VARIABLE REFRIGERANT FLOW-HEAT RECOVERY SYSTEM PERFORMANCE MAPPING

HT.10.SCE.250 Report

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EXECUTIVE SUMMARY

Southern California Edison (SCE), in collaboration with the Electric Power Research Institute (EPRI), performed a laboratory analysis of two commercially available variable refrigerant flow heating and air conditioning systems with heat recovery (VRF-HR).

VRF-HR heating and cooling systems are relatively new to the United States and marketed with promise of high performance and efficiency gains. VRF systems have gained some market penetration in the United States, but there remains a need for verified performance data and accurate performance modeling for multi-zone VRF and VRF-HR systems.

Variable refrigerant flow (VRF) systems move refrigerant to the zone to be heated or cooled, allowing the temperature of that area to be precisely controlled. VRF-HR systems are inverter-driven heating, ventilating, and air conditioning (HVAC) systems, similar to residential ductless heat pumps. However, VRF-HR systems are typically larger, installed in commercial buildings, include more indoor units per outdoor unit and are capable of simultaneous heating and cooling. A VRF-HR system can simultaneously heat and cool building zones. Zones may be single or multiple room spaces that are conditioned to a set temperature and are operated independently from other rooms within the same structure There are two basic types of VRF multi-split systems: heat pump and heat recovery. Heat pumps can operate in heating or cooling mode. A heat-recovery system (referred to as VRF-HR), by managing the refrigerant through a gas flow device, can simultaneously heat and cool—some indoor fan coil units in heating and some in cooling, depending on the requirements of each building zone.

Traditionally, U.S.-based Heating, Ventilation and Air Conditioning (HVAC) industry testing laboratories have been designed to evaluate the performance of single-evaporator/single-condenser systems only. EPRI evaluated the operational testing and performance mapping of a VRF-HR system under various ambient conditions and operating modes in their laboratory. There was additional collaboration with Florida Solar Energy Center (FSEC) to assist in developing the test ranges that determined parameters required for the development of algorithms. Identical tests were conducted on two systems, each consisting of one six-ton outdoor unit and four two-ton ducted, low-static indoor units. One system was a two-pipe design and the other was a three-pipe design configuration. Combined overall capacity for each system represented 133 percent of rated equipment capacity. Data collected was compared with manufacturer’s published data to determine if those published values could be duplicated in a laboratory environment.

In heating mode, the laboratory data trends are similar to the data published by the manufacturer. The capacity measurements are within +/- 8% of published data when corrected for a combined ratio of pipe length, defrost and outdoor wet bulb temperature. The manufacturer’s data indicates that the capacity remains constant beyond a certain outdoor wet bulb temperature but laboratory data indicates that the capacity increases as the wet bulb temperature increases. Power input in heating mode does not change across the operating range of outdoor wet bulb temperatures, which is very close to the maximum power published by the manufacturer. The coefficient of performance (COP) of the test systems in the heating mode were found to be lower than the manufacturer’s published data.

The cooling mode capacity was measured to be approximately 25% lower than the manufacturer’s published data when corrected for a combined ratio of pipe length and outdoor dry bulb temperature. The power measurements are in line with the manufacturer’s published numbers. Even though the cooling mode trends match the manufacturer’s data,

lower cooling capacity and higher power measurements resulted in a significantly lower energy efficiency ratio (EER) for the system

Simultaneous cooling and heating (SCH) mode operation was also measured in the laboratory. Mixed mode operation for four different outdoor temperatures (65ºF, 75ºF, 85ºF and 95ºF) was studied to understand system behavior. The system does experience increased EER / COP when operating in mixed mode. Since the manufacturer does not publish mixed mode data, a comparison could not be made.

These future activities are recommended to further assess VRF and VRF-HR systems:

Perform Additional Laboratory Testing: Additional laboratory testing will allow for a more comprehensive performance map to assist software vendors.

Perform Field Testing: Data from additional VRF-HR products and applications will further support this research.

Integrate VRF with Outside Air and Economizer Systems: Currently, ventilation systems used in conjunction with VRF systems are engineered separately on a case-by-case basis. Manufacturers are evaluating potential approaches for an integrated solution, incorporating controls to ensure adequate outside air for ventilation and economizing, while optimizing overall performance.

Develop VRF Models for Energy Modeling Tools: Enhance the current capabilities of building energy simulation tools like eQuest, Energy Plus, DOE-2 and others to model VRF systems.

ABBREVIATIONS/ACRONYMS

A/C	Air Conditioner
AHU	Air Handler Unit
AHRI	Air Conditioning, Heating and Refrigeration Institute (formerly ARI)
ARI	Air Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BC	Branch Circuit
BTU	British Thermal Unit
CFM	Cubic Feet per Minute, ft^3/min
COP	Coefficient of Performance
DAT	Discharge Air Temperature, °F
DBT	Dry-bulb temperature, °F
DX	Direct Expansion
EER	Energy Efficiency Ratio
EEV	Electronic Expansion Valve
EPRI	Electric Power Research Institute
fpm	Feet per minute
hg	Inches of Water Gauge
HP	Horsepower
HVAC	Heating, Ventilation, and Air Conditioning
IDU	Indoor Unit
kW	Kilowatt
MBh	Thousand BTU’s Per Hour

OD-DBT	Outdoor – Dry Bulb Temperature, °F
ODU	Outdoor Unit (Air Cooled outdoor unit)
OD-WBT	Outdoor – Wet Bulb Temperature, °F
PID	Proportional-Integrative-Derivative
PSI	Pounds per Square Inch (gauge)
PSIA	Pounds per Square Inch (Absolute)
PSIG	Pound-force per Square Inch Gauge
PWM	Pulse-Width Modulation
RA-DBT	Return Air – Dry-Bulb Temperature, °F
RA-WBT	Return Air – Wet-Bulb Temperature, °F
RAT	Return Air Temperature
RH	Relative Humidity, %Rh
RTD	Resistive Thermal Device
SAT	Supply Air Temperature
SCE	Southern California Edison
SCFM	Standard Cubic Feet per Minute
SCH	Simultaneous Cooling and Heating
SH	Superheat
SHR	Sensible Heat Ratio
TC	Thermocouple
TDF	Time-Dependent Valuation
TXV	Thermostatic Expansion Valve
UA	Heat Transfer Coefficient ; U = the overall heat transfer coefficient (W/m2 K) A = the contact area for each fluid side
V	Volt

VAV	Variable air volume
VRF-HR	Variable Refrigerant Flow with Heat Recovery
VSD	Variable Speed Drive
WBT	Wet-bulb temperature, °F
WLHP	Water-loop heat pump

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FIGURES

TABLES

EQUATIONS

INTRODUCTION

This document summarizes operational testing and performance mapping of variable refrigerant flow heating and air conditioning systems with heat recovery (VRF-HR). A test stand was built in EPRI's Thermal Environmental Laboratory in Knoxville, TN.

Variable refrigerant flow (VRF) air conditioning systems offer savings of electricity and time-dependent valuation (TDV) of energy as well as reduction of peak electricity demand. However, the 2008 California Building Energy Efficiency Standards (Title 24) do not provide compliance credits for VRF systems, because modeling procedures do not exist in the nonresidential Alternative Calculation Manuals (ACM).

The VRF system is a R410A refrigerant-loop heat pump system that operates in a similar way to a conventional water-loop heat pump (WLHP) system. The VRF system, however, uses an outdoor unit (ODU) to remove or add heat to the refrigerant loop, while the WLHP system uses a cooling tower to remove heat and a boiler to add heat to the water loop. A heat recovery VRF system can serve multiple zones providing simultaneous heating and cooling to different zones. A VRF system has an air-cooled ODU, multiple indoor units (IDU), the refrigerant piping loop, one or more optional distribution units, and corresponding system and zone controllers. A VRF-HR system integrates a heat recovery unit (HRU) to enable the simultaneous heating and cooling feature. Figure 1 shows components of a VRF-HR system.

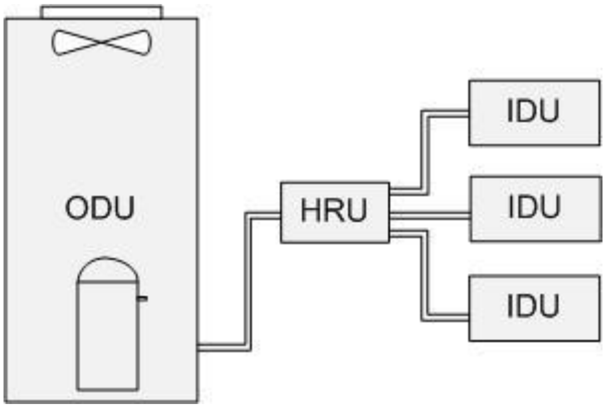


FIGURE 1. COMPONENTS OF A TYPICAL VARIABLE REFRIGERANT FLOW WITH HEAT RECOVERY (VRF-HR) SYSTEM

ASSESSMENT OBJECTIVES

The objective of this assessment was to perform operational tests on variable refrigerant flow with heat recovery (VRF-HR) units to perform the following:

- Develop detailed performance maps for two commercially available VRF-HR systems.
- Compare this data to manufacturers' published data, building energy simulation modeling outputs and EPRI's Energy Efficiency Demonstration database of VRF-HR system performance.
- Provide data to be incorporated into one or more nonproprietary building energy simulation modeling tools.

TECHNOLOGY/PRODUCT EVALUATED

Variable refrigerant flow (VRF) systems are still relatively new to the U.S. market, but have been used in Asia and Europe for more than 20 years. A VRF system is a split system air conditioner (AC) or heat pump incorporating a single refrigerant circuit. The system may contain one or more ODUs, at least one variable-speed compressor, or an alternate compressor combination for varying the capacity of the system by three or more steps. A VRF system also contains multiple indoor fan coil units, each of which is individually metered and controlled by a proprietary control device and a common communications network.

The VRF system can operate as an AC or as a heat pump. The system can provide simultaneous heating and cooling. Recovered energy from the indoor units (IDUs) operating in one mode can be transferred to one or more IDUs operating in the other mode. “Variable refrigerant flow” implies three or more steps of control on common, interconnecting piping.

The setup, data collection, and controls for testing these systems are complex. The systems can be tested with up to five IDUs. This analysis tests four IDUs with specifically induced control parameters to simulate room conditions. The ODU was placed inside the thermal test chamber to simulate outdoor conditions. VRF systems are more complex than standard rooftop or split-system units, with integrated controls and multiple IDUs; the testing time is greater along with the complexity of the test setup.

The VRF system uses inverter technology to vary the speed of the compressor in the ODU and meet the changing load requirements of each IDU. The heat recovery VRF system recycles the energy in other zones to provide comfort only to the zones calling for cooling or heating. The VRF system is energy efficient, quiet in operation, and saves ductwork space. The VRF system competes with two incumbent technologies, namely, the variable air volume (VAV) system and the fan-coil plus fresh air system.

TECHNICAL APPROACH/TEST METHOD

Two commercially available VRF-HR systems from different manufacturers, one a two-pipe design and the other a three-pipe design, were tested and analyzed in EPRI's Thermal Environmental Lab in Knoxville, TN. Data was collected and compared with manufacturer's published data to determine if the published values could be duplicated in a laboratory environment.

LAB TESTING OF TECHNOLOGY

This summarizes operational testing of the test stand constructed for performance mapping of advanced VRF-HR systems.

LAB TEST PLAN

The test stand has four circuits that control the temperature, relative humidity, and flow rate of return air for indoor units:

- Heating circuit
- Cooling and dehumidifying circuit
- Humidifying circuit
- Airflow circuit

The outdoor chamber has similar circuits that control the temperature and humidity of the outdoor chamber. The outdoor chamber is a part of EPRI's Thermal Environmental facility and has been in operation since 2009. The indoor section of the test setup was commissioned as a part of this project.

The system return air (RAT) and outdoor chamber relative humidity (RH) conditions are presented later in the test conditions section below.

The test stand could reach all the conditions on the indoor and outdoor side as listed in Table 1. The RH conditions on the outdoor unit during cooling mode are not critical and will be controlled between 30% and 50%.

TABLE 1 CHAMBER SELECTED SET POINTS

OUTDOOR CHAMBER		INDOOR TEST SETUP		SETPOINTS
DBT	WBT	DBT	WBT	
34	33	60	NA	MAINTAINED
65	NA	85	70	MAINTAINED
95	NA	80	67	MAINTAINED

TEST PROTOCOL

The VRF-HR performance evaluation used the ASRHAE 37-2005 Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment test protocol. Instrumentation procedures, test setup and measurement methodologies were derived from this protocol and applied to the calculations used.

The 2010 ARI Standard ANSI/AHRI Standard 1230 test method was used in this evaluation. Test procedures, indoor and outdoor baseline climate conditions and tolerances were derived from this test method and applied to the test procedure.

TEST CONDITIONS

The range of conditions under which the VRF systems were tested are sufficient to characterize heating and cooling capacity, and power use profiles under expected operating conditions. The initial range of testing was determined by the model development requirements as defined by FSEC. This will generally range from 60°F to 105°F for net cooling operation and 10°F to 60°F for net heating operation. Within this range of conditions, the typical rating conditions as defined by standards such as AHRI 1230 or AHRI 210/240 will be a tested subset. In heat recovery operation, the outdoor air temperature range is 55°F to 85°F. These ranges may be expanded / adjusted according to available time and needs as they develop over the course of testing.

General testing for performance mapping falls into five general categories:

1. Full load cooling tests
2. Full load heating tests
3. Partial load cooling only tests
4. Partial load heating only tests
5. Heat recovery mode

Data from these tests will be incorporated into the overall performance map.

As the name suggests, the full load tests (heating and cooling) will be conducted with all four units providing heating or cooling at the same time. Partial load is simulated by turning off units. Partial load is simulated for three steps - 75% load (1 indoor-unit off), 50% load (2 indoor-units off) and 25% load (three indoor-units off). The indoor units remaining in ON state are running full load conditions, which will represent the required partial load on the outdoor unit. These tests will be conducted at full fan speed rated airflow, however, as time permits and as warranted by data collected, some tests may be performed with reduced indoor unit fan speed and airflow. The outdoor unit will be allowed to reach its natural steady-state fan speed as determined by the VRF control system. Since all conditions on the system remain constant in a given test, the VRF control system will regulate the fan speed to satisfy the load. As per ANSI/AHRI Standard 1230 ‘Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment’ the test unit’s fan should be configured as per the manufacturer’s specifications and should be unchanged for all tests.

In heat recovery mode, instead of turning units off as in case of partial load, the units are forced to operate in the opposite mode by supplying air appropriate for that mode. For example, two units will be forced to operate in cooling mode and the two units forced to operate in heating mode. In heat recovery mode heat is recovered from the units in cooling mode and transferred to the units in heating mode. Thermostatic setpoints will be maintained at unachievable levels to ensure the indoor units continue to operate at fully loaded levels.

Indoor-unit temperature sensors will be installed in the return-air ducts. The set point on the thermostat will be lower (in cooling mode) or higher (in heating mode) than the return air temperature. For example, if the return air temperature is 80°F in cooling mode, the thermostat will be set at 70°F. In this case, since we are always supplying 80°F air on the return side, the thermostat will never be satisfied and the unit will continue to operate at full load. If time permits, additional condition with set point closer to the return air temperature might be tested to study the dynamic performance of the system.

The test conditions for this project are summarized in Table 2.

TABLE 2. RANGE OF TEST CONDITIONS

TEST CONDITION	**MIN**	**MAX**	**COMMENTS**
FULL COOLING LOAD - ALL 4 UNITS COOLING			
OAT	65	95	Temperature steps - 5°F (65, 70,95)
IAT (DB/WB)	70/58	85/70	Wet bulb steps - 3°F (58, 61, 64, 67, 70)
FULL HEATING LOAD - ALL 4 UNITS HEATING			
OAT (DB/WB)	34/33	63/51	Some conditions might not be reachable
IAT	60	80	Temperature steps - 5°F (60, 65,…80)
COOLING PART LOAD - 75%, 50%, 25% LOAD (1, 2 OR 3 UNITS TURNED OFF)			
OAT	75	95	Temperature steps - 5°F (75, 80,95)
IAT (DB/WB)	70/58	85/70	Wet bulb steps - 3°F (58, 61, 64, 67, 70)
HEATING PART LOAD - 75%, 50%, 25% LOAD (1, 2 OR 3 UNITS TURNED OFF)			
OAT (DB/WB)	34/33	63/51	Some conditions might not be reachable
IAT	65	80	Temperature steps - 5°F (65, 70,…80)
HEAT RECOVERY MODE (1, 2 OR 3 UNITS IN COOLING MODE, REMAINING UNITS IN HEATING MODE)			
OAT	65	85	Conditions are for cooling coils, heating coils at 70/60
IAT (DB/WB)	70/61	80/67	
			LEGEND:
			OAT : Outdoor Air Temperature
			IAT: Indoor Air Temperature

TEST CONDITION	MIN	MAX	COMMENTS
			DB: Dry Bulb
			WB: Wet Bulb

Figure 2 shows the range of conditions for an indoor unit on a psychrometric chart. The red area represents the return air conditions for IDUs in cooling mode. The darker red hashed area shows less common, lower priority conditions. The blue line shows the return air conditions that were tested in heating mode. In heating mode, return air humidity was not a controlled parameter and was held to approximately 55%. ANSI/AHRI Standard 1230 uses 70°F DBT / 60°F WBT (RH 56%) as a rating condition in heating mode.

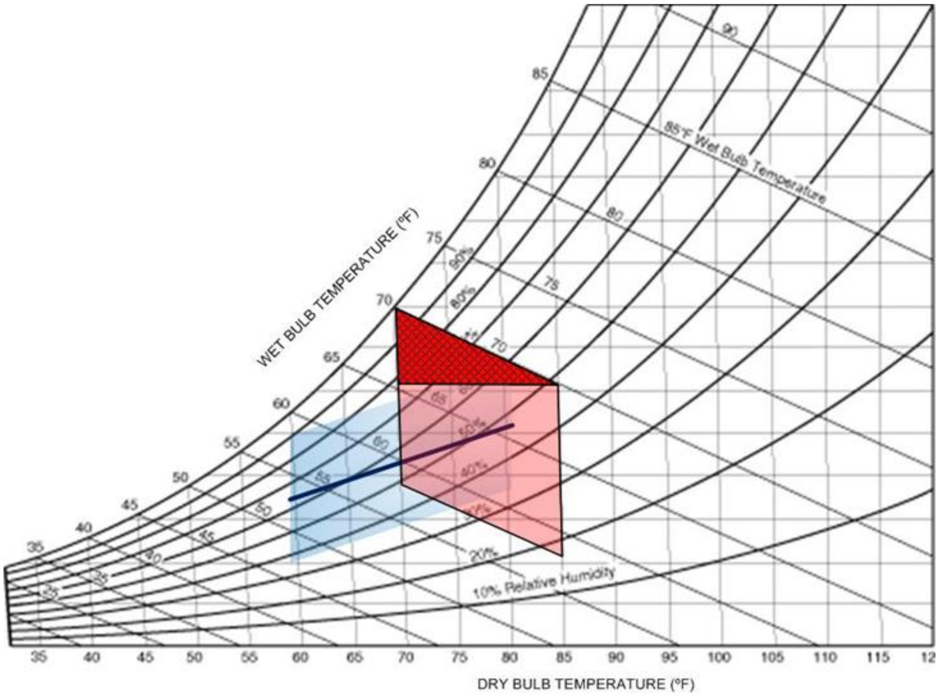


FIGURE 2. RANGE OF CONDITIONS FOR INDOOR UNIT

Figure 3 shows the range of conditions for an outdoor chamber on a psychrometric chart. The shaded red area shows the ODU range of operating conditions while in cooling mode. The blue area highlights the range of conditions to which the ODU operates while in heating mode. ANSI/AHRI Standard 1230 uses an outdoor condition of 95°F DBT / 75°F WBT as a rating condition for cooling mode and 47°F DBT / 43°F WBT as a rating condition in heating mode.

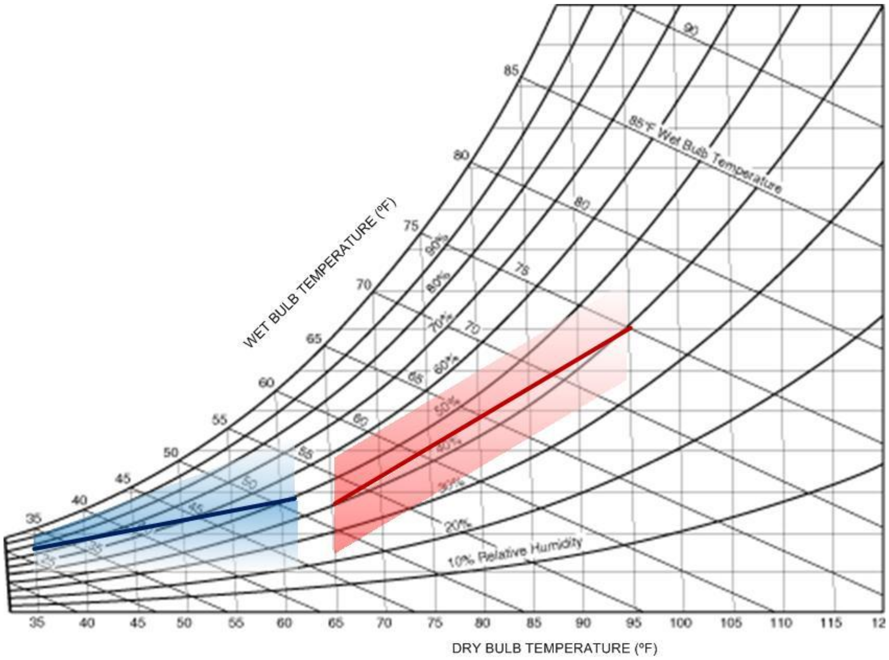


Figure 3. Range of Conditions for Outdoor Unit

Test Modes

The test unit was operated in five different modes:

- Full load cooling
- Full load heating
- Partial load cooling only
- Partial load heating only
- Heat recovery

The partial load tests and the heat recovery mode tests are a subset of the full load tests as far as indoor and outdoor conditions are concerned. The following conditions were chosen from Figure 2 and Figure 4 to represent some of the extremities.

