the local communities

ensured that recruitment was extremely effective; these network connections allowed for extensive signups in a matter of weeks.

Appendix A: Site Install Data Measurements

HVAC Capacity Controller Site-Install Data Measurements									
Site 1 Information: Unit 1_5 Ton-AC, Church									
Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	241	14.89	3.38	.95	286	154	55.8	77.9	-
60	205	16.46	3.45	.99	307.1	157.6	59.5	82	-
55	191	17.09	3.22	.97	313	163	61.3	82.4	-
50	179	17.12	2.88	.94	312	164	61.9	81.9	-
45	162	17.78	2.63	.92	317	168	61.2	81.7	-
40	145	17.83	2.31	.89	314	171	61.7	81.7	-
35	130	19.34	2.22	.88	320	175	62.8	81.9	-
30	107	20.14	1.94	.90	319	179	63.9	81.5	-
Site 1 Information: Unit 2_5 Ton-AC, Church									
Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	243	13.48	3.09	.94	272	202	66.4	90.7	-
60	206	14.7	3.02	.98	285	210	66.2	91.2	-
55	197	14.08	2.66	.96	275	205	67.5	90.9	-
50	180	14.47	2.41	.93	278	206	67.8	91.2	-
45	162	15.19	2.17	.90	272	203	68.9	91.0	-
40	145	15.47	1.92	.87	265	202	70.3	90.9	-
35	129	16.11	1.77	.85	267	201	70.3	91.0	-
30	106	15.99	1.44	.86	258	201	71.4	91.0	-

HVAC Capacity Controller Site-Install Data Measurements

Site 2 Information: Unit 1_5 Ton-HP, Church

Unit not functioning properly;; Improper operating pressures

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	238	13.13	3.05	.98	170	30	71.6	71.6	-
60	-	-	-	-	-	-	-	-	-
55	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-

Site 2 Information: Unit 2_4 Ton-AC, Church

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	243	12.39	2.42	.98	264.8	118.6	48.9	75.2	-
60	216	11.21	2.26	.93	260	119	53.8	76.3	-
55	207	11.76	2.04	.84	260	120	51.6	75.9	-
50	189	12.35	1.80	.77	261	121	51.3	77.0	-
45	172	13.01	1.58	.71	262	127	51.6	75.9	-
40	154	13.78	1.40	.67	263	130	54.1	76.3	-
35	137	14.50	1.25	.63	262	135	53.6	74.7	-
30	114	14.85	1.09	.65	260	141	57.4	76.1	-

SITE 3 Information: Unit 1_3 Ton-AC, Church

HVAC Capacity Controller Site-Install Data Measurements

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	232	9.98	2.27	.97	170.8	62.5	-	-	-
60	204	11.20	2.28	.99	182	65	-	-	-
55	197	10.80	2.00	.95	178	66	-	-	-
50	179	11.10	1.84	.93	183	68	-	-	-
45	161	11.80	1.70	.91	185	70	-	-	-
40	144	12.60	1.50	.89	185	73	-	-	-
35	128	13.00	1.40	.87	185	75	-	-	-
30	106	12.30	1.10	.86	186	79	-	-	-

Site 3 Information: Unit 2_3 Ton-AC, Church

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	231	9.7	2.2	.97	161	63	-	-	-
60	205	10.6	2.1	.98	162	63	-	-	-
55	196	10.4	1.9	.95	166	65.5	-	-	-
50	179	10.5	1.7	.92	165	67.5	-	-	-
45	161	11.2	1.5	.89	167	69	-	-	-
40	144	11.7	1.4	.87	169	71	-	-	-
35	127	12.1	1.3	.85	169.8	74	-	-	-
30	107	11.6	1.02	.83	170	77.3	-	-	-

Site 3 Information: Unit 3_4 Ton-AC, Church

Compressor Electrical System Measurements	HVAC System Measurements

HVAC Capacity Controller Site-Install Data Measurements

FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	232	13.44	2.94	.93	336	145	-	-	-
60	203	14.41	2.87	.97	338	142	-	-	-
55	194	14.55	2.67	.94	348	143	-	-	-
50	178	15.01	2.46	.91	359	146	-	-	-
45	160	16.11	2.30	.89	377	149	-	-	-
40	143	16.91	2.15	.88	385	154	-	-	-
35	126	18.03	1.98	.88	388	157	-	-	-
30	104	17.90	1.69		388	163	-	-	-

Site 3 Information: Unit 4_5 Ton-HP, Church

Unit not functioning properly; Reversing Valve jammed.