Heating Mode:

Return air for IDU: 60°F DBT

Outdoor chamber condition: 34°F DBT / 33°F WBT. This condition was chosen to verify that the outdoor chamber could be maintained at 34°F DBT. This point, shown Figure 4, represents the lower left corner of the blue line in Figure 3.

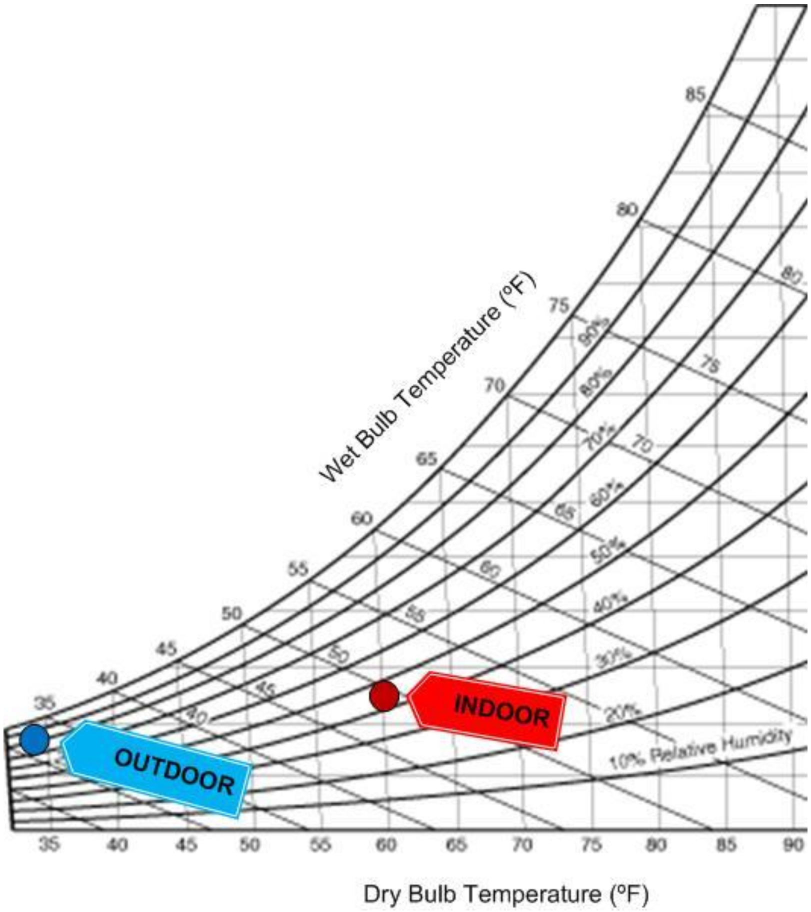


FIGURE 4. **INDOOR AND OUTDOOR CONDITIONS IN HEATING MODE**

Cooling Mode:

Return air for indoor unit: 85°F DBT / 70°F WBT

Outdoor chamber condition: 65°F DBT

The return air for the indoor unit requires 70°F WBT, which translates to 48% RH, as shown in Figure 5. This point represents the upper right corner of the shaded red area shown in Figure 2. These conditions also yield the highest cooling capacity of the unit within the operating envelope.

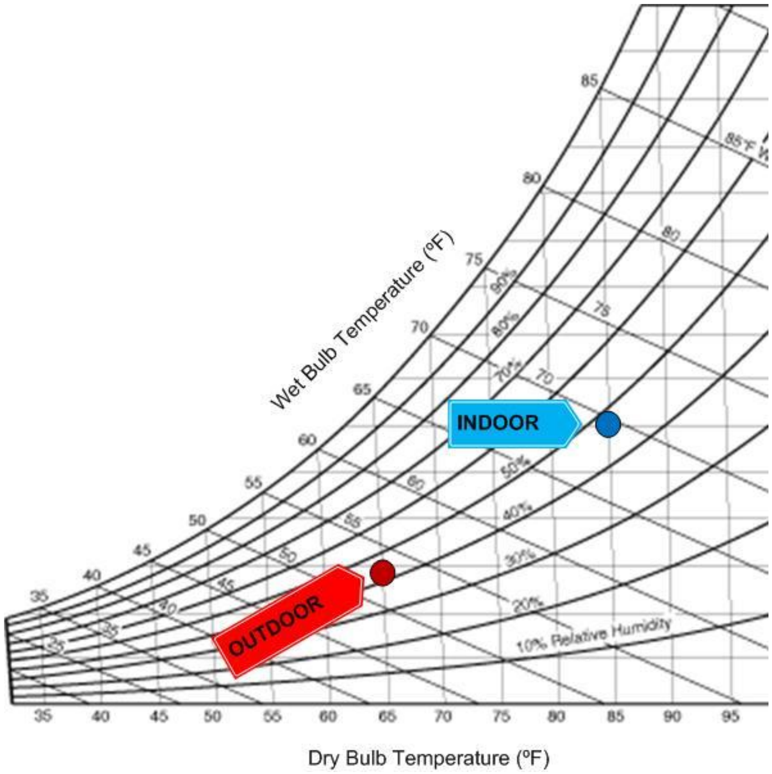


FIGURE 5. INDOOR AND OUTDOOR CONDITIONS IN COOLING MODE

Rating Test:

Return air for indoor unit: 80°F DBT / 67°F WBT

Outdoor chamber condition: 95°F DBT

This test, shown in Figure 6, is the stand rating condition from ANSI/AHRI Standard 1230. The condition is easy to reach, but was chosen for inclusion to verify that data collected during the test compared evenly with the published data from manufacturer.

FIGURE 6. INDOOR AND OUTDOOR CONDITIONS FOR RATING TEST

The test stand reached all the conditions on the indoor and outdoor sides. The RH conditions on the ODU during cooling mode are not critical and are controlled between 30% and 50%. This is in accordance with the ANSI / AHRI 1230 Standard. Since these tests were meant to be commissioning tests the only parameters of interest were test conditions. Detailed data collection and analysis reports were collected during the actual testing.

COMPONENTS CONTROLLED DURING TEST

To reach and maintain a particular set point, numerous components were controlled. Table 3 shows the hardware that was adjusted to maintain steady state conditions.

TABLE 3. LIST OF COMPONENTS CONTROLLED DURING A TEST

HARDWARE	CONTROLLER	TYPE	COMMENTS
HEATERS			
Duct	LabVIEW	PWM	Multiple safety interlocks, manual override
Chamber	Honeywell	PWM	
HUMIDIFIERS			
Duct	OEM	Modulated	Air/water atomizing humidifier control box
Chamber	Honeywell	PWM	Steam generator
DEHUMIDIFIER			
Duct	Cooling coil	ON/OFF	Cooling coil used for dehumidifying
Chamber	OEM	ON/OFF	Munters unit attached to the chamber
AIRFLOW			
Duct	Damper	Manual	
Overall airflow	Fan drive	Manual	Manually adjust fan speed to required flow rate
COOLING			
Duct	Solenoid valve	ON/OFF	Manually turn On/Off as per requirement
Chamber	Solenoid valve	ON/OFF	Manually turn On/Off as per requirement
TEST SYSTEM			
IDUs	OEM Remote		Set conditions on remote control provided
ODUs			Minimal control if any, reacts to set conditions

VARIABLES

The main data parameters collected are listed below.

Indoor Unit (four total):

- Return Air Temperature
- Return Air Relative Humidity
- Supply Air Temperature
- Supply Air Relative Humidity
- Airflow Rate
- Unit Power
- Liquid Line Temperature
- Suction Line Temperature
- Suction Line Pressure
- Refrigerant Flow Rate (only on one unit initially)
- Condensate Measurement

Outdoor Unit:

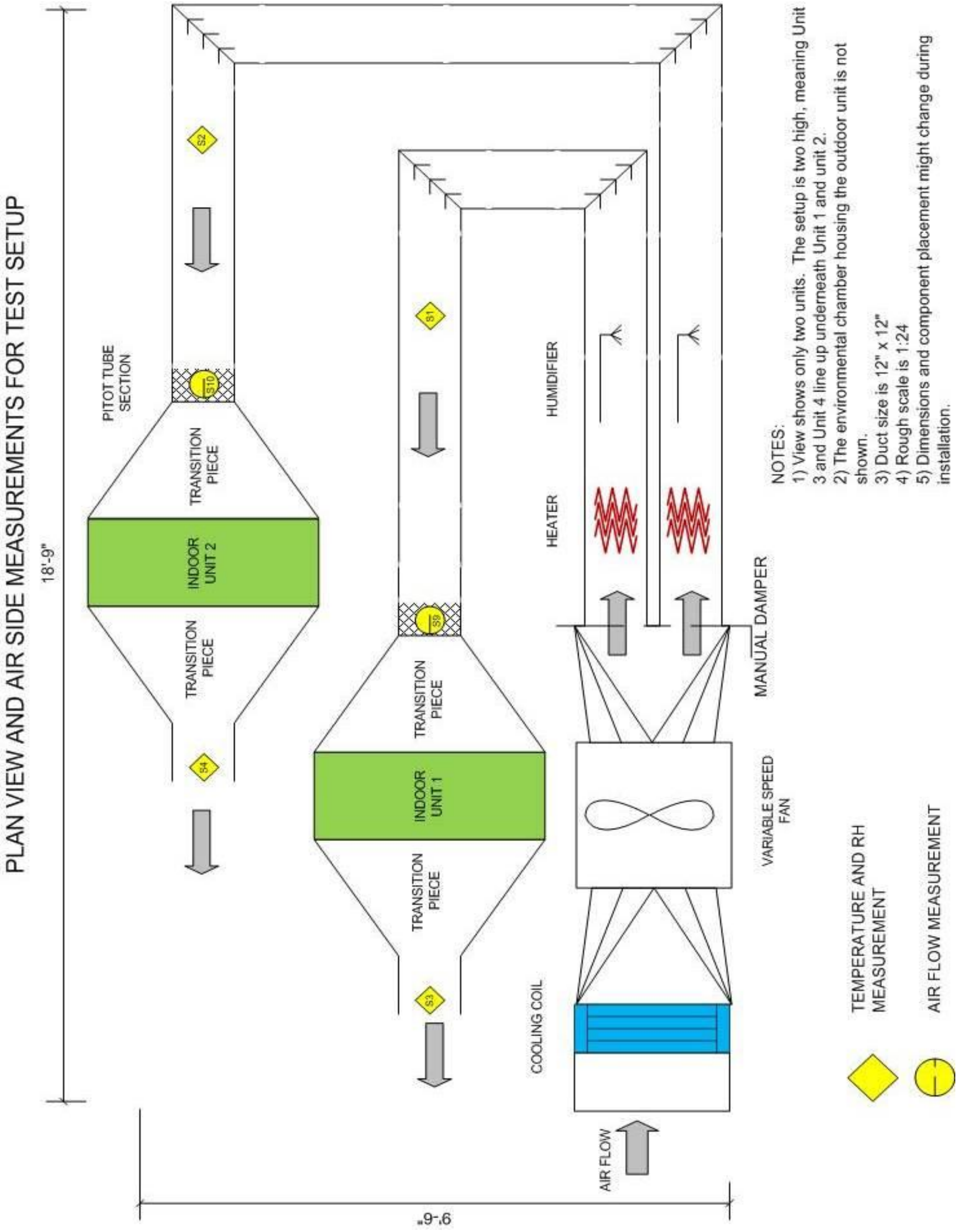
- Condenser Entering Air Temperature
- Condenser Entering Air Relative Humidity (or other moisture indicating measurement)
- Condenser Leaving Air Temperature
- Condenser Leaving Air Relative Humidity (or other moisture indicating measurement)
- Total Power
- Suction Line Temperature
- Suction Line Pressure
- Liquid Line Temperature

INSTRUMENTATION PLAN

The instrumentation plan describes the test stand design, experiment setup and data collection for testing variable refrigerant flow heat recovery (VRF-HR) systems. This serves as a guide for constructing the test stand at EPRI's Thermal Environmental Lab in Knoxville, TN.

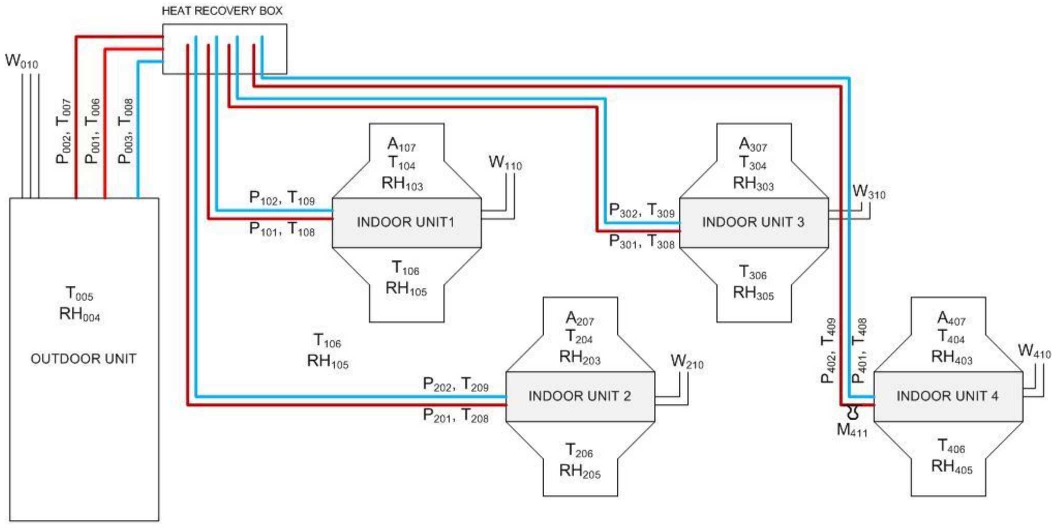
DATA ACQUISITION INSTRUMENTS

The data acquisition and control of the test stand were accomplished through a dedicated National Instruments PXI system. Programming was done in LabVIEW software from National Instruments. To calculate capacity, power consumed and COP, sensors and transducers were placed in the test setup. Some points were for input parameter and output measurement, while others were for general system diagnostics. The calibration dates of the equipment can be found in Appendix C. The general locations of the instrumentation are shown as a schematic in Figure 7. Figure 8 shows the entire instrumentation mapping.



NOTES:
1) View shows only two units. The setup is two high, meaning Unit 3 and Unit 4 line up underneath Unit 1 and unit 2.
2) The environmental chamber housing the outdoor unit is not shown.
3) Duct size is 12" x 12"
4) Rough scale is 1:24
5) Dimensions and component placement might change during installation.

FIGURE 7. TEST SETUP SCHEMATIC



Naming Convention:

(Physical Quantity)(Channel Number)

Details provided in Table 4

A	Air Flow Rate (cfm)
M	Refrigerant Mass Flow (lbs/hr)
P	Absolute Pressure (psia)
RH	Relative Humidity(%)
T	Temperature (^{0}F)
W	Power (W)

FIGURE 8. INSTRUMENTATION MAP

SENSORS

Table 4 shows the list of sensors and transducers used for data acquisition.

TABLE 4. LIST OF SENSORS AND TRANSDUCERS FOR DATA ACQUISITION

EQUIPMENT	H/W	P/N	QTY	COMMENTS
DATA ACQUISITION EQUIPMENT				
PRESSURE				
Differential Pressure				Airflow measurement
Pitot Tube	Veltron	DPT2500 Plus	4	Flow through IDU
Absolute Pressure				Refrigerant pressure
IDU (IN)	Setra	205-2	4	
IDU (OUT)	Setra	205-2	4	
Liquid Line	Setra	205-2	1	
Suction Line	Setra	205-2	1	
Hot Gas Line	Setra	205-2	1	
TEMP & RELATIVE HUMIDITY				Air side measurement
IDU (RETURN)	Vaisala	HMD60Y	4	
IDU (SUPPLY)	Vaisala	HMT333	4	
Return Air for test setup	Vaisala	HMD60Y	1	
Outdoor Chamber	Vaisala	HMD60Y	1	

EQUIPMENT		**H/W**	**P/N**	**QTY**	**COMMENTS**
TEMPERATURE					Refrigerant Temperature
	Liquid Line	Omega	Type T	1	
	Suction Line	Omega	Type T	1	
	Hot Gas Line	Omega	Type T	1	
	IDU (OUT)	Omega	Type T	4	
	IDU (IN)	Omega	Type T	4	
POWER					
	IDU	Shark	Shark 100T	4	For each IDU
	ODU	Shark	Shark 200T	1	For ODU

CIRCUITS

As described above, the test stand has four different circuits that control the temperature, relative humidity and flow rate of return air for indoor units. The following describes each of the circuits in detail.

Heating Circuit

The heating circuit used a three-phase, 208 volt (V), 7.5 kilowatt (kW) resistance heater for each duct. Figure 9 shows the heater wiring schematic. The main breaker was installed in the 208 V panel and manually operated. A 120 V circuit energized the contactor between the main breaker and the solid-state power switching relay. An airflow switch acted as a safety mechanism, which prevented the heaters from turning ON without any airflow through the ducts. All four heating circuits were tested individually to verify operation and check the airflow switches.

Each heating circuit was tested individually with a set temperature of 95°F on the computer. A PWM signal was generated by the control loop in the LabVIEW program. The RAT reached the set point of 95°F after 10 minutes. The same results were achieved for return air on all four units when all heaters were operated together.

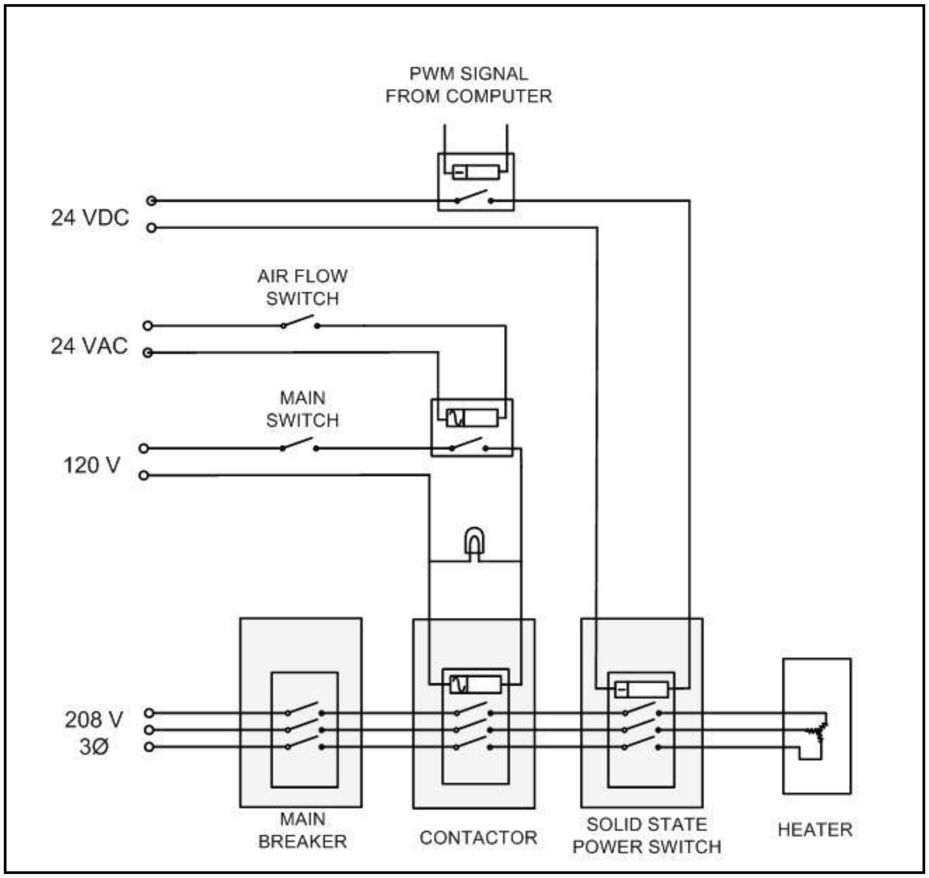


FIGURE 9. HEATER WIRING SCHEMATIC

COOLING AND DEHUMIDIFYING CIRCUIT

The cooling and dehumidification circuit shown in Figure 10 used two five-ton ODUs to provide a total staged capacity of 10 tons. The ODUs were controlled by two solenoid valves on the liquid lines, which were turned ON or OFF based on the cooling requirements. When the solenoid valve was in the OFF state, the ODU shut off on the low-pressure switch (which is an integral part of the ODU).

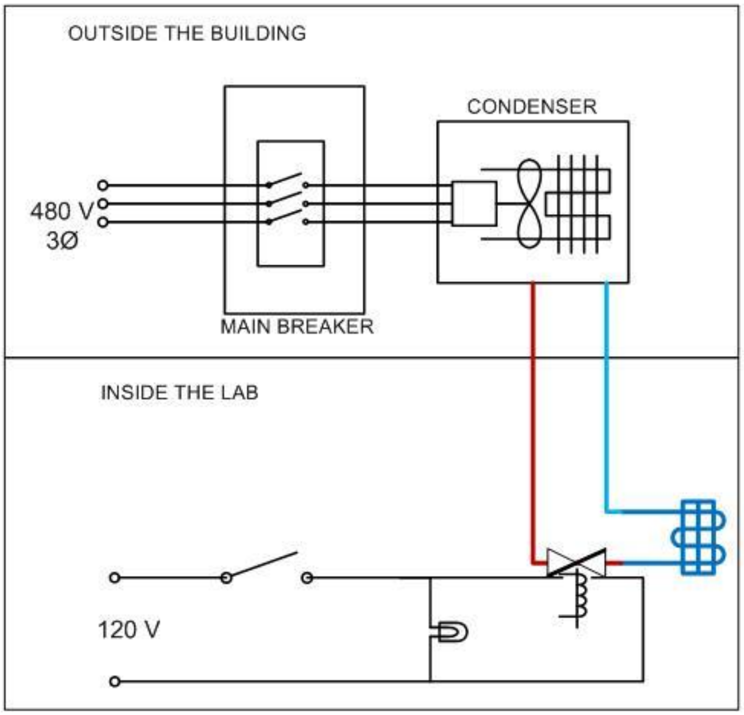


FIGURE 10. COOLING AND DEHUMIDIFICATION CIRCUIT

HUMIDIFICATION CIRCUIT

The humidification was carried out by four individual air / water atomizing humidifiers. Figure 11 shows the humidifier circuit. Each duct has its own humidifying nozzle and a control box to control the air and water mixture. The humidifiers are supplied with shop air (90 psi) and a utility water line (30 psi). The humidifiers were controlled in three ways:

1. Set point control: A humidifier was set to a certain percentage relative humidity (% RH) requirement and the built-in controller controls the return air humidity (RAH). This approach made the controller prone to hunting and did not yield very good control.
2. PID control from computer: Instead of using the humidifier controller, the computer acted as the controller, which gave the project team the ability to apply different control schemes and avoid the hunting issues associated with the on-board controller.
3. Manual control: Manual humidity control was provided either from the on-board controller or from the computer.

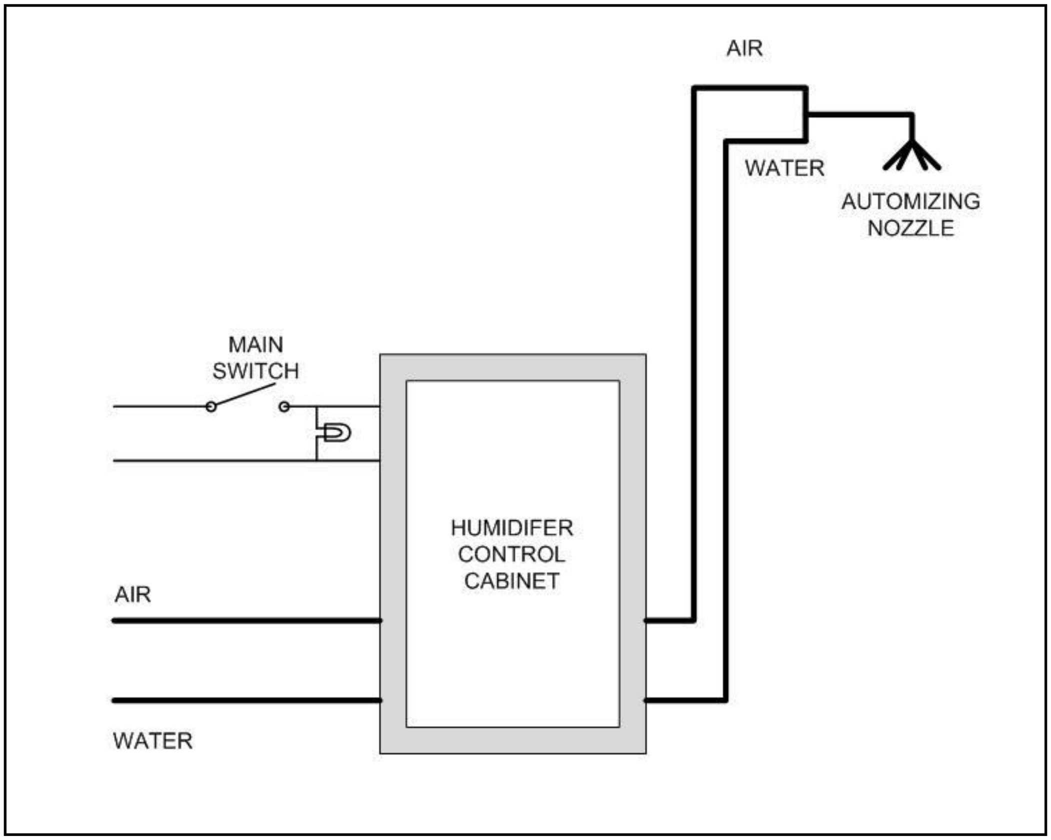


FIGURE 11. HUMIDIFIER CIRCUIT

A combination of manual control and PID control from the computer provided good humidity control.

AIRFLOW CIRCUIT

The rated airflow for each IDU was 671 cubic feet per minute (cfm). These IDUs cannot draw air through the ducted section of the test stand without affecting airflow. A variable speed axial fan was provided on the return airside, as shown in Figure 12, to overcome the resistance of the ducts, heater, cooling coil, blender and bends.

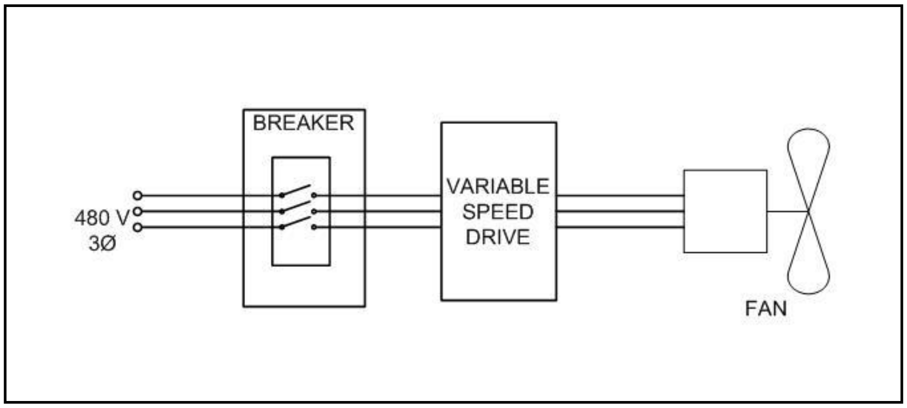


FIGURE 12. VARIABLE SPEED AXIAL FAN CIRCUIT

A pressure gauge was installed on each duct to measure the differential pressure between the inlet on the return air and the ambient pressure (shown in Figure 13). The differential pressure was dialed in to a zero value, indicating no pressure difference between return air and ambient air. This was accomplished by adjusting dampers on each duct and varying the fan speed. Once the damper position and the fan speed were fixed, there was no need to change the settings in subsequent tests for a given indoor fan speed. The fans on the IDUs have high, medium and low speed settings. The variable speed axial fan could be adjusted such that differential pressure between return air and ambient air was zero at the three different fan speeds.

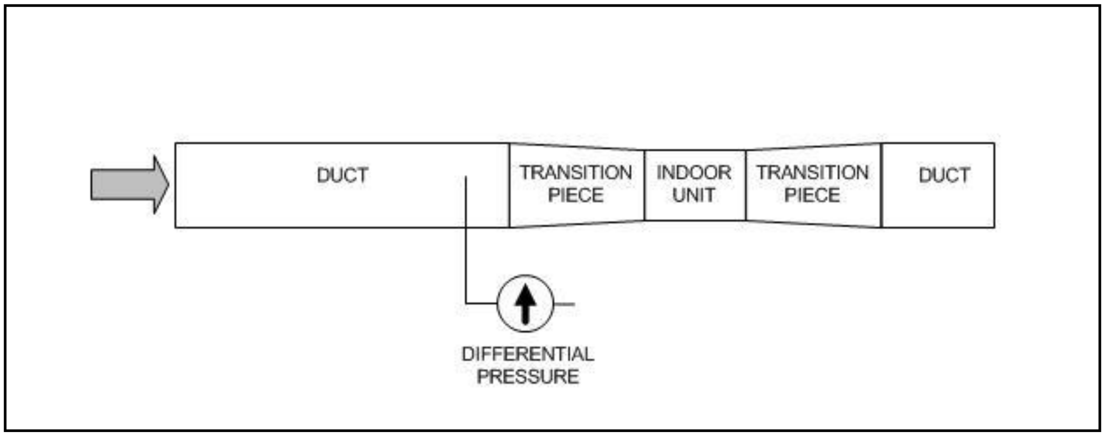


FIGURE 13. DIFFERENTIAL PRESSURE GAUGE

COOLING AND HEATING MODES

As the name suggests, the full load tests (heating and cooling) will be conducted with all four units providing heating or cooling at the same time. Partial load is simulated by turning off units. These tests will be conducted at full fan speed rated airflow, however, as time permits and as warranted by data collected, some tests may be performed with reduced indoor unit fan speed and airflow. The outdoor unit will be allowed to reach its natural steady-state fan speed as determined by the VRF control system. Since all conditions on the system remain constant in a given test, the VRF control system will regulate the fan speed to satisfy the load.

COOLING MODE

Generally, in the cooling mode, indoor units are supplied with liquid refrigerant. The amount of refrigerant flowing through the unit is controlled via an electronic expansion valve located inside the unit. when the refrigerant enters the coil it undergoes a phase change (evaporation) that extracts heat from the space, thereby cooling the room. the heat extracted from the space is exhausted to ambient air.

COOLING MODE OPERATION

The manufacturer’s refrigerant flow diagram in cooling mode operation is shown in Figure 14. The red lines indicate the flow of high-pressure refrigerant and blue lines indicate the flow of low-pressure refrigerant. Details of the labeled components in the refrigerant flow diagram are provided in Appendix C.

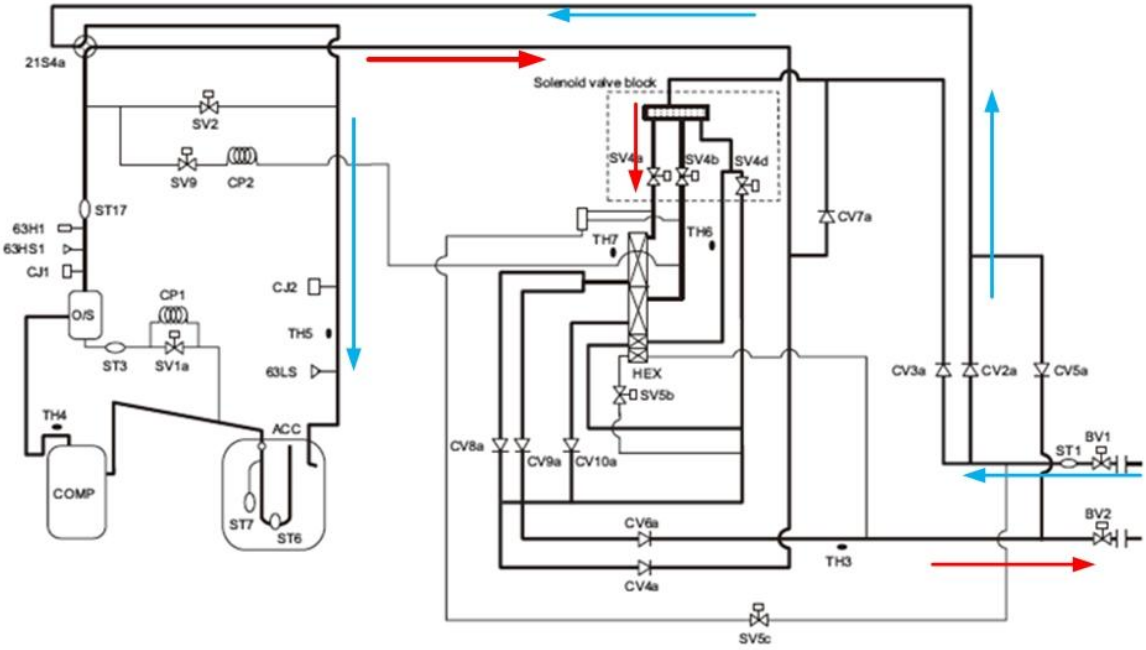


FIGURE 14. REFRIGERANT FLOW DIAGRAM FOR OUTDOOR UNIT IN COOLING MODE (LINE DIAGRAM FROM MANUFACTURER)

Figure 15 shows the refrigerant flow through the Branch Circuit (BC) controller. The diagram is not from the exact model used in the lab but the operating principles are the same. The high-pressure refrigerant is sub-cooled in the BC controller by tube-in-tube heat exchangers. The sub-cooled refrigerant is routed to the IDUs through the check valve block. The low-pressure superheated refrigerant comes back from the IDUs through the solenoid valve block and is routed back to the ODU.

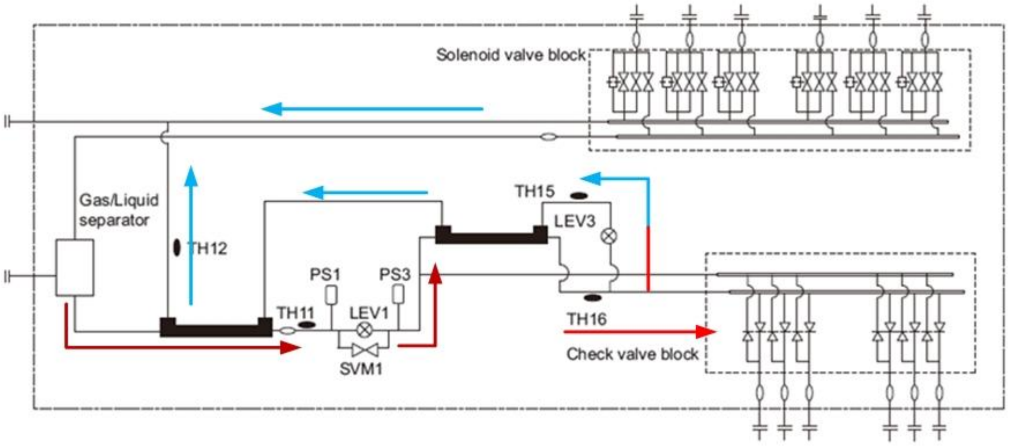


FIGURE 15. REFRIGERANT FLOW DIAGRAM IN BC CONTROLLER IN COOLING MODE (LINE DIAGRAM FROM MANUFACTURER)

COOLING MODE PERFORMANCE MAPPING

The reference point used in cooling mode was the AHRI rating condition of 95°F OD-DBT and 80°F RA-DBT / 67°F RA-WBT. The performance of the system was then tested under varying conditions:

- The OD-DBT was changed with constant RA conditions.
- The OD-DBT was held constant with varied indoor WBT and constant indoor DBT.
- All tests performed at above conditions were repeated by varying the RAT.
- At all the test points, the number of IDUs was changed (4, 3, 2, and 1) to obtain data for % IDU operation.

TEST METHOD FOR COOLING MODE TESTS

In cooling mode, the four temperature controllers were set at 67°F, which is the minimum possible temperature setting for cooling mode. The thermistors measure the temperature of the conditioned zone on the return side of each IDU. The RAT is held constant (above 67°F, typically 75°F, 80°F and 85°F) for a given test. Because the RAT is maintained higher than the thermostat setting of 67°F, the system runs continuously. The system adjusts the compressor speeds, the fan speed on the ODU and the electronic expansion values (EEVs) for each IDU. The system is considered to be operating in steady state if the conditions on the system (RA-DBT, RA-WBT, OD-DBT and the IDU airflow) and the supply air DBT are within the following tolerance zones for 10 minutes:

- RA-DBT and OD-DBT is ± 2 °F
- OD-WBT is ± 1°F
- IDU airflow is ± 2% of rated airflow
- Supply air temperature is ± 1°F

The percentage of IDU operation was also observed in cooling mode to gain an understanding of the capacity delivered and power consumed in conditions where one or more IDUs were turned off.

COOLING PERFORMANCE MAPPING – TEST RESULTS

Figure 16 shows capacity measurements from lab and the manufacturers’ data with varying outdoor DBT and varying RA-WBT. The RA-DBT is fixed at 80°F.

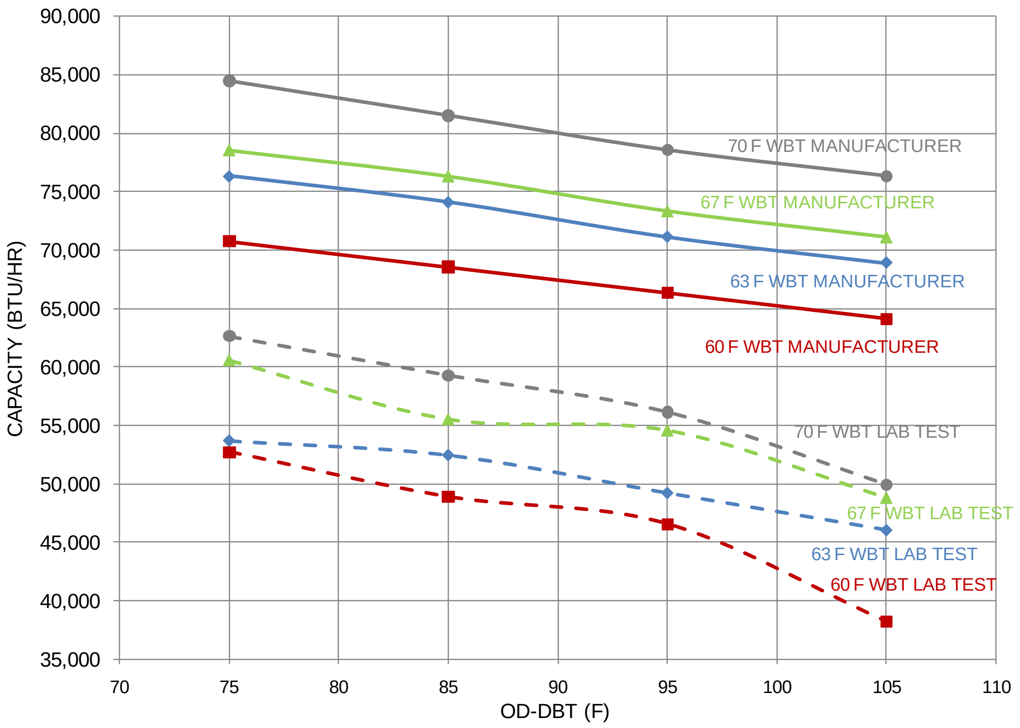


FIGURE 16. COOLING CAPACITY, VARYING OD-DBT AND RA-WBT

The manufacturer data is calculated from capacity charts provided by the manufacturer. Appendix A includes the manufacturer charts and the procedure to calculate capacity and power for the system under test. At the AHRI rating point of 95°F OD-DBT and 80°F RA-DBT / 67°F RA-WBT the measured capacity is 25% less than the manufacturer published data. All the other data points revealed similar lower capacity throughout the tested envelope. The overall trend in capacity followed the trend of the published data from the manufacturer. The cooling capacity is a function of the RA-WBT and OD-DBT. The cooling capacity decreases with increasing OD-DBT and increases with increasing RA-WBT.

Figure 17 shows the power measurements for the same conditions that are shown in Figure 16. The power measurements are close to the manufacturers' published data. The maximum difference of 10% is observed at the lower RA-WBT of 60°F. For all other data points, the difference in measured and published power is within 5%.

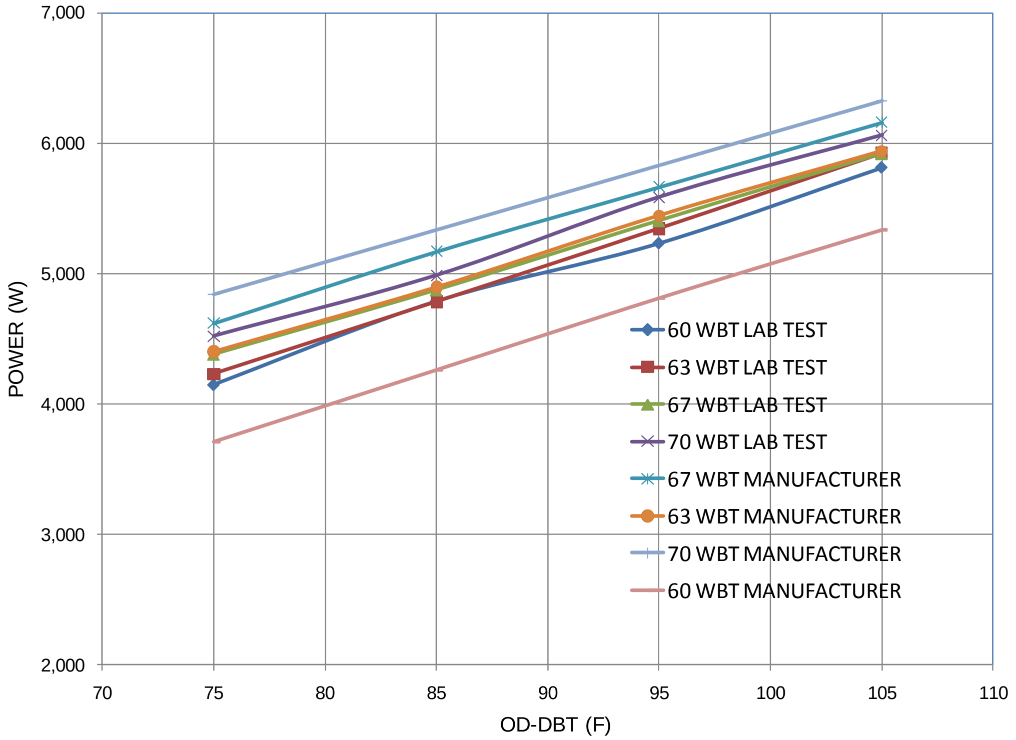


FIGURE 17. COOLING MODE POWER DRAW, VARYING OD-DBT AND RA-WBT

PERCENTAGE OF IDU OPERATION (COOLING MODE)

In a multi-zone system, one or more zones might not be calling for cooling. The system test results for four, three, two and one IDUs in cooling mode are shown in Figure 18. The system was tested at an outdoor condition of 95°F DBT and 80°F RA-DBT / 67°F RA-WBT. After steady state was reached on all four units, one IDU was turned off and the other three IDUs were kept running at the same conditions. Once steady state was reached on the three IDUs, another IDU was shut off and so on. The corresponding steps in percentage of IDU operation are 100%, 75%, 50% and 25%. Figure 18 shows results for the tests at an RA-WBT of 67°F. The cooling capacity provided by the aggregate system decreases as the units are turned off. The power usage for the same conditions is shown in Figure 19.