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
55	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-

Site 5 Information: Unit 1_3 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP

HVAC Capacity Controller Site-Install Data Measurements

60-BYPASS	240	7.79	1.8	.97	235	98.8	52.3	65.7	
60	215	8.03	1.72	.99	235	105	55.8	65.9	66.9
55	206	7.83	1.56	.97	236	105	52.7	65.3	66.8
50	188	7.99	1.39	.93	236	110	53.1	64.6	66.3
45	170	8.35	1.25	.88	236	115	52.9	64.8	66.2
40	152	8.78	1.12	.85	236	121	53.1	64.6	65.6
35	135	9.17	1.01	.82	230	125	53.4	64.4	65.5
30	-	-	-	-	-	-	-	-	-

Site 5 Information: Unit 2_3 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	241	7.59	1.77	.97	231	108	55	70.2	-
60	216	7.93	1.70	.99	231	108	52.5	69.3	53.1
55	207	7.52	1.50	.97	227	109	54.9	68.0	54.0
50	189	7.66	1.34	.93	226	112	53.2	67.10	51.5
45	171	7.95	1.19	.88	225	116	52.7	57.5	51.7
40	153	8.52	1.10	.85	231	120	53.1	66.6	51.7
35	135	9.14	1.02	.83	230	125	53.6	66.0	51.3
30	-	-	-	-	-	-	-	-	-

Site 6 Information: Unit 1_5 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	248	12.98	2.63	.83	119	47	52	65	-

HVAC Capacity Controller Site-Install Data Measurements

60	220	11.53	2.44	.96	121	49	54	66	48
55	211	12.20	2.24	.87	124	52	51	65	49
50	193	12.83	2.01	.81	125	52	49	64	50
45	175	13.32	1.75	.75	122	56	49	63	50
40	156	14.32	1.58	.71	123	60	50	64	50
35	140	15.39	1.46	.69	126	66	51	63	51
30	116	15.68	1.24	.69	134	69	52	64	52

Site 7 Information: Unit 1_5 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	235	17.57	3.93	.96	347	119	60	76	-
60	200	20.00	3.92	.98	360	121	58	75	77.6
55	191	19.57	3.54	.96	352	123	58	75	77.3
50	174	19.90	3.22	.93	351	129	58	76	76.9
45	157	20.36	2.93	.91	354	136	61	76	77.2
40	140	21.09	2.65	.90	356	143	63	76	76.9
35	124	22.28	2.45	.89	363	151	65	78	76.8
30	102	22.10	2.04	.90	367	158	67	78	75.6

Site 8 Information: Unit 1_4 Ton-HP, School

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	202	15.89	3.14	.98	312	112	46.0	70	-
60	180	17.84	3.14	.99	312	112	45.9	70	-

HVAC Capacity Controller Site-Install Data Measurements

55	172	16.72	2.77	.97	301.9	117.7	47.8	61.3	-
50	157	16.78	2.49	.95	296	123	49.10	61.3	-
45	143	16.85	2.27	.92	285	139	61.3	73.4	-
40	127	16.87	1.95	.91	298	144	59.2	70.0	-
35	121	16.89	1.85	.91	294	144	58.5	68.4	-
30	-	-	-	-	-	-	-	-	-

Site 8 Information: Unit 2_4 Ton-HP, School

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	204	15.24	3.07	.98	288	107	57.2	70.9	-
60	181	16.80	3.04	.99	287	106	54.1	67.5	-
55	174	16.22	2.74	.97	292	116	55.8	67.6	-
50	158	16.06	2.42	.95	287	124	55.8	65.8	-
45	143	16.09	2.12	.93	282	130	54.9	66.0	-
40	128	16.29	1.89	.91	280	137	56.1	65.5	-
35	113	16.9	1.70	.90	282	141	57.2	65.8	-
30	94	17.54	1.70	.92	276	151	58.5	64.8	-

Site 8 Information: Unit 3_4 Ton-HP, School

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	203	15.11	3.06	.99	289	109.9	48.2	68	-
60	178	17.35	3.03	.99	292	108	47.8	66.7	-
55	170	16.58	2.73	.97	285	112	46.4	65.3	-

HVAC Capacity Controller Site-Install Data Measurements

50	156	16.58	2.48	.96	284	116	45.9	64.4	-
45	140	16.68	2.19	.95	278	119	46.4	63.5	-
40	126	16.82	1.95	.92	272	123	46.9	62.6	-
35	111	17.67	1.77	.92	267	125	46.2	62.9	-
30	92	21.16	1.80	.94	267	130	47.3	61.2	-
Site 8 Information: Unit 4_4 Ton-HP, School									
Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	202	14.8	2.96	.99	296	102	43.2	64.4	-
60	180	16.9	2.98	.98	298	110	43.5	63.1	-
55	172	15.9	2.64	.97	294	114	46.9	64.2	-
50	156	16.16	2.39	.95	296	120	48.9	64.6	-
45	141	16.12	2.11	.93	285	125	50.0	64.9	-
40	126	16.59	192	.91	281	132	52.3	66.4	-
35	113	16.89	1.36	.87	260	148	54.7	67.3	-
30	93	16.78	1.42	.91	261	149	56.1	67.1	-
Site 9 Information: Unit 1_3 Ton-AC, Single Family Residence									
Compressor Electrical System Measurements					HVAC SYSTEM MEASUREMENTS				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	234	7.68	1.76	.98	-	-	52.2	73.2	-
60	205	8.32	1.69	.99	-	-	50.5	72.0	70.4
55	195	7.81	1.51	.99	-	-	50.5	71.6	70.2
50	179	7.95	1.37	.96	-	-	51.6	71.6	69.1