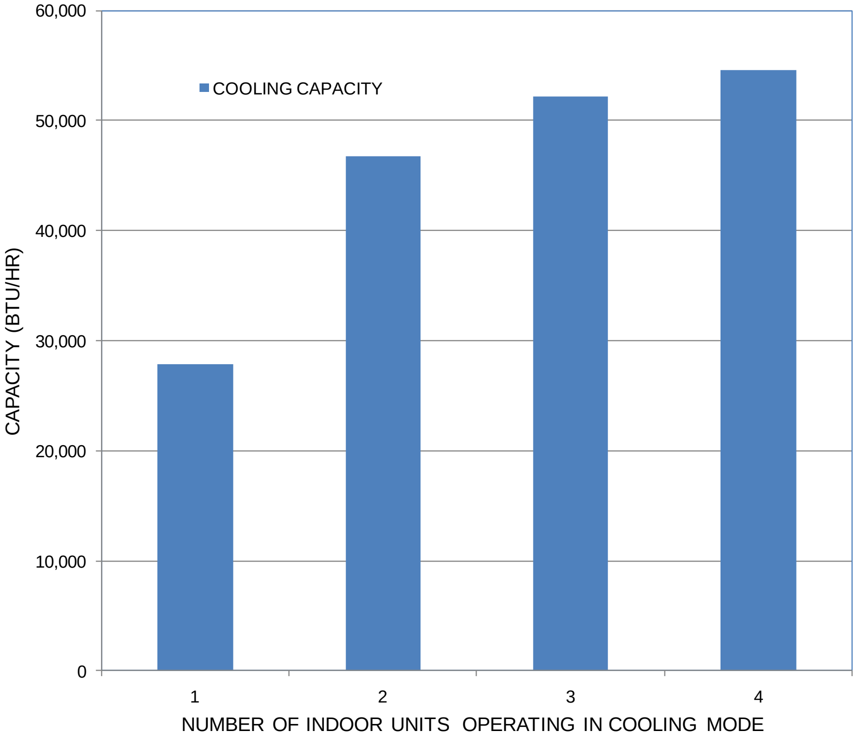


FIGURE 18. COOLING CAPACITY MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION

Starting with all four units operating, the total system capacity decreased as the number of IDUs were reduced. The individual capacity of each IDU increased as the number of IDUs was reduced. As a result, the drop in total capacity from four units operating to three to two units operating is not substantial. During the transition from four to three to two units, the compressor power is constant as seen in Figure 19. The operating parameter that changes during this transition is the suction pressure. The suction pressure is controlled to a set pressure of 103 psig by the system. The compressor is running full speed until only one IDU is calling for cooling, at which point the compressor speed reduces to attain the required suction and hence the reduction in power seen in Figure 19.

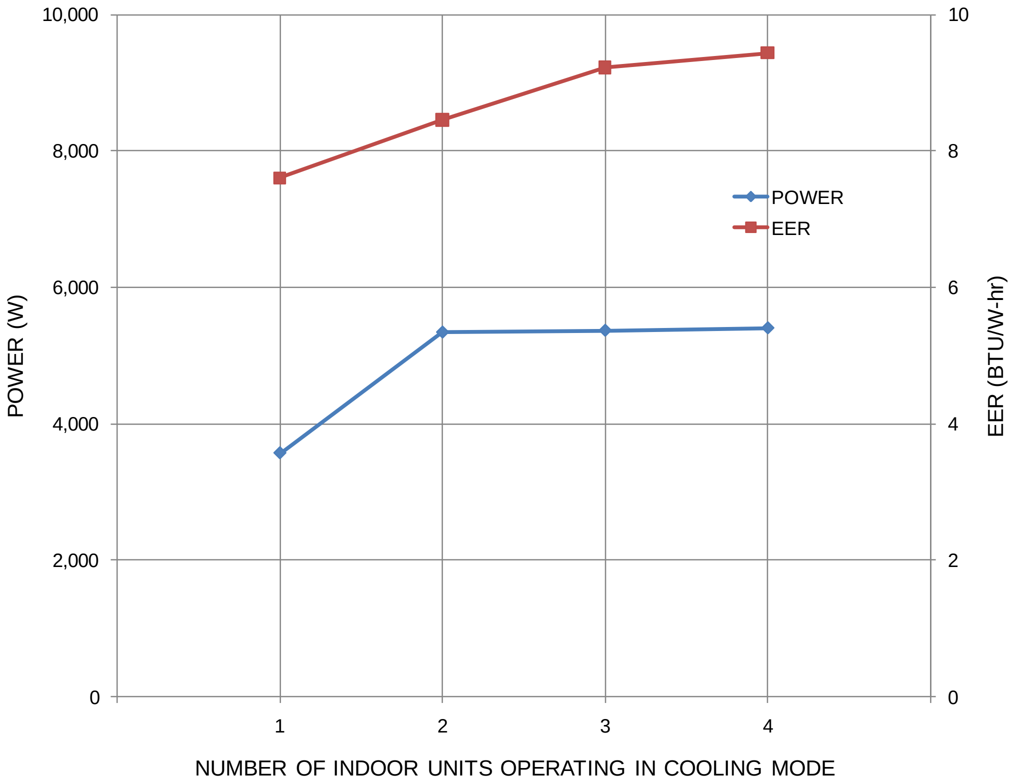


FIGURE 19. POWER AND EER MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION

HEATING MODE

When the equipment operates in heating mode, indoor units are supplied with hot gas refrigerant. Again, the amount of hot gas flowing through the unit is controlled via the same electronic expansion valve. As with the liquid refrigerant, the hot gas undergoes a phase change (condensation), which releases heat energy into the space.

HEATING MODE OPERATION

The manufacturer’s refrigerant flow diagram in heating mode operation is shown in Figure 20. The red lines indicate the flow of high-pressure refrigerant and blue lines indicate the flow of low-pressure refrigerant. The reversing valve switches the direction of refrigerant in heating mode operation and refrigerant bypasses the outdoor heat exchanger. The hot refrigerant is routed to the IDUs by the BC controller. The low-pressure, low-temperature refrigerant returns back to the ODU and is routed through the ODU heat exchanger to absorb heat from the ambient air. It should be noted that the ODU does not have an expansion valve. The BC controller expansion valve is used as the throttling device in heating mode.

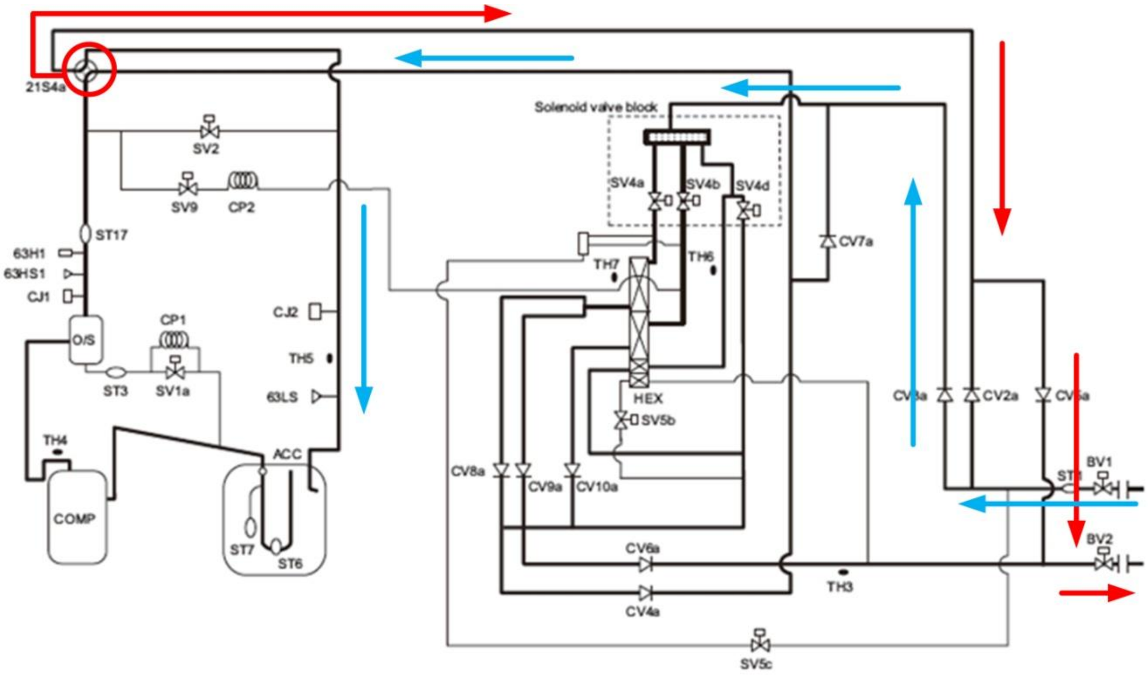


FIGURE 20. REFRIGERANT FLOW DIAGRAM FOR OUTDOOR UNIT IN HEATING MODE (LINE DIAGRAM FROM MANUFACTURER)

Figure 21 shows the refrigerant flow through the BC controller. The high-pressure, high-temperature refrigerant is routed straight to the IDUs. The refrigerant is condensed in the IDUs and the liquid returns back to the BC controller. The BC controller routes the high-pressure liquid refrigerant back to the ODU through the expansion valve. The pressure drops as the refrigerant flows through the expansion valve, which provides the throttling effect.

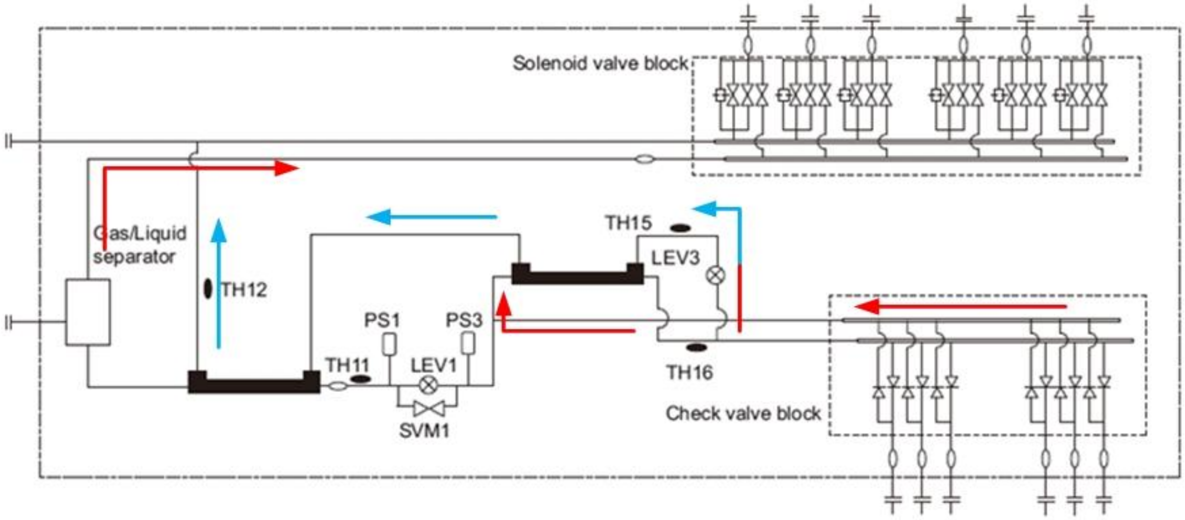


FIGURE 21. REFRIGERANT FLOW DIAGRAM IN BC CONTROLLER IN COOLING MODE (LINE DIAGRAM FROM MANUFACTURER)

HEATING MODE PERFORMANCE MAPPING

The reference point used in heating mode was the AHRI rating condition of 47°F OD-DBT / 43°F OD-WBT and 70°F RA-DBT. The performance of the system was then tested under varying conditions:

- The outdoor DBT and WBT was changed with constant RA conditions.
- All tests performed at above conditions were repeated by varying the RAT.
- At all the test points, the number of IDUs was changed (4, 3, 2, and 1) to obtain data for percentage of IDU operation.

TEST METHOD FOR HEATING MODE TESTS

In heating mode the four temperature controllers were set at 83°F, which is the maximum possible temperature setting for heating mode. The thermistors measure the temperature of the conditioned zone on the return side of each IDU. The RAT is held constant (below 83°F, typically 65°F, 70°F and 75°F) for a given test. Because the RAT is maintained lower than the thermostat setting of 83°F, the system runs continuously. The system adjusts the compressor speeds, the fan speed on the ODU and the EEV's for each IDU. The system is considered to be operating in steady state if the conditions on the system (RA-DBT, OD-WBT, OD-DBT and the IDU airflow) and the supply air DBT are within the following tolerance zones for 10 minutes:

- RA-DBT and OD-DBT is ± 2 °F.
- OD-WBT is ± 1°F.
- IDU airflow is ± 2% of rated airflow.
- Supply air temperature is ± 1°F.

The percentage of IDU operation was also observed in heating mode to gain an understanding of the capacity delivered and power consumed in conditions where one or more IDUs were turned off.

HEATING PERFORMANCE MAPPING – TEST RESULTS

Figure 22 shows the heating capacity measurements at various OD-WBT and varying indoor RAT. The solid red line shows the manufacturer-published data at 70°F RAT with corrections applied for indoor capacity, OD-WBT and piping length. The lab data follows the manufacturer's trend until a certain point. In the case of 70°F RAT, the manufacturer's data shows that after a certain upper limit on the OD-WBT (37°F WBT) the capacity does not increase. In lab test though, the capacity increased linearly with increase in OD-WBT. For the period where the capacity increases with increasing WBT, the lab data follows the trends with a 15% lower capacity. The system does not show a flattening of capacity measurements as published by the manufacturer.

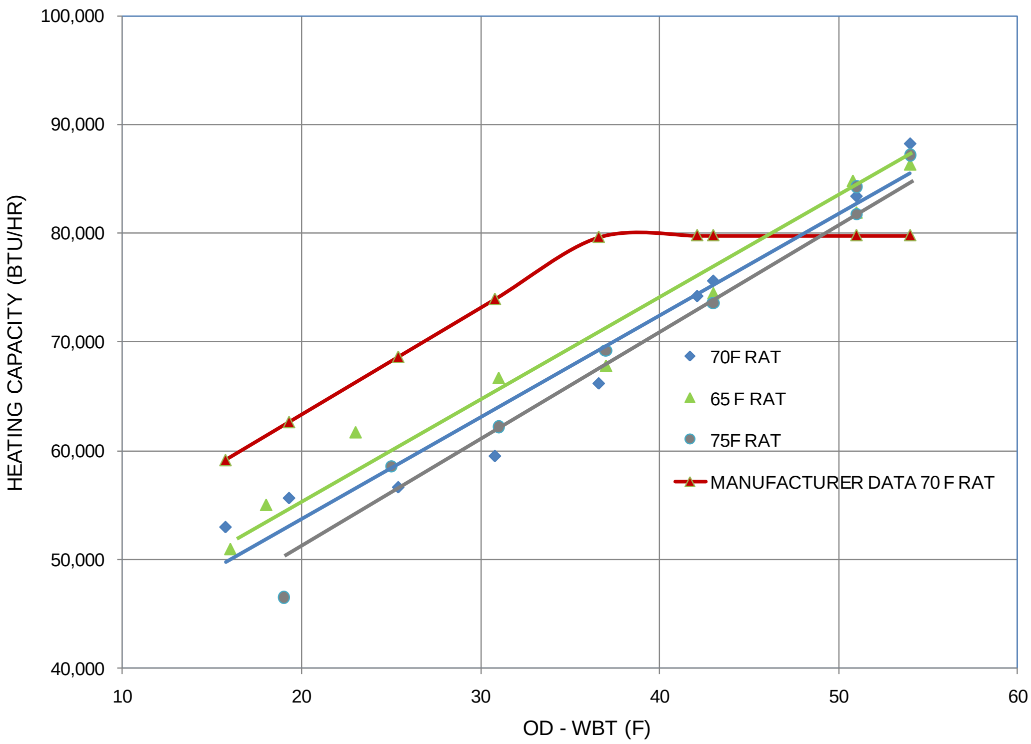


FIGURE 22. HEATING CAPACITY, VARYING OD-WBT AND RA-DBT

The data looks very similar if the chart is plotted as a function of OD-DBT instead of OD-WBT. The OD-WBT was chosen because the manufacturer published the data in terms of OD-WBT. Figure 22 and Figure 23 show the power draw and the COP in heating mode. The power draw trends are different from the manufacturer-published data. The red line in Figure 23 shows the manufacturer published power data for a 70°F RAT. From manufacturer’s data, the power draw increases until about 38°F WBT and then decreases. The lab data shows a different characteristic in which the power draw actually decreases right around the 38°F WBT mark and then increases again as the WBT increases. The COP values are not published by the manufacturer.

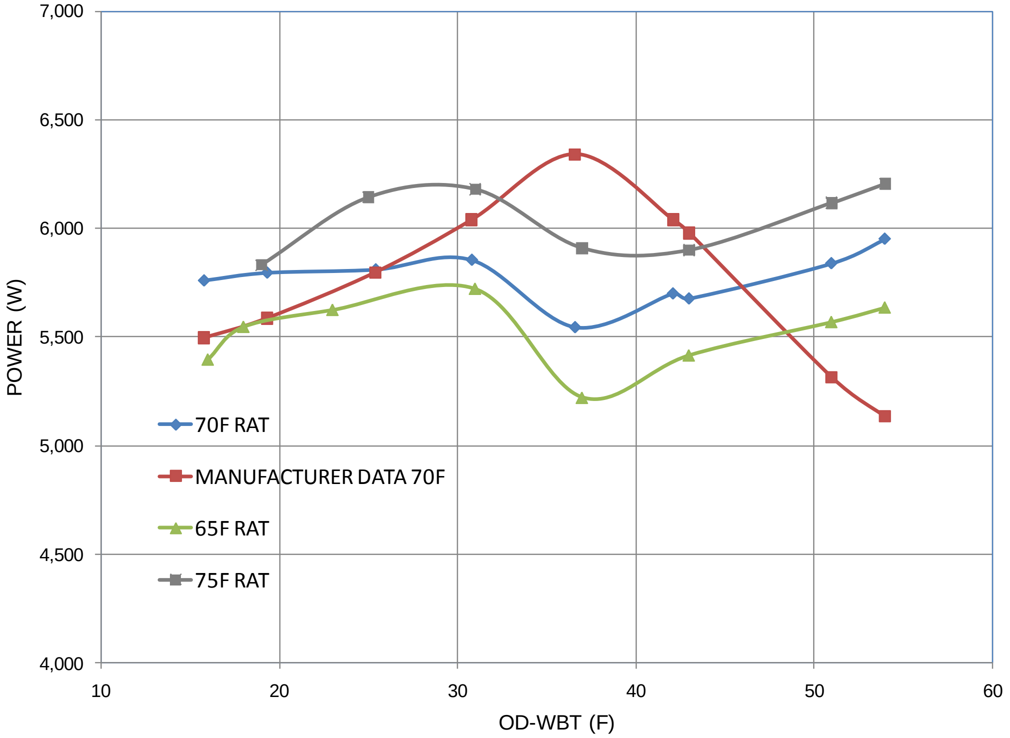


FIGURE 23. HEATING MODE POWER DRAW, VARYING OD-WBT AND RA-DBT

A linearly increasing trend in COP is observed in the COP chart (Figure 24).

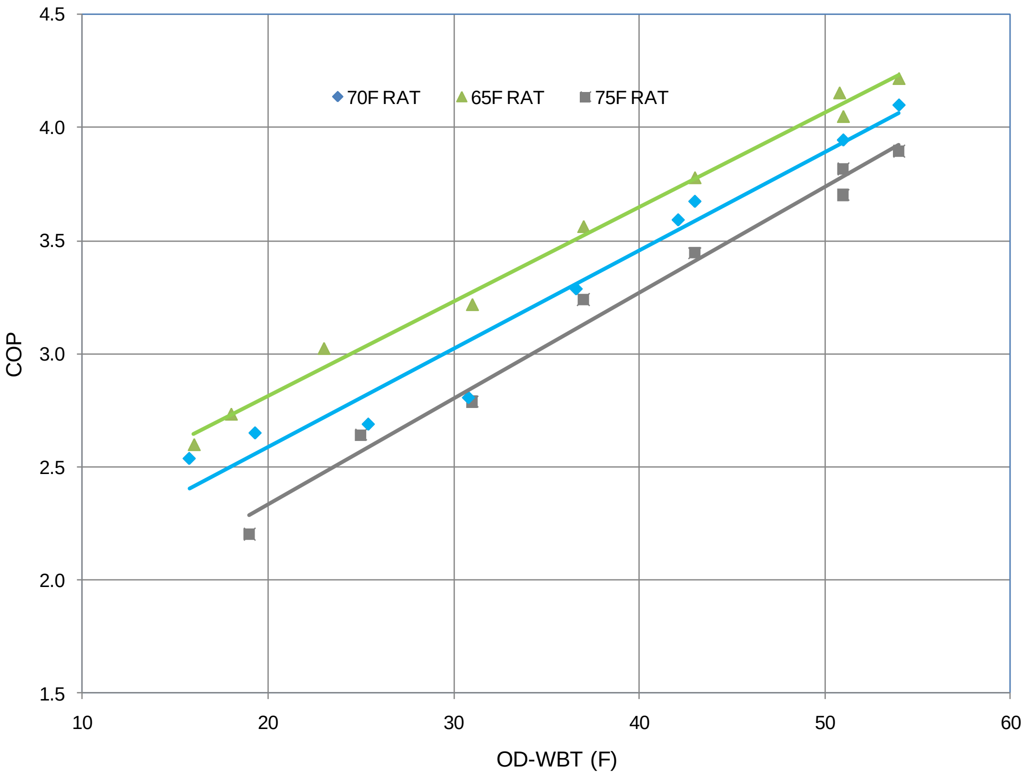


FIGURE 24. HEATING MODE COP, VARYING OD-WBT AND RA-DBT

PERCENTAGE OF IDU OPERATION (HEATING MODE)

In a multi-zone system, one or more zones might not be calling for heating. The systems test results for four, three, two and one IDUs in heating mode are shown in Figure 25. The system was tested with all four IDUs running at return air condition of 70°F DBT and outdoor condition of 47°F DBT / 43°F WBT.

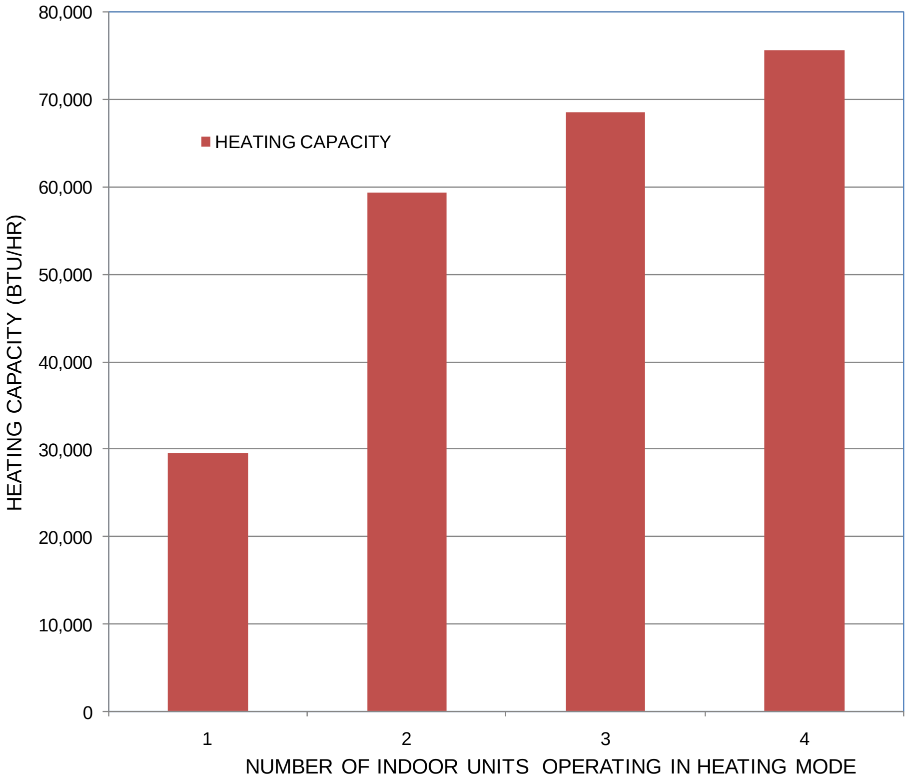


FIGURE 25. **HEATING CAPACITY MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION**

After steady state was reached on all four IDUs, one IDU was turned off and the system was allowed to run with three IDUs. Once steady state with three IDUs was reached, the same procedure was followed to collect data for two units and one unit operating in heating mode. The corresponding steps in percentage of IDU operation are 100%, 75%, 50% and 25%. Figure 25 shows the total capacity increasing with the increasing number of IDUs turned ON. The individual capacity of each unit decreases as the number of units turned ON increases. For example, when two units are ON, the capacity is close to 60,000 Btu/hr, but with three IDUs ON, the capacity only increases to 68,000 Btu/hr. This is because the compressor is running at maximum load and cannot provide any more output. This is further confirmed by the compressor power, which remains constant. In the case of only one unit running, the control system reduces the compressor speed to meet the high-pressure setpoint of 418 psig.

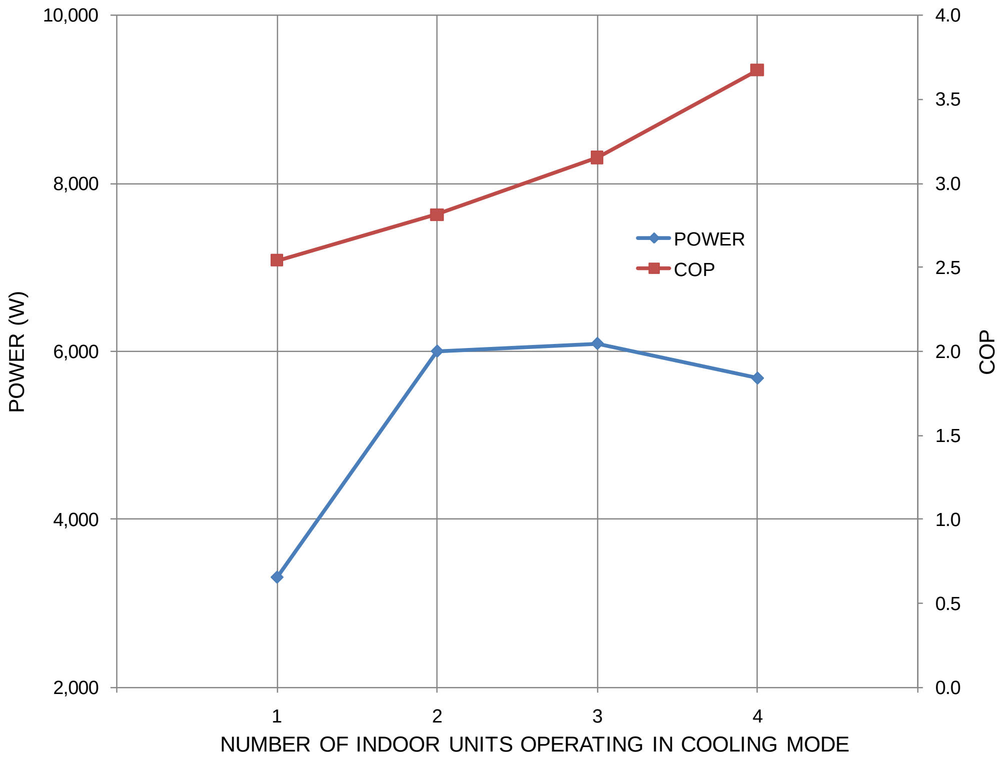


FIGURE 26. POWER AND EER MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION

SIMULTANEOUS COOLING AND HEATING MODE (SCH)

In this project, the performance of a simultaneous heating and cooling heat pump was investigated in the heat recovery mode. This mode is described in detail in the sections below.

SCH MODE OPERATION

In SCH mode, the system has the ability to deliver cooling or heating required by each zone, independent of other zones. In this mode, one IDU can be in cooling mode while other three can be in heating mode. An example of such an installation is an office building where the server room needs cooling even in winter months whereas the office space needs heating. Another example is a building in which the east facing side of building has higher heat load in the morning, requiring cooling mode operation, whereas the west facing side or internal zones might require heating mode operation. The ability of the system to redistribute energy from one zone to another without rejecting or absorbing all the energy from outdoor air results in tremendous energy savings.

To achieve this exchange of energy between individual zones, the BC controller plays a critical role. With multiple solenoid valves and compact refrigerant-to-refrigerant heat exchangers, the BC controller can transfer liquid, hot gas and low-pressure gas amongst the IDUs and the ODU to satisfy the requirements of each zone. As a result, the ODU sees only the net requirement of the total system. This means if the system needs more cooling capacity than heating capacity, the ODU acts as a condenser, providing only the difference between cooling and heating requirements. If the system needs more heating capacity than cooling capacity, the ODU acts as an evaporator, providing the difference between the heating and cooling requirements.

In the two-pipe system that was tested, the refrigerant flow path is controlled by the BC controller. The ODU has two pipe connections; one pipe is the refrigerant supply line and the other is the refrigerant return line. These two pipes from the ODU are connected to the BC controller. Each individual IDU is also connected to the BC controller with two pipes. The refrigerant flow circuit inside a BC controller is shown in Figure 27. A gas liquid separator separates out the liquid refrigerant from the vapor inside of the BC controller. The solenoid valve block and the check valve block together control the direction of refrigerant flow through each IU. The two tube-in-tube heat exchangers (solid black U-shaped components) control the sub cool and super heat depending on the mode in which the ODU is operating. The expansion valves LEV 1 and LEV 3 are controlling the amount of refrigerant flowing through each circuit. Multiple pressure sensors and thermistors incorporated within the BC box are used to determine the state of refrigerant at each point and to control expansion and solenoid valves as determined by the control logic. The BC controller also has multiple strainers (not shown in the flow diagram) as a safety mechanism for catching any debris in case of a failure. The BC controller that was installed in the EPRI lab was a different model number than the one shown in this refrigerant flow diagram and was capable of handling five indoor units instead of six shown in Figure 27.

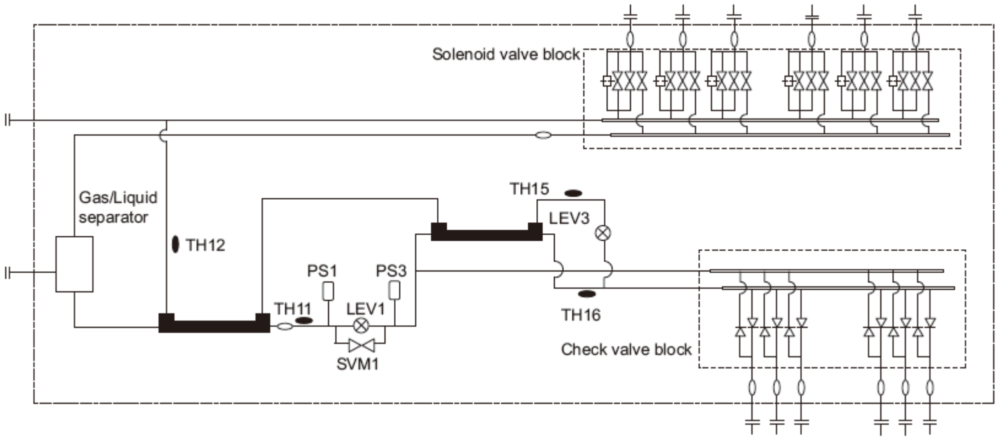


FIGURE 27. REFRIGERANT FLOW DIAGRAM BC BOX AND INDOOR UNITS (FROM MANUFACTURER)

Figure 28 shows the refrigerant flow diagram in the ODU. In simultaneous cooling and heating operation, the outdoor unit acts either as a condenser or as an evaporator. The two modes are described as heating main mode or cooling main mode. In heating main mode, three or more IDUs are running in heating mode while in cooling main mode two or more IDUs are running in cooling mode.

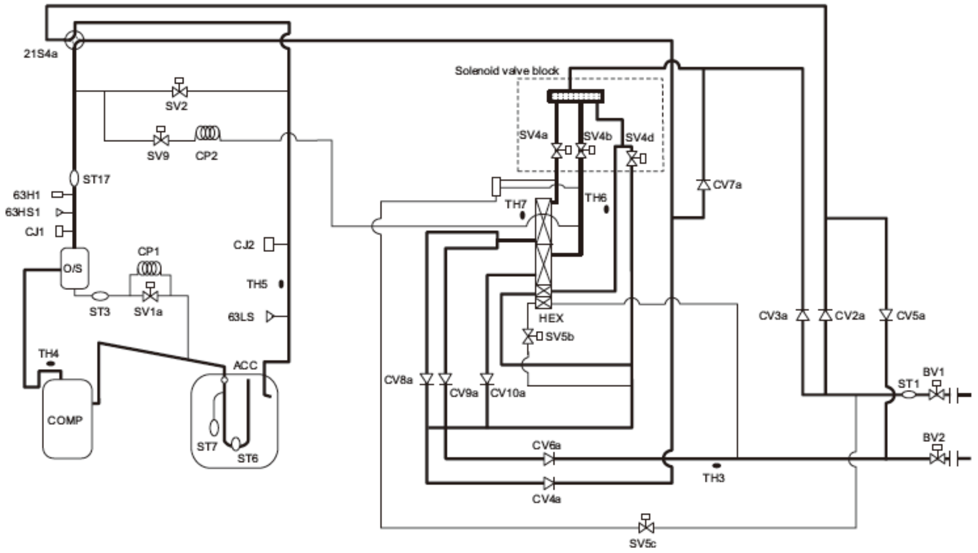


FIGURE 28. OUTDOOR UNIT REFRIGERANT FLOW DIAGRAM (FROM MANUFACTURER)

The cooling main mode operation is shown in Figure 29. The red arrows indicate high-pressure, high-temperature refrigerant coming from the compressor. The reversing valve directs this refrigerant through the solenoid valve block and the ODU heat exchanger and out to the BC controller.

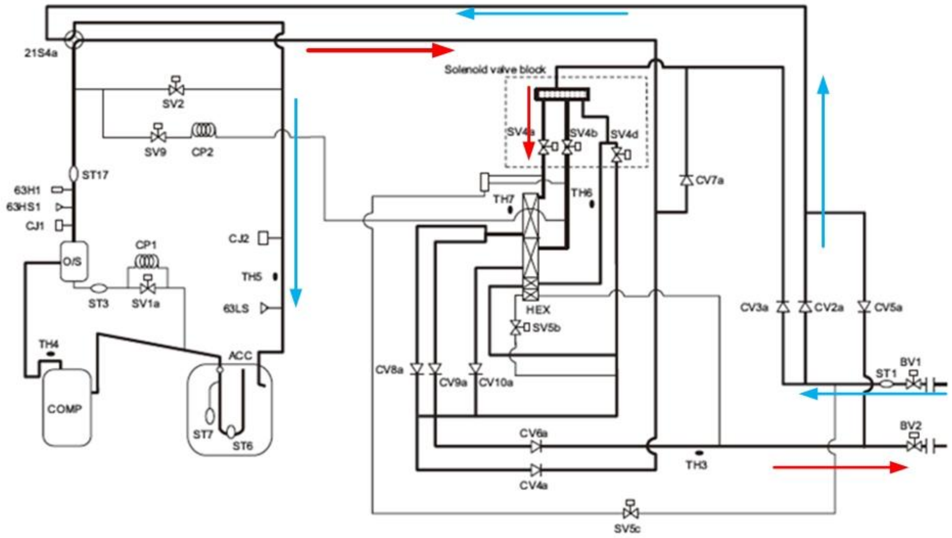


FIGURE 29. OUTDOOR UNIT REFRIGERANT FLOW PATH IN COOLING MAIN MODE

In cooling main mode, the three solenoid valves connected to the ODU heat exchanger are individually controlled to allow flow through each circuit. Depending on the cooling required, heat exchanger circuits are brought in or cut out. In cooling main mode, full capacity of the outdoor heat exchanger is not utilized so as to allow high-temperature refrigerant to flow from the ODU to the IDUs that are in heating mode. The ODU fan is also modulated so that heat is not lost to the ambient air. In the BC controller (as shown in Figure 27), the hot gas flows through the solenoid block to the IDUs calling for heat. The hot gas is condensed by losing heat to the room air that flows over the heat exchanger. The liquid refrigerant flows back to the BC controller and is rerouted internally by the check valve block. This liquid refrigerant and the liquid refrigerant from the gas/liquid separator is sub cooled with the help of two tube-in-tube heat exchangers. The sub cooled liquid refrigerant is then routed back through the check valve block to the IDUs running in cooling mode. The low-pressure refrigerant from the IDUs in cooling mode returns back through the solenoid block into the BC controller and is routed back to the ODU. In the ODU, the-low pressure refrigerant flows back through the reversing valve to the accumulator and then into the compressor.

Figure 30 shows the ODU refrigerant flow path in heating main mode. In heating main mode the reversing valve routes the high-pressure, high-temperature refrigerant from the compressor straight to the BC controller. The red arrows in Figure 30 show the path of the refrigerant. In the BC controller the high-temperature, high-pressure refrigerant is routed to the IDUs in heating mode through the solenoid valve block. The high-pressure, high-temperature refrigerant condenses in the units calling for heat and the liquid refrigerant returns back to the BC controller through the check valve block. The refrigerant flow is then routed through the sub cooling circuit to sub cool it further for the units running in cooling mode. Finally, the low-pressure gas from the unit in cooling mode and the liquid refrigerant from the sub cooling circuit are routed back to the ODU. In the ODU the solenoid valve block directs the refrigerant flow through the heat exchanger circuit and where the refrigerant gains heat from the ambient air.

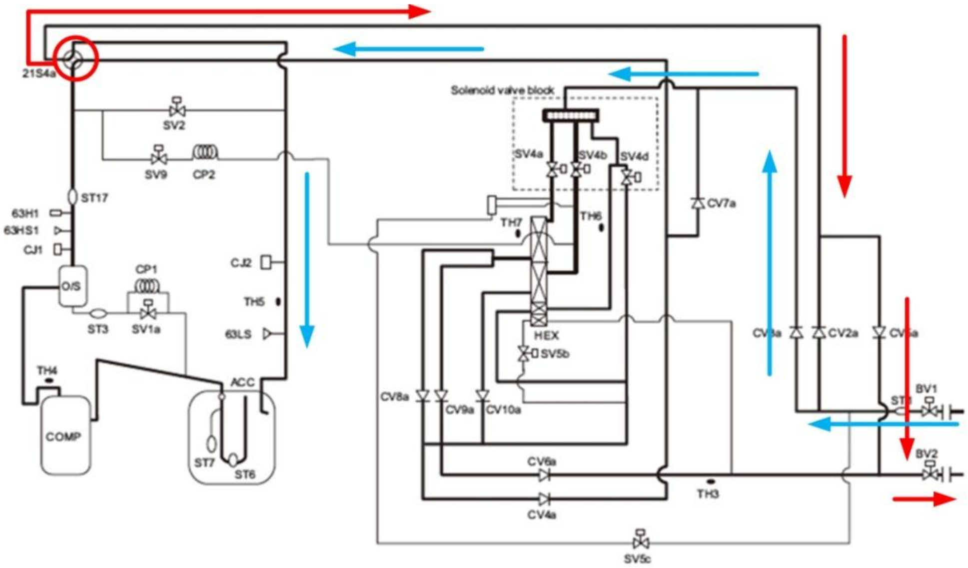


FIGURE 30 . OUTDOOR UNIT REFRIGERANT FLOW PATH IN HEATING MAIN MODE

SCH MODE PERFORMANCE MAPPING

The AHRI simultaneous cooling and heating test condition has a set outdoor condition of 47°F DBT and 43°F WBT. Since SCH mode is predominantly used in milder climates, outdoor temperatures of 65°F and 75°F DBT were studied. For comparison with the data obtained in cooling mode tests additional outdoor temperatures of 85°F and 95°F were also evaluated. The system was tested using the following procedure:

- Outdoor temperature was maintained at 65°F, 75°F, 85°F and 95°F (four data sets).

- The return air conditions for units in cooling mode are 80°F DBT / 67°F WBT and 75°F DBT / 63°F WBT.
- Return air conditions for units in heating mode are 65°F, 70°F and 75ºF.
- The number of units in cooling mode and heating mode are varied to study the effect on capacity and power.

EFFECT OF CHANGING MODES ON CAPACITY AND POWER

Figure 31 shows the effect on capacity of changing modes. The OD-DBT in this case is 65°F and the return air in cooling mode is at 80°F DBT / 67°F WBT in cooling mode and 70°F in heating mode. In "4 COOL" mode each individual temperature controller is set in cooling mode and the resulting capacity and power is measured. After capturing data in steady state, one of the temperature controllers is set to heating mode with a target temperature of 83°F DBT and the remaining three are in cooling mode.

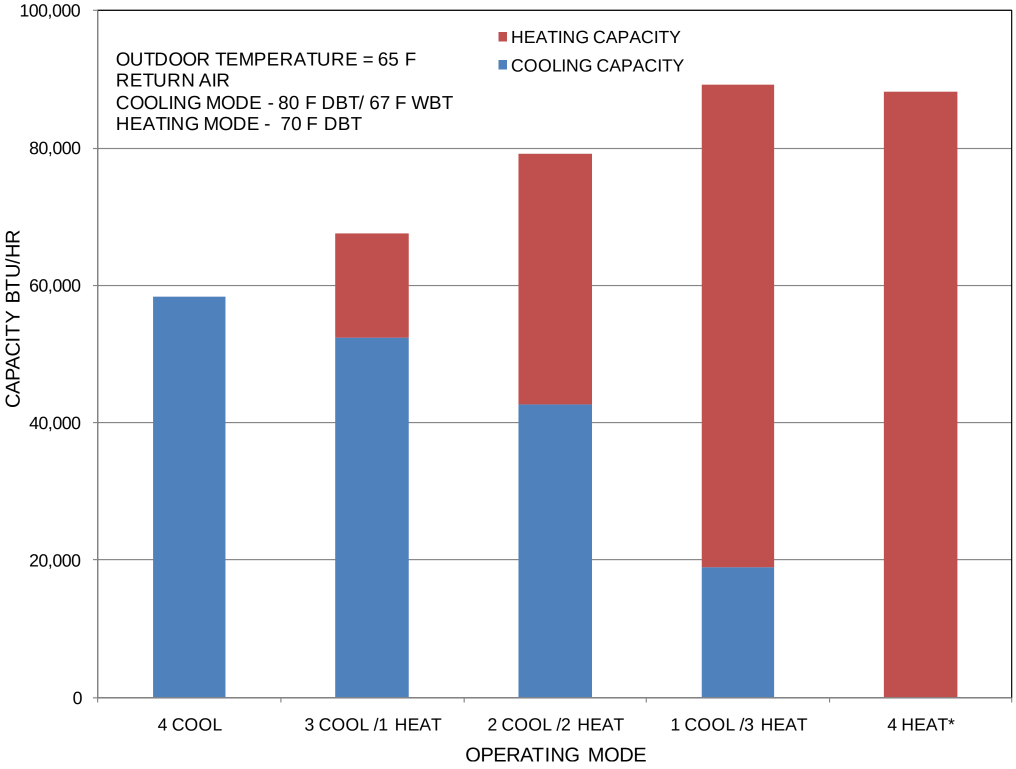


FIGURE 31. CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES (65F)

In the "3 COOL/1 HEAT" mode the ODU runs in a cooling main mode and in "1 COOL/3 HEAT" mode the ODU runs in a heating main mode. Figure 31 shows that as the units are turned to heating mode, the heating capacity starts increasing and the cooling capacity starts decreasing. The data point with all four units in heating mode is at 60ºF outdoor temperature. The power and EER of the system operating at various conditions is shown in Figure 32. The power draw is dependent on the operating mode of the ODU. Figure 32 also reveals some interesting characteristics of the two-pipe system.