HVAC Capacity Controller Site-Install Data Measurements

45	161	8.23	1.23	.94	-	-	52.5	71.4	71.5
40	145	8.90	1.10	.90	-	-	53.6	71.4	70.4
35	128	9.17	1.04	.89	-	-	54.10	71.2	69.8
30	106	9.78	0.948	.90	-	-	55.80	71.2	71.3

Site 10 Information: Unit 1_3 Ton-AC, Single Family Residence, Unit not functioning properly; Low refrigerant

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	240	6.73	1.56	.97	219.5	41.8	66.7	67.5	-
60	207	7.36	1.50	.99	226.5	39.2	66	67.5	72.6
55	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-

Site 10 Information: Unit 2_3 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	240	8.21	1.86	.95	242	92.5	52.0	69.9	-
60	206	8.60	1.76	.99	244	94.8	50.4	66.4	66.6
55	198	8.21	1.59	.98	246	99.9	49.3	66.2	65.9
50	180	8.38	1.43	.90	247	104	49.1	65.1	65.8
45	163	8.66	1.28	.91	245	109	49.1	65.7	65.6

HVAC Capacity Controller Site-Install Data Measurements

40	146	9.22	1.18	.88	248	114	49.0	65.5	66.9
35	129	10.1	1.13	.87	248	119	50.0	64.8	67.0
30	107	10.42	.977	.88	250	124	50.5	65.1	67.2

Site 11 Information: Unit 1_4 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	238	13.71	3.12	.95	286	205	61	85	-
60	205	15.48	3.36	.97	305	219	56	79	-
55	197	14.20	2.94	.95	301	219	57	80	-
50	180	15.22	2.42	.92	284.7	213.4	56	79	-
45	164	15.76	2.32	.90	291	219.8	58	78	-
40	146	16.46	2.15	.89	296	219	60	78	-
35	129	16.85	1.96	.86	286	208.1	62	79	-
30	106	16.60	1.53	.87	284	216	64	79	-

Site 12 Information: Unit 1_5 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	234	17.85	3.75	.94	310	85.9	50.2	76.3	-
60	196	19.46	3.75	.98	325	93.5	47.3	75.2	67.5
55	189	18.62	3.39	.96	321	99	46.6	73.6	67.0
50	173	19.04	3.08	.94	324	107	46.8	72.3	64.0
45	156	19.40	2.77	.92	322	114	46.9	71.2	62.8
40	139	19.87	2.49	.90	320	122	48.2	71.1	61.0

HVAC Capacity Controller Site-Install Data Measurements

35	124	20.28	2.23	.89	315	131	50.2	71.6	60.0
30	-	-	-	-	-	-	-	-	-

HVAC Capacity Controller Site-Install Data Measurements

Site 13 Information: Unit 1_5 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	247	10.53	2.32	.90	226	84.3	54.3	72.6	-
60	211	10.85	2.22	.98	225	79.2	54.5	72.3	63.6
55	202	10.49	1.98	.93	224	85	55.2	70.3	61.0
50	184	11.10	1.79	.89	224	86	55.4	69.1	59.0
45	166	11.43	1.61	.85	224	94	56.8	67.8	62.2
40	149	11.89	1.43	.81	225	99	58.3	66.8	60.0
35	133	12.52	1.30	.79	227	106	58.3	68.0	62.0
30	111	12.50	1.04	.77	228.	122	60.6	67.6	59.0

HVAC Capacity Controller Site-Install Data Measurements

Site 15 Information: Unit 1_5 Ton-AC, Single Family Residence, Unit not functioning properly: Improper operating pressures.

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
55	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-

HVAC Capacity Controller Site-Install Data Measurements

40	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-

HVAC Capacity Controller Site-Install Data Measurements

Site 16 Information: Unit 1_3 Ton-AC, Single Family Residence

Compressor Electrical System Measurements					HVAC System Measurements				
FREQ-HZ	VOLTS	CURRENT (Amps)	POWER (kW)	PF	HI-PRESS (PSI)	LOW-PRESS (PSI)	SUPPLY TEMP (˚F)	RETURN TEMP (˚F)	SUCTION LINE-TEMP
60-BYPASS	243	10.99	2.44	.91	150	45	59.5	69.9	-
60	211	12.03	2.48	.98	155	55	53.2	67.10	57.6
55	203	11.98	2.29	.95	155	53	50.5	66.4	55.0
50	184	13.04	2.19	.91	155	59	49.8	66.20	52.4
45	166	13.66	2.02	.89	156	62	49.8	65.8	49.0
40	149	14.73	1.91	.87	156	66	50.0	65.7	43.5
35	132	14.66	1.64	.85	158	70	51.3	65.7	45.5
30	110	13.85	1.27	.83	200	73	52.7	65.3	47.2