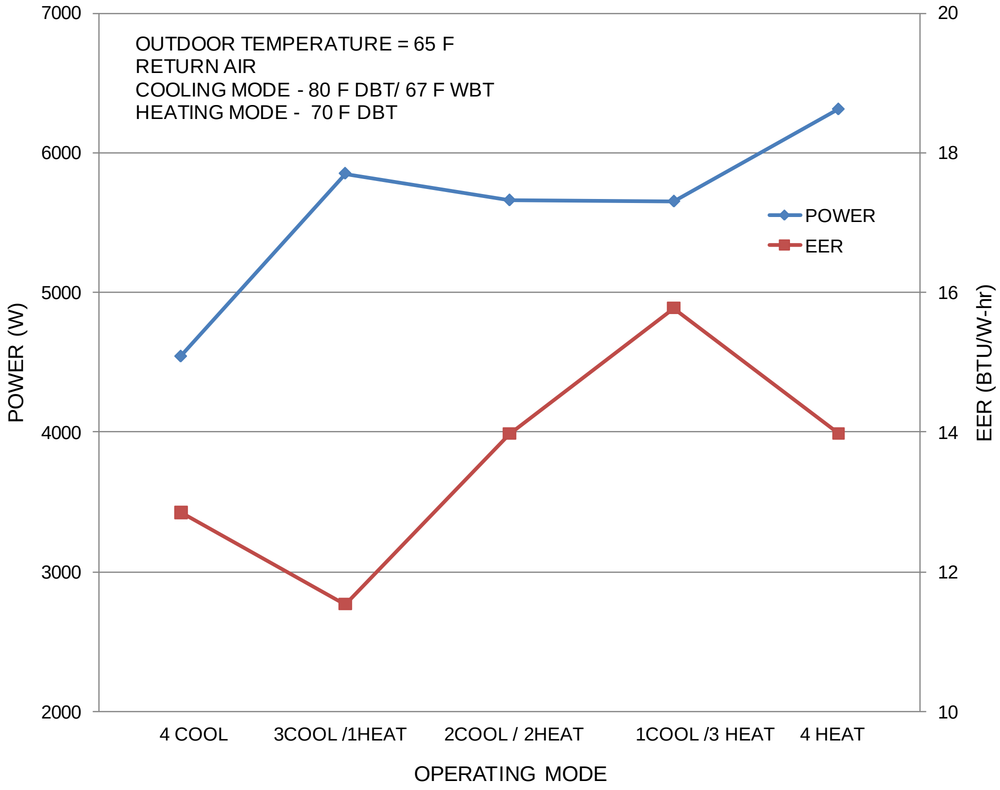


FIGURE 32. **POWER AND EER MEASUREMENTS FOR CHANGING OPERATING MODES (65F)**

The system, when running in "4 COOL" mode (i.e., the cooling-only mode), has a better EER due to lower power consumption. Once the unit is switched to "3 COOL/1 HEAT" mode the power draw increases and the EER reduces. This is counterintuitive to what a simultaneous cooling and heating mode is thought to be. Normal understanding of SCH is that in mixed mode the heat absorbed from one zone (i.e., units in cooling mode) can be rejected in other zones (i.e., units in heating mode), with a small penalty for refrigerant pumping from one zone to another. Further analysis of the diagnostic data from lab instrumentation and a thorough understanding of the two-pipe system reveal some important characteristics of a two-pipe system.

In cooling-only mode, the ODU heat exchangers are used to provide liquid refrigerant to the BC controller. This liquid refrigerant is above the outdoor ambient temperature. The liquid refrigerant from the ODU gets sub cooled in the BC controller. In cooling main mode, where there is heating load from one of the IDUs, the system encounters an issue. If the unit continues to operate in a similar way as in cooling-only mode, the temperature of the refrigerant at the BC controller is not high enough to provide heating to any IDU. For example, in the case discussed above, at 65°F outdoor temperature and in cooling-only mode, the temperature of the refrigerant in the BC controller is 83°F. The refrigerant at 83°F is not hot enough to provide any heating to the zones calling for heating. The ODU needs to transfer some hot refrigerant to the BC controller to satisfy the heating zones. This is achieved by increasing the refrigerant pressure and temperature at the ODU by reducing the amount of heat exchanger area, reducing outdoor fan speed or modulating the compressor frequency. As the refrigerant pressure rises, the temperature rises too. This high-pressure, high-temperature refrigerant is then routed to the BC controller. A drawback of this method is that the system is unable to utilize the favorable ambient temperature (65°F) and the compressor has to work hard to provide the high-pressure, high-temperature refrigerant. The combined effect is increased ODU power. This increased power consumption results in a reduced EER.

In "2 COOL/2 HEAT" heat mode the ODU is still operating in the cooling main mode. In the "2 COOL /2 HEAT" mode the ODU power decreases slightly because of fan speed and compressor modulation. The power draw is still higher than it was in "4 COOL" mode. The EER is higher because of the increased capacity. The overall energy balance in this case dictates that the ODU be used as a condenser.

In "3 HEAT/1 COOL" mode the ODU operates in heating main mode and the outdoor heat exchanger acts as an evaporator. The reversing valve sends the high-pressure, high-temperature refrigerant from the compressor straight to the BC controller where the refrigerant is routed to the IDUs. The condensed liquid coming from the units in heating mode is sub cooled and sent to the unit in cooling mode to provide cooling for that particular zone. The overall power consumption remains similar to the "2 COOL/2 HEAT" case, but the refrigerant conditions at various points in the system change. The higher capacity results from the increased performance of three units in heating mode, which also increases the system EER.

Figure 33 shows capacity measurements similar to Figure 31 except at the higher outdoor temperature of 75°F. The trends are similar to trends in capacity measurements from Figure 31. Note that the data point for "4 HEAT" mode is not available at 75°F because the system cannot operate in heating-only mode beyond 73°F.

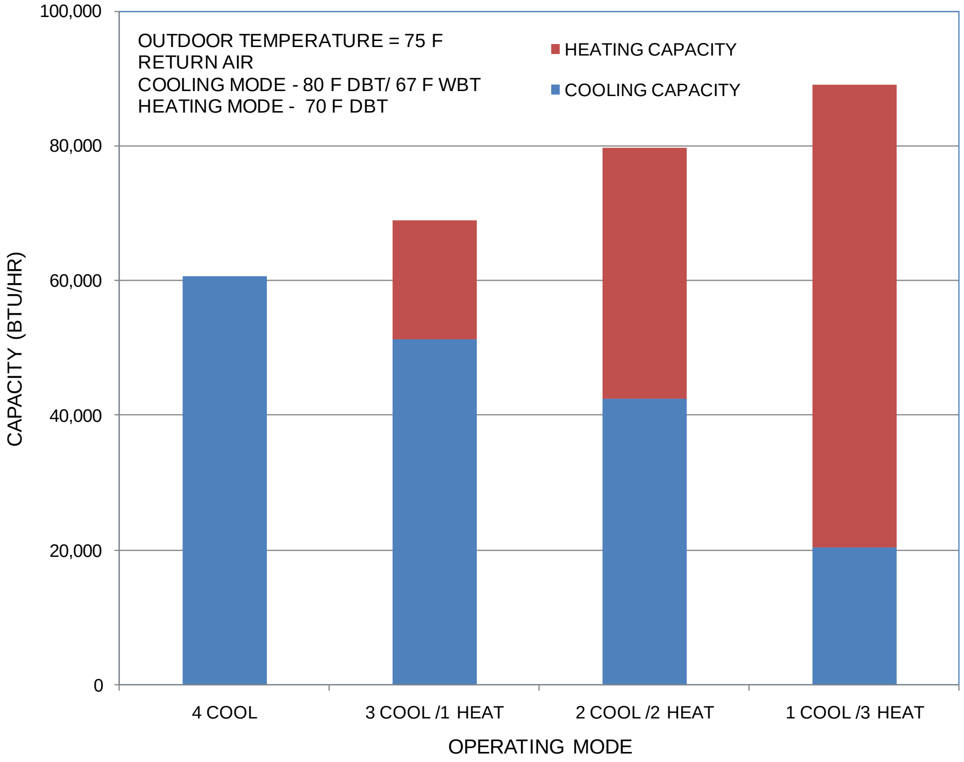


FIGURE 33. CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES (75°F)

Figure 34 shows the power and EER measurements for simultaneous cooling and heating mode at 75°F outdoor temperature. Again, in this case the trends are very similar to the 65°F case. Although there is no data point in heating-only mode in Figure 34, the figure can be compared to Figure 32 by excluding that point.

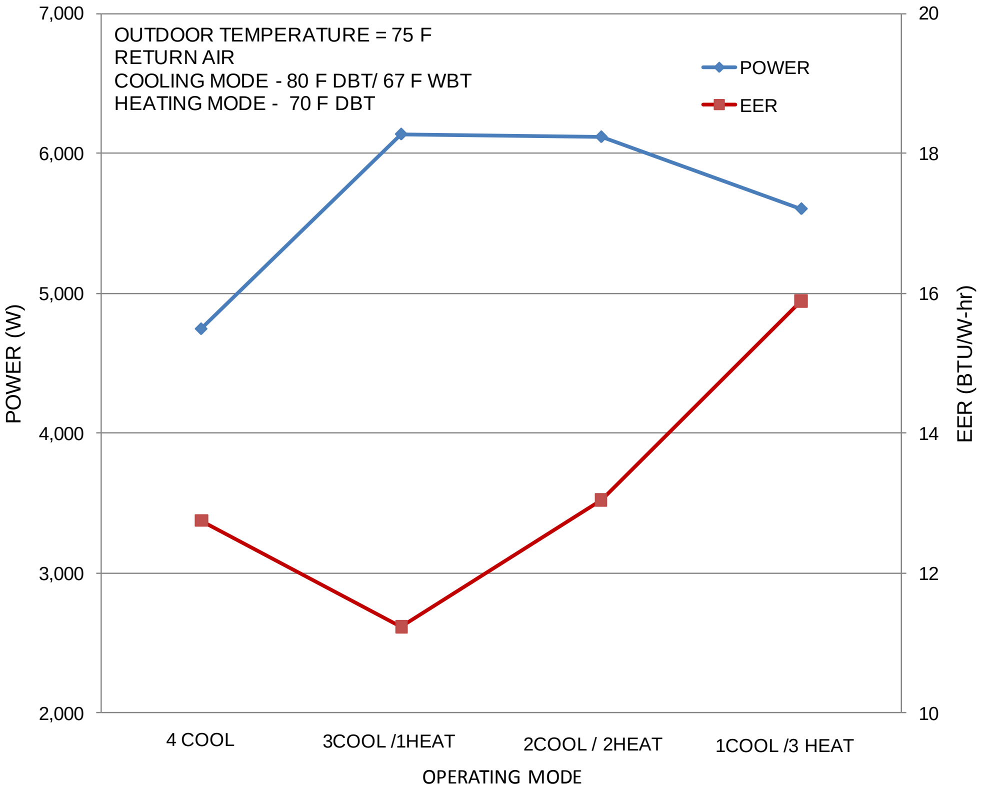


FIGURE 34 . POWER AND EER MEASUREMENTS FOR CHANGING OPERATING MODES (75°F)

This effect of increasing power when switched from cooling-only to simultaneous heating and cooling mode was studied at various temperatures to verify and understand the behavior. Figure 35 shows the power draw with return air at 80°F DBT /60°F WBT in cooling mode and 70°F DBT in heating mode for varying outdoor temperatures and operating modes. The trend is similar, though the power draw difference decreases with increasing outdoor temperature. This can be explained by the fact that the compressor is already working hard because of the higher outdoor temperature in cooling-only mode. As the system is switched into “3 COOL/1 HEAT” mode, the compressor does not have to work any harder and thus the power draw is not affected much. The effect is much more prominent at milder ambient conditions and is important because the SCH mode might be used more in milder conditions.

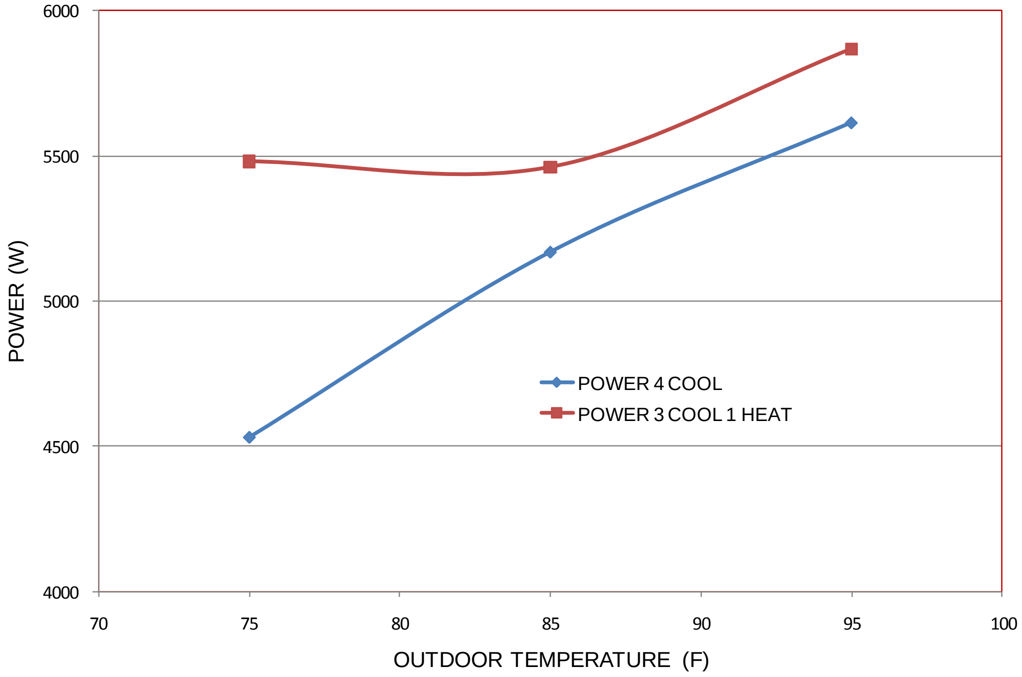


FIGURE 35 . COMPARISON OF POWER DRAW FOR THREE DIFFERENT OUTDOOR TEMPERATURES

EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY

Outdoor temperature effect on capacity is studied in simultaneous cooling and heating mode to determine if trends seen in cooling-only mode and heating-only modes are applicable in SCH mode. In “2 COOL/2 HEAT” Figure 36)) and “3 COOL/1 HEAT” mode (Figure 37), the cooling capacity remains constant across the temperature range (from 65°F to 95°F). In these two cases, the ODU is operating in cooling main mode and is utilizing the IDUs as condensers with little support from the outdoor heat exchanger. Since the return air on the units in heating mode is fixed at 70°F, the outdoor temperature does not have significant impact on the capacity.

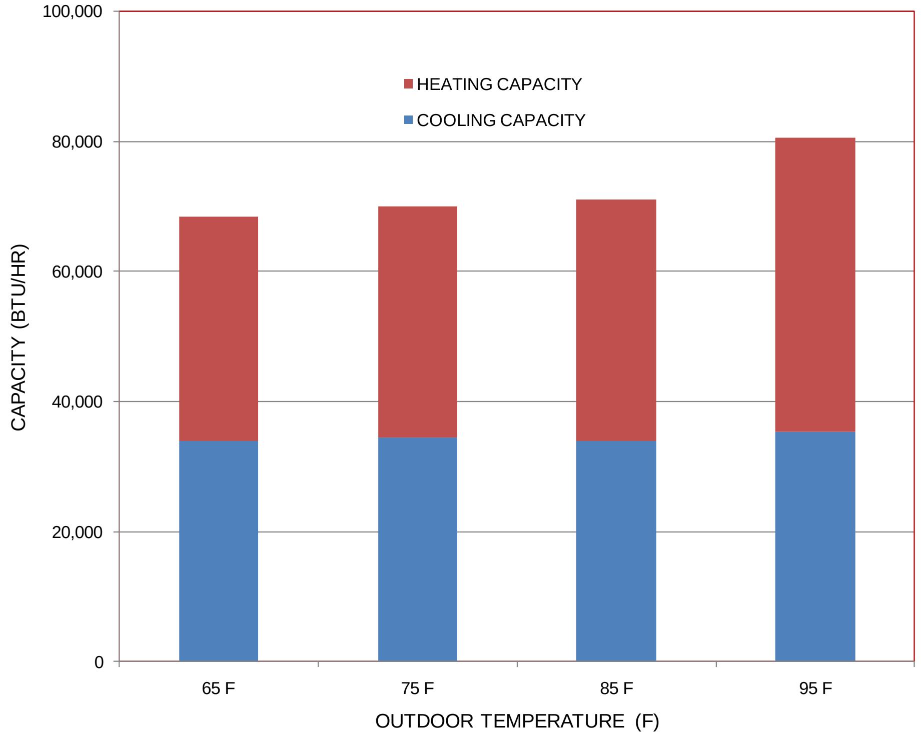


FIGURE 36 . EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY (2 COOL / 2 HEAT)

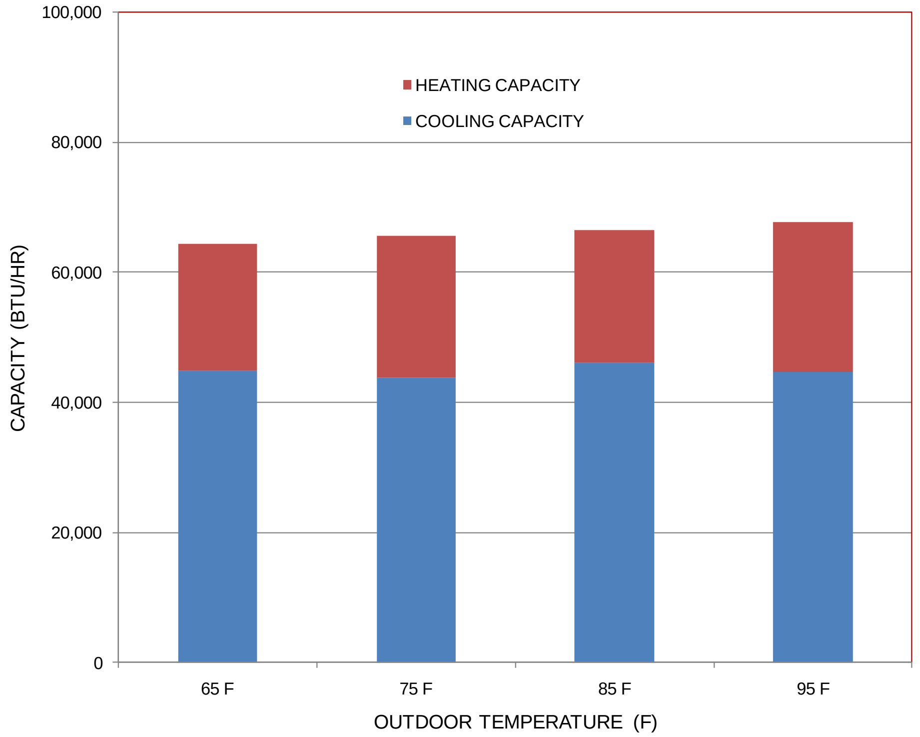


FIGURE 37 . EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY (3 COOL / 1 HEAT)

In “1 COOL/3 HEAT” (Figure 38), a similar thing happens as the condensing pressure is determined by the return air in heating mode. The evaporator is the unit in cooling mode and the outdoor heat exchanger, which is seeing varying outdoor temperatures. The influence of the outdoor temperature is reduced to the percentage of the condensing / evaporating capacity used by the outdoor heat exchanger.

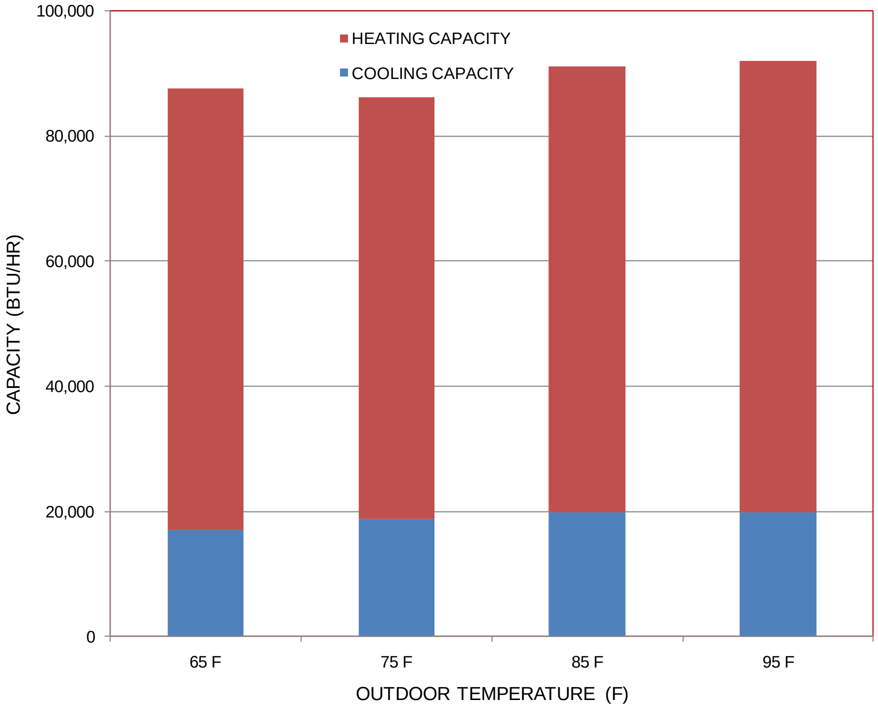


FIGURE 38. EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY (1 COOL / 3 HEAT)

EVALUATIONS

The test data showed that the capacity measurements in heating mode were in line with the manufacturer's data but the systems' power measurements were higher than the published data. The overall trends in heating capacity the lab testing match the trends seen in the published data. Due to the difference in published power and actual lab power measurements, the system's coefficient of performance (COP) was also lower than the manufacturers' published data. In cooling mode, the capacity delivered by the system was lower than the manufacturers' published capacity tables and the power measurements were higher. These differences result in a significantly lower energy efficiency ratio (EER) for the system. Data from these tests are incorporated into the overall performance map.

The full load tests (heating and cooling) are conducted with all four units providing heating or cooling at the same time. Partial load is simulated by turning off units for three steps: 75% load (one IDU off), 50% load (two IDUs off) and 25% load (three IDUs off). The IDUs remaining ON are running at full-load conditions, which represent the required partial load on the ODU. These tests are conducted at full fan speed rated airflow; however, some tests may be performed with reduced indoor unit fan speed and airflow. The ODU is allowed to reach its natural steady-state fan speed as determined by the VRF control system. Since all conditions on the system remain constant in a given test, the VRF control system regulates the fan speed to satisfy the load. As per ANSI/AHRI Standard 1230 "Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment" the test unit's fan are configured as per the manufacturer's specifications and be unchanged for all tests.

In heat recovery mode, instead of turning units off (as in case of partial load), the IDUs are forced to operate in the opposite mode by supplying air appropriate for that mode. For example, two units are forced to operate in cooling mode and two units are forced to operate in heating mode. In heat-recovery mode heat is recovered from the units in cooling mode and transferred to the units in heating mode. Thermostatic set points are maintained at unachievable levels to ensure the IDUs continue to operate at fully loaded levels.

IDU temperature sensors are installed in the return-air ducts. The set points on the thermostat are lower (in cooling mode) or higher (in heating mode) than the return air temperature. For example, if the return air temperature is 80°F in cooling mode, the thermostat are set at 70°F. In this case, since we are always supplying 80°F air on the return side, the thermostat is never satisfied and the unit continues to operate at full load.

The raw data is provided in Appendix B

Equations are shown below.

EQUATION 1. CAPACITY EQUATIONS

$$Capacity\ =\ (Enthalpy\ of\ return\ air -\ Enthalpy\ of\ supply\ air) *\ Mass\ Flow\ of\ air$$

$$Calculations\ for\ enthalpy\ of\ air\ (return\ or\ supply, calculations\ are\ same, use\ the\ right\ values)$$

$$T(Absolute\ Temperature)\ =\ (Measured\ Temperature)^{\circ}F\ + 459.67$$

$$Ln\ pws\ (saturation\ vapor\ pressure\ at\ T) = C8/T\ +\ C9\ +\ C10 * T\ +\ C11 * T2\ +\ C12 * T3\ +\ C13 lnT$$

$Where$

$$C8 = -1.0440397\,E + 04$$

$$C9 = -1.1294650\,E + 01$$

$$C10 = -2.7022355E - 02$$

$$C11 = 1.2890360\,E - 05$$

$$C12 = -2.4780681\,E - 09$$

$$C13 = 6.5459673\,E + 00$$

$$Pw\ \ (partial\ pressure\ of\ water\ vapor) = pws * (Measured\ Relative\ Humidity)$$

$$W\ (humidity\ ratio)\ = 0.621954 * \ pw\ /\ (14.696 - pw)$$

$$H\ (Enthalpy\ in\ BTU/lb) = 0.240 * (Measured\ Temperature)\ +\ W * (1061\ +\ (0.444 * (Measured\ Temperature)))$$

EQUATION 2. CALCULATIONS FOR MASS FLOW OF AIR

$$v\ (specific\ volume\ ft3/lb)\ = \ 0.3704 * T * (1 + 1.6078 * W)/14.696$$

$$Mass\ Flow\ of\ Air\ (lbs/hr)\ = \ CFM\ \ * 60/v$$

$$Qfan\ is\ the\ electric\ consumption\ of\ the\ fans\ of\ the\ indoor\ unit\ fan\ and\ of\ the\ fan - coil, which\ is\ measured\ by\ the\ electric\ counter.$$

ANALYSIS OF THREE-PIPE SYSTEM DATA

A 3-pipe Variable Refrigerant Flow – Heat Recovery (VRF-HR) unit manufactured by LG Electronics was tested in EPRI’s Thermal Environmental Lab. The test data shows that capacity measurements are in line with the manufacturer data but the power measurements on the system are higher than the published data. The overall trends in capacity and power from the lab testing match the trends seen in the published data. Table 5 lists the equipment tested in the laboratory.

TABLE 5 THREE PIPE EQUIPMENT DATA

	OUTDOOR UNIT	**INDOOR UNITS (4)**
	Multi V Sync II	Ducted Low Static
Model #	ARUB076BT2	ARNU243B2G2
Electrical	208-230V/60Hz/3 Ph	208-230V/60Hz/1 Ph
Capacity		
Cooling	76,400 Btu/h	24,200 Btu/h
Heating	86,000 Btu/h	27,300 Btu/h
Power Input		
Cooling	6.2 kW	0.8 kW
Heating	7.0 kW	0.8 kW
Refrigerant	R410a	N/A
Refrigerant Charge	17.6 lbs	N/A
Indoor Units (attached)	4	N/A
Airflow Max	6,700 cfm	671 cfm

COOLING MODE ANALYSIS

The refrigerant flow diagram in cooling main mode operation is shown in Figure 39. In cooling mode the high-pressure, high -temperature discharge gas is routed to the outdoor heat exchanger through the four-way valve. The gas condenses to high-pressure liquid and flows through the main EEV, which is wide open in cooling mode. A sub-cooler uses a small amount of liquid refrigerant to cool down the high-pressure liquid, which is then routed to the heat recovery box through the liquid line. The heat recovery box connects the liquid line coming from the ODU to liquid lines on the individual IDUs. For individual IDUs, the sub-cooled refrigerant flows through its EEV, the heat exchanger coil and then back to the heat recovery box as a low-pressure gas. The low-pressure gas is conveyed back to the ODU through the common suction line (low-pressure gas line). In cooling mode, the high-pressure, high-temperature gas line is not used to transfer refrigerant from the ODU to HR box and vice-versa.

The reference point in cooling mode is the AHRI rating condition of 95°F OD- DBT and 80°F RA-DBT / 67°F RA-WBT. The performance of the system is observed under varying conditions:

- Reference point - ODU at 95°F DBT; RA- 80°F DBT/ 67°F WBT.
- Vary outdoor DBT with constant RA conditions.
- Hold outdoor DBT constant and vary indoor WBT with constant indoor DBT.
- For all the above conditions, vary the RAT.
- Follow up all the above test points with varying percentages of IDU operation.

Figure 39 shows the heat exchanger in IDU 3. Tests at cooling mode rating points resulted in low-capacity measurement. All measurements from the test setup were checked and double-checked to confirm no errors in instrumentation or in calculations. A physical inspection of IDU 3 was carried out by removing all the ductwork attached to the unit.

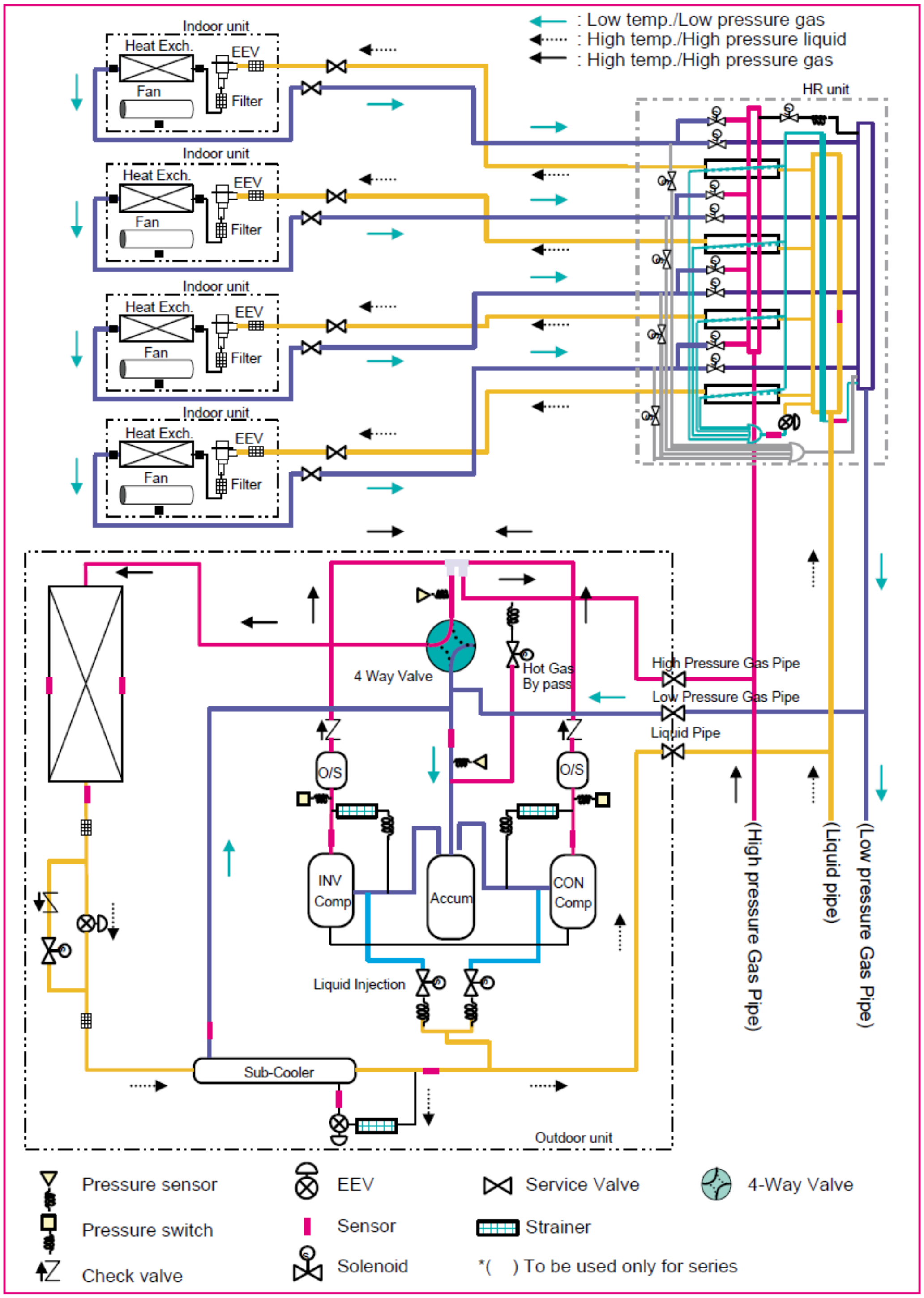


FIGURE 39. REFRIGERANT FLOW DIAGRAM IN COOLING MODE

Figure 40 shows the capacity measurements with varying outdoor DBTs from the manufacturer as well as laboratory measurements from EPRI. The manufacturer provides only RA-WBT data and does not provide capacity and power for RA-DBT. The manufacturer data is plotted for various outdoor DBTs with a fixed return air WBT of 67°F. EPRI lab data is also plotted for a fixed return air WBT of 67°F with a varying RA-DBT of 75°F, 80°F and 85°F.

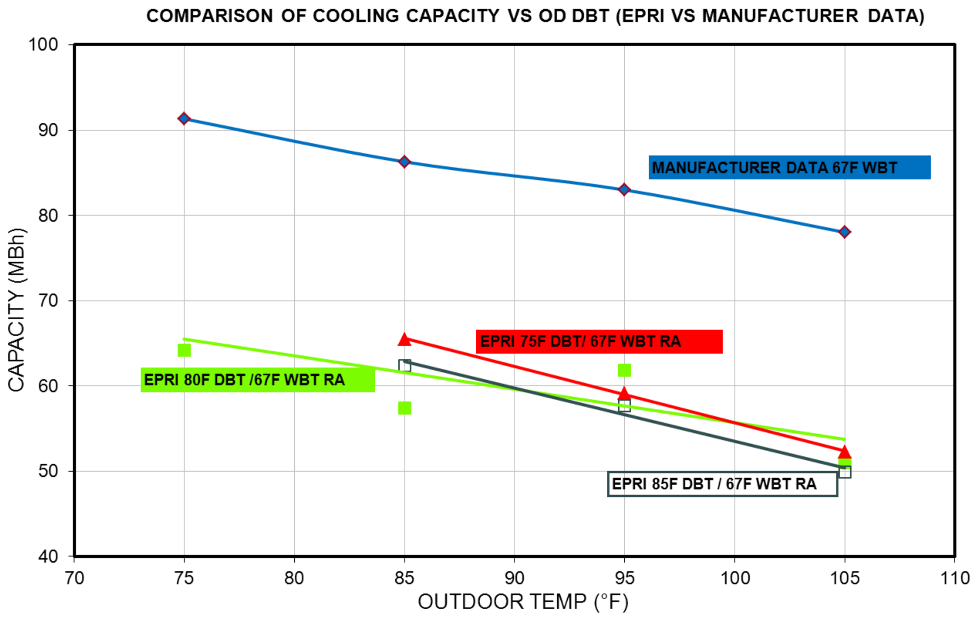


FIGURE 40. THREE-PIPE SYSTEM : COOLING CAPACITY SUMMARY

At the AHRI rating point of 95°F OD-DBT and 80°F RA-DBT / 67°F RA-WBT, the measured capacity is less than the manufacturer-published data. All the other data points revealed similar lower capacity throughout the tested envelope. The overall trend in capacity followed the trend of the published data from the manufacturer as seen in Figure 40.

From Figure 40 we can see that the cooling capacity delivered by the system is a strong function of the OD-DBT. The RA-DBT does not have a significant impact on the capacity and can be seen by the closely grouped data points for a given OD-DBT. For a given RA WBT (67°F in this case) the capacity changes by 630 BTU/hr/°F OD-DBT and 310 BTU/hr/°F RA-DBT confirming that RA-DBT does not have a significant impact on capacity.

Figure 41 shows power measurement for the same data set shown in Figure 40. The power measurements are higher than the manufacturer published data. The power measurements were verified with a Voltech Instruments PM300A three-phase power analyzer. The overall trend in power is similar to the published data. As the outdoor temperature increases the power draw increases. The RA-DBT has minimal effect on the power draw, which is evident from the closely bunched data points for each OD-DBT. For a fixed OD-DBT the capacity changes by 1800 BTU/hr/°F RA-WBT as compared to 310 BTU/hr/°F RA-DBT. This further confirms that the capacity is a strong function of RA-WBT and explains why the manufacturer's capacity tables do not refer to the RA-DBT.

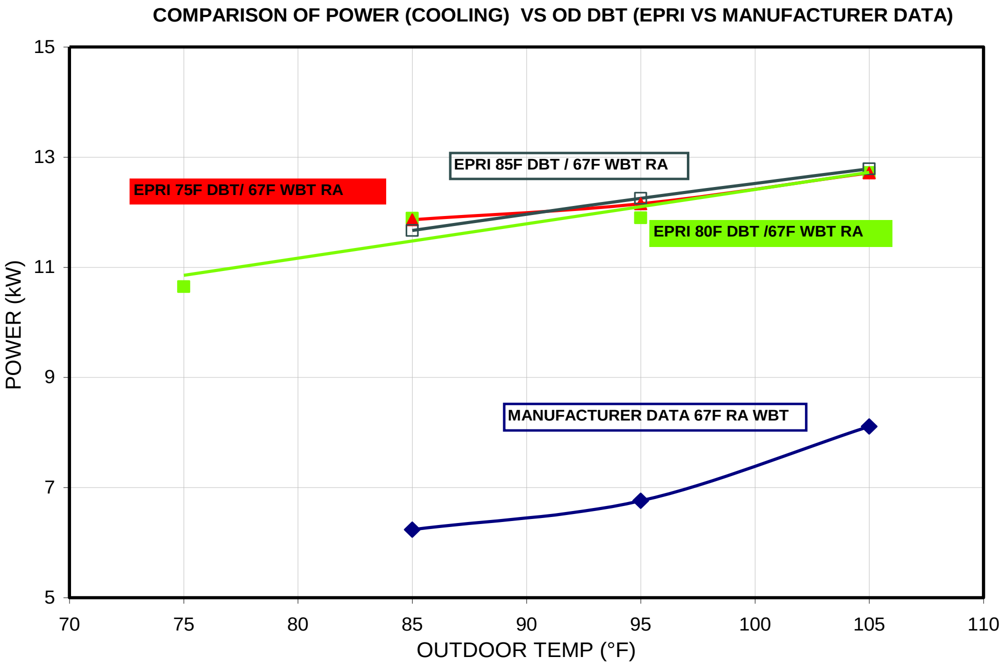


FIGURE 41. THREE-PIPE SYSTEM : POWER, COOLING MODE LAB VS MANUFACTURE DATA

Figure 42 shows the effect of OD-DBT on the system EER. EER is the ratio of delivered capacity to power consumed. The EER is lower than the manufacturer published numbers due to the lower capacity and higher power measurements. The overall trend in the EER is very similar to the published performance. From Figure 42 we can conclude that the EER is a strong function of OD-DBT and does not vary much according to RA-DBT.

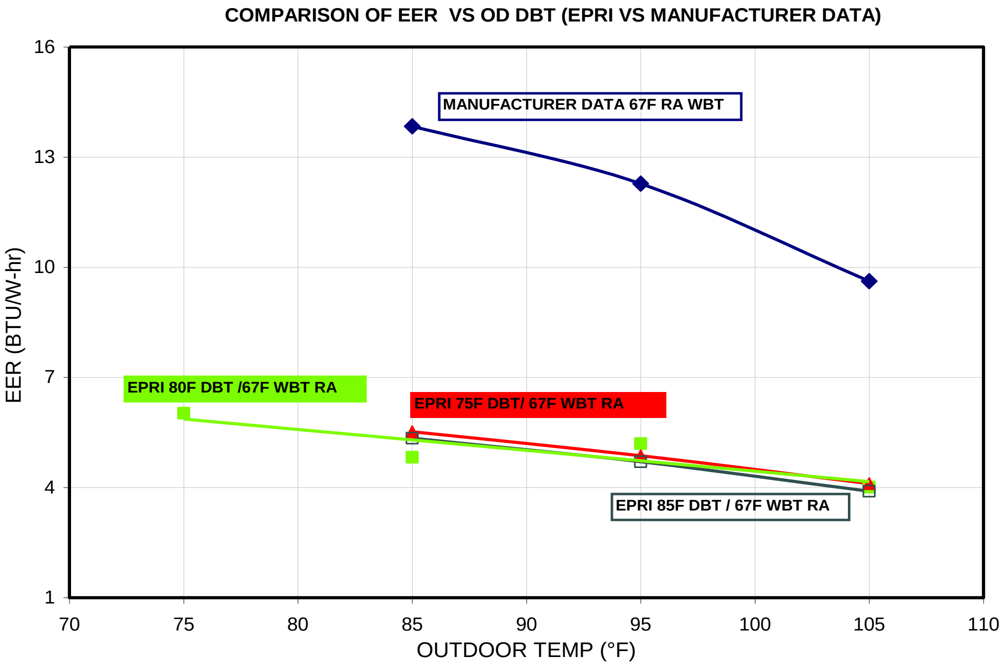


FIGURE 42. EER – VARYING OD-DBT, VARYING RA – DBT

HEATING PERFORMANCE TEST RESULTS

Figure 43 shows the capacity measurements with varying OD-DBT from the manufacturer as well as the laboratory measurements by EPRI in heating mode.

The data at 70°F return air temperature (RAT or indoor air temperature) tracks very closely with the manufacturer-published data. The manufacturer's data at 64°F matches their 70°F data very closely – in fact, it is almost coincidental with the 70°F data. In a fixed speed system, we expect the heating capacity to increase with decrease in RAT but the coincident data for 64°F and 70°F from the manufacturer may be a result of internal control logic. In contrast, the EPRI lab data at 65°F RAT shows some increase in capacity (red data points) as compared to 70°F RAT.

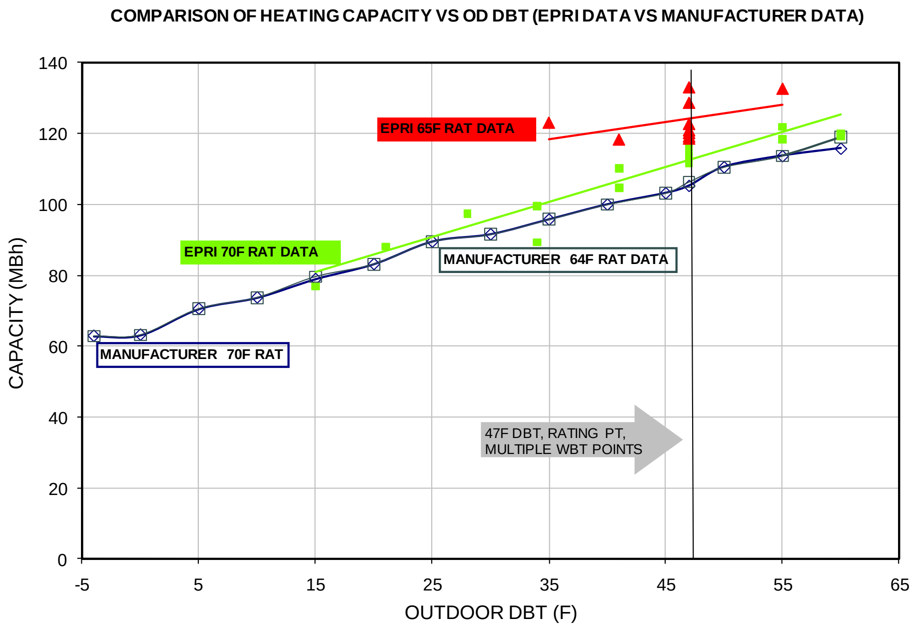


FIGURE 43. CAPACITY MEASUREMENTS IN HEATING MODE (EPRI LAB DATA AND MANUFACTURER DATA)

Figure 44 shows power measurements for the same data set shown in Figure 43. The power measurements in the lab are higher than the published data by about 3kW. Lab measurements were verified with a Voltech Instruments PM3000A three-phase power analyzer with calibration traceable to NIST. The overall trend in power is similar to the published data.

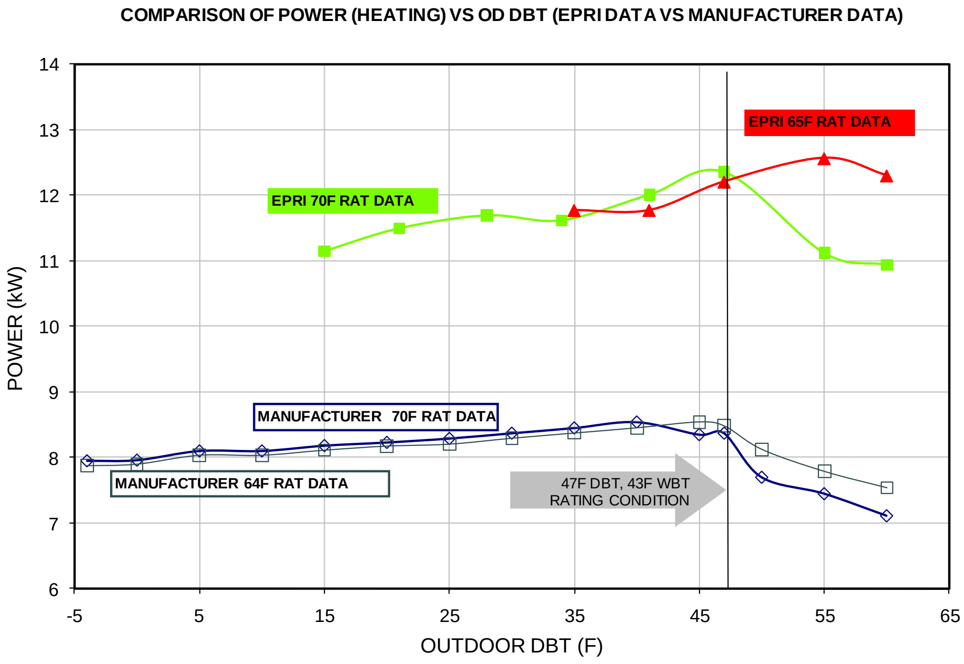


FIGURE 44. POWER MEASUREMENTS IN HEATING MODE (EPRI LAB DATA AND MANUFACTURER DATA)

In Figure 45 we can see that the overall COP trend from EPRI lab tests is very similar to the manufacturer published data. Since the capacity measurements are in line with the manufacturer data, the difference in measured COP and manufacturer COP can be attributed to the power measurements.

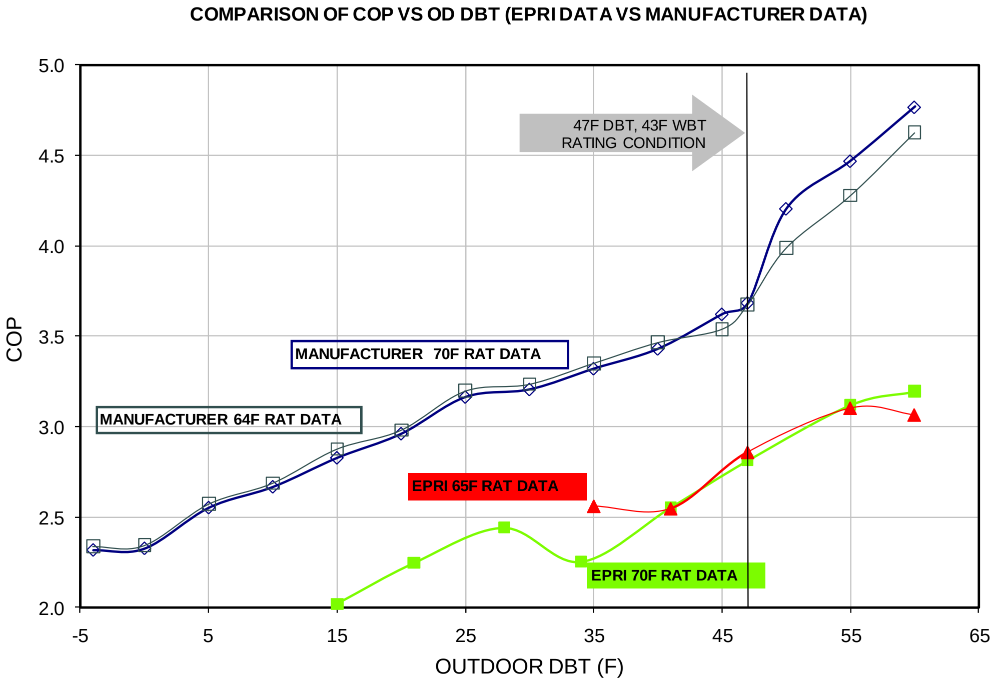


FIGURE 45. COP MEASUREMENTS IN HEATING MODE (EPRI LAB DATA AND DATA DEDUCED FROM MANUFACTURER PROVIDED CAPACITY AND POWER)

SIMULTANEOUS COOLING AND HEATING MODE (SCH)

As described in a previous section, in simultaneous heating and cooling mode the system has the ability to deliver cooling or heating required by each zone, independent of other zones. The three pipe system achieves this exchange of energy between individual zones via a heat recovery box is connected between the ODU and IDUs.

The refrigerant flow diagram is shown in Figure 46 in a cooling-based operation. In the figure, three indoor units are shown in cooling mode, whereas the fourth IDU is in heating mode.

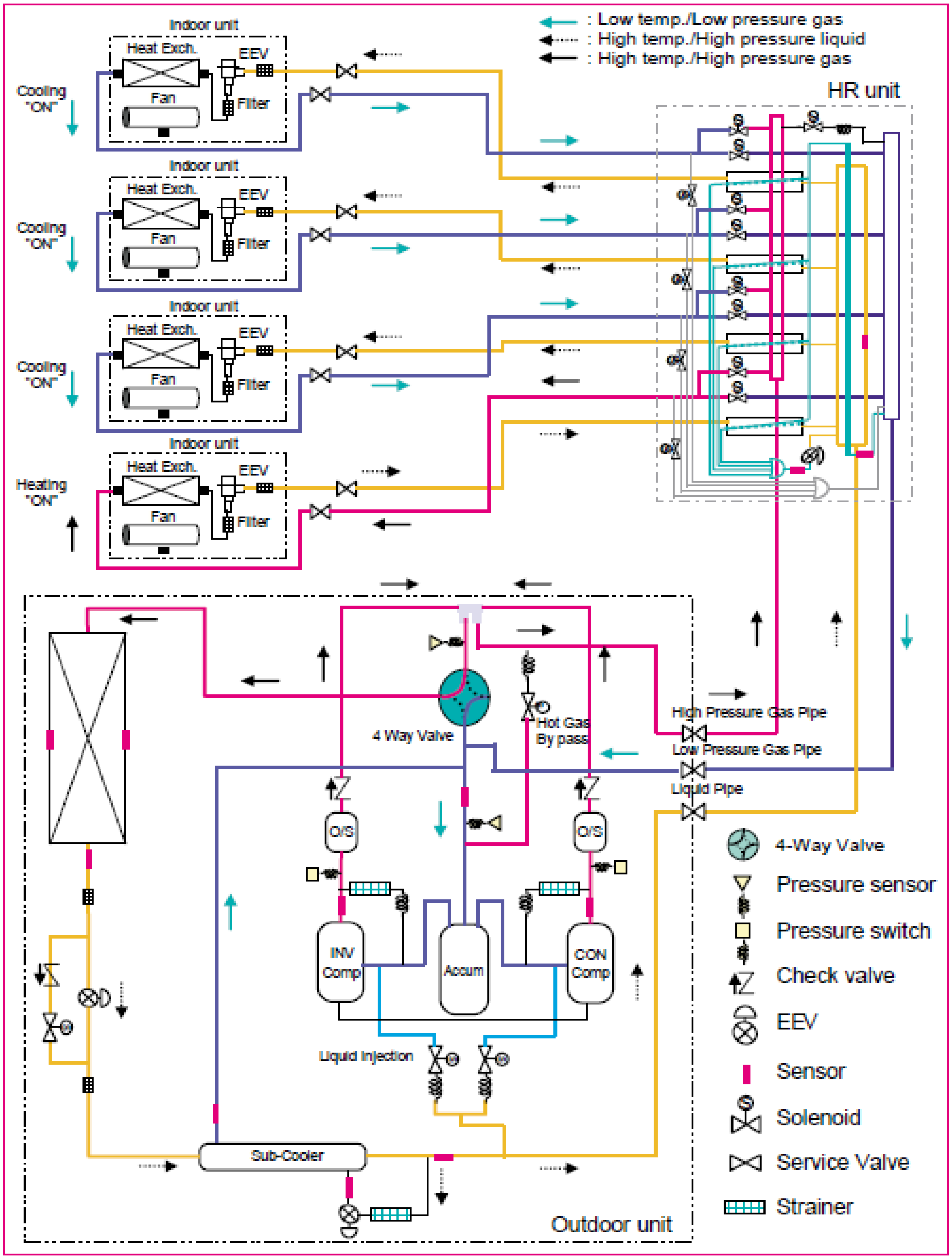


FIGURE 46 REFRIGERANT FLOW DIAGRAM IN SCH MODE (COOLING BASED OPERATION)

The ODU in this case works as a condenser because of the predominantly cooling operation. The critical part of the SCH mode is the refrigerant routing and heat exchange in the heat recovery box. In the cooling-based operation, liquid refrigerant from the ODU is routed to the heat recovery box through the liquid line. At the same time, a part of hot gas discharged from the compressor that was supposed to be condensed in the ODU is routed to the heat recovery box through the high-pressure gas line. This is done to satisfy the IDU in heat mode. The unit in heating mode rejects heat from the hot gas to the air stream and condenses the refrigerant to liquid. This liquid goes back to the heat recovery box where it is connected to the same header as the liquid line from the ODU. The liquid can now be transferred to any IDU that is calling for cooling and then return to the ODU as low-pressure gas. The effect of routing hot gas to satisfy a heating zone and consequently utilizing the liquid from that zone to satisfy a cooling zone leads to tremendous efficiency gains.

When three IDUs are in heating main mode and the fourth IDU is in cooling mode, The ODU works as an evaporator because the operation needed is predominantly heating. In heating-based operation, hot gas from the compressor is routed to the heat recovery box through the high-pressure gas line. This hot gas is condensed to liquid in the process of exchanging heat with the zones that are in heating mode. This condensed liquid is then routed through the unit calling for cooling. The low-pressure gas from the unit in cooling mode is routed back to the ODU through the low-pressure gas line straight to the accumulator. The liquid refrigerant from the heat recovery box is routed back to the ODU through the liquid line.

The AHRI SCH test has a set outdoor condition of 47°F DBT, 43°F WBT. Since SCH mode is used predominantly in milder climates, outdoor temperatures of 65°F and 75°F DBT were studied. The manufacturer had an upper limit of 81°F OD-DBT for SCH mode operation. The performance of the system was observed under varying conditions:

- Outdoor temperature was set at 65°F and 75°F (one data set for 65°F and the other for 75°F).
- The return air conditions for units in cooling mode are 80°F DBT/ 67°F WBT and 75°F DBT / 63°F WBT.
- Return air conditions for units in heating mode are 65°F and 70°F.
- The number of units in cooling mode and heating mode are varied to study the effect on capacity and power.

Note that due to the difficulties in cooling mode operation for the unit, the purpose of SCH testing is to understand the behavior of the unit rather than to accurately measure delivered capacity.

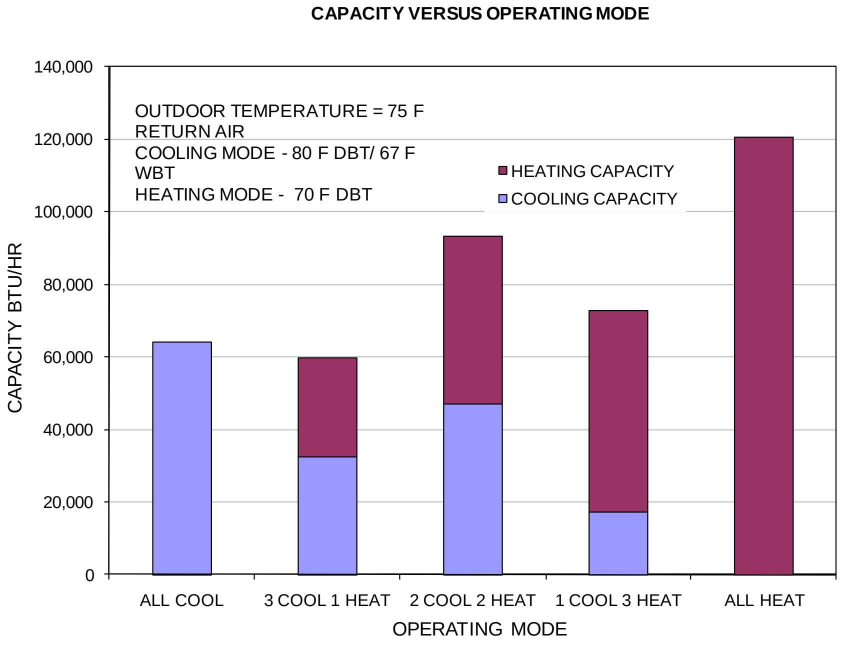


FIGURE 47. CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES

The effects of changing modes on capacity are shown on Figure 47. The outdoor DBT in this case is 75°F and the return air in cooling mode is at 80°F DBT / 67°F WBT in cooling mode and 70°F in heating mode. In “4 COOL” mode, each individual temperature controller is set in cooling mode and the resulting capacity and power is measured. After capturing data in steady state, one of the temperature controllers is set to heat mode with target temperature of 86°F DBT and the remaining three are in cooling mode.

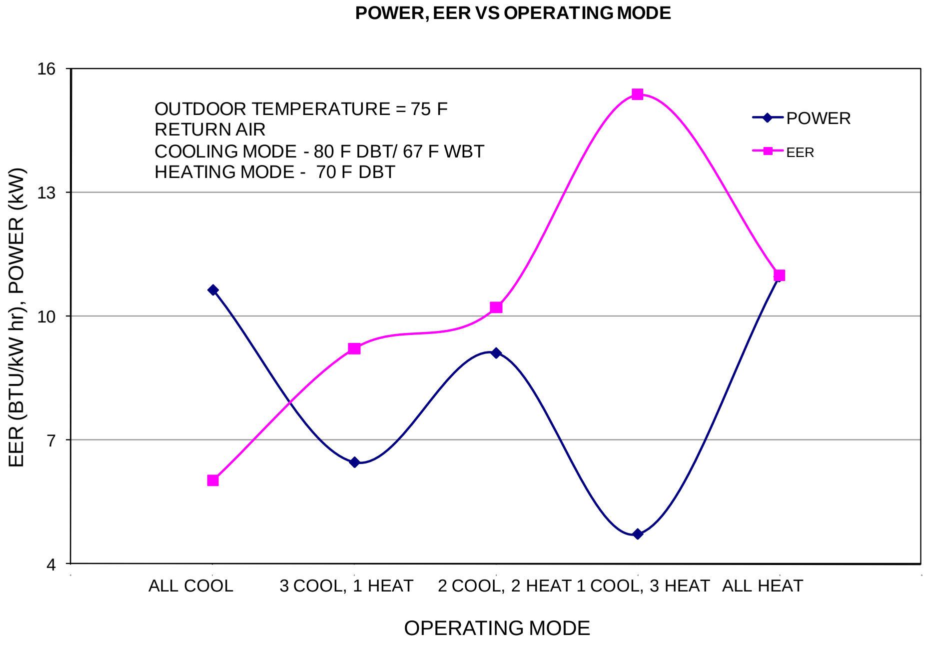


FIGURE 48. THREE-PIPE SYSTEM : POWER, EER VS OPERATING MODE

From Figure 48, the power draw in “2 COOL/2 HEAT” mode is more than “3 COOL/1 HEAT” mode and “1 COOL/3 HEAT” mode. It is clear that both the compressors are running but it is still not clear whether the ODU is acting as a condenser or evaporator. Analyzing the diagnostic data from EPRI instrumentation, it becomes clear that the ODU in this case was operating in condensing mode. This was evident from the liquid line temperature and verification of the air leaving the ODU, the measurement of which was carried out by the operator simply extending his hand into the exhaust air stream from the ODU. From the capacity measurements in Figure 48, it is clear the system was trying to satisfy the cooling load in the “2 COOL/2 HEAT” mode.

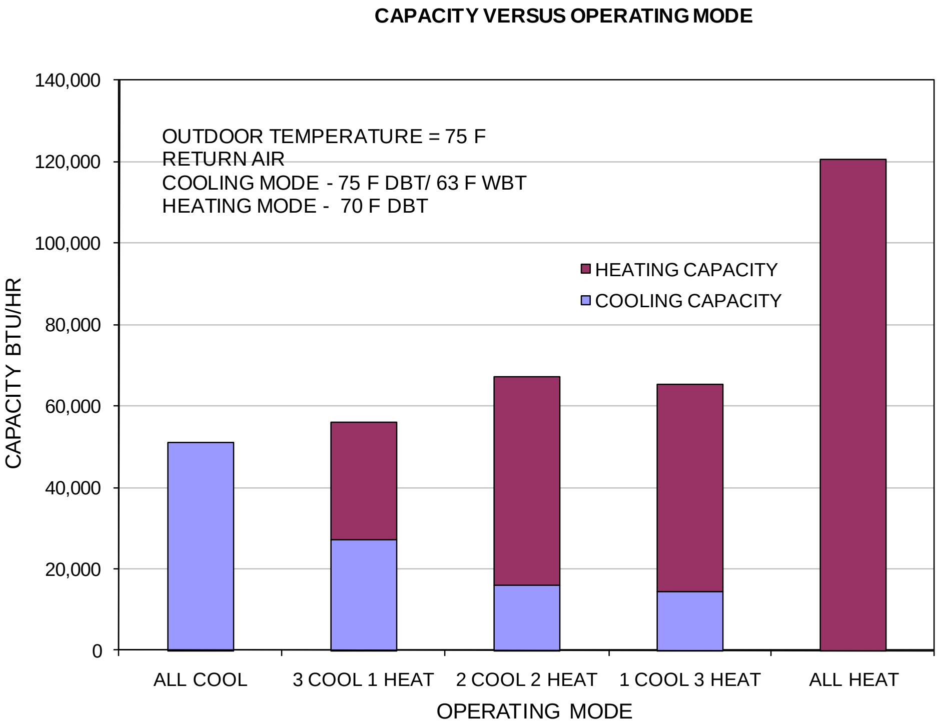


FIGURE 49. THREE-PIPE SYSTEM : CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES

Figure 49 shows capacity measurements similar to the ones in Figure 47 except that the return air conditions in cooling mode are 75°F DBT and 63°F WBT. In this case the “2 COOL/2 HEAT” operation shows different characteristics than what was seen in Figure 47 and Figure 48. The ODU is running in the evaporator mode and thus is in heating-based operation. The operation of the unit is very similar to the “1 COOL/3 HEAT” mode and can be seen in the capacity measurements in Figure 49.

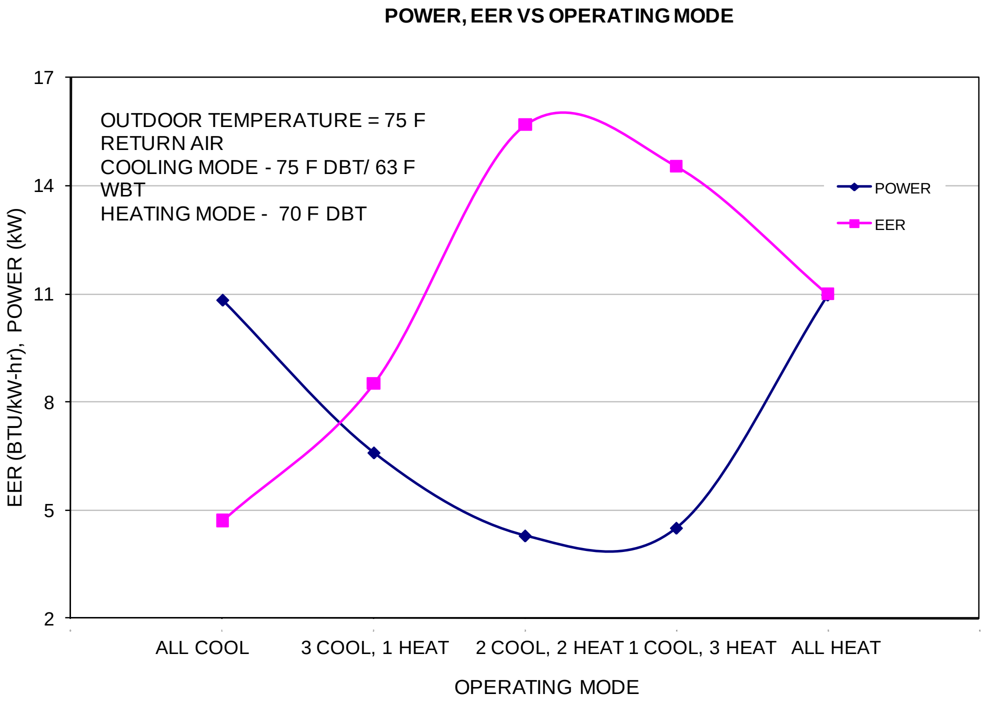


FIGURE 50. POWER AND EER MEASUREMENT FOR CHANGING OPERATING MODES

Figure 50 shows the corresponding power and EER measurements for operating conditions in Figure 49. In heating based operation for “2 COOL 2 HEAT” operation only the variable speed compressor in the outdoor unit is running resulting in low power consumption and hence an increased EER measurement.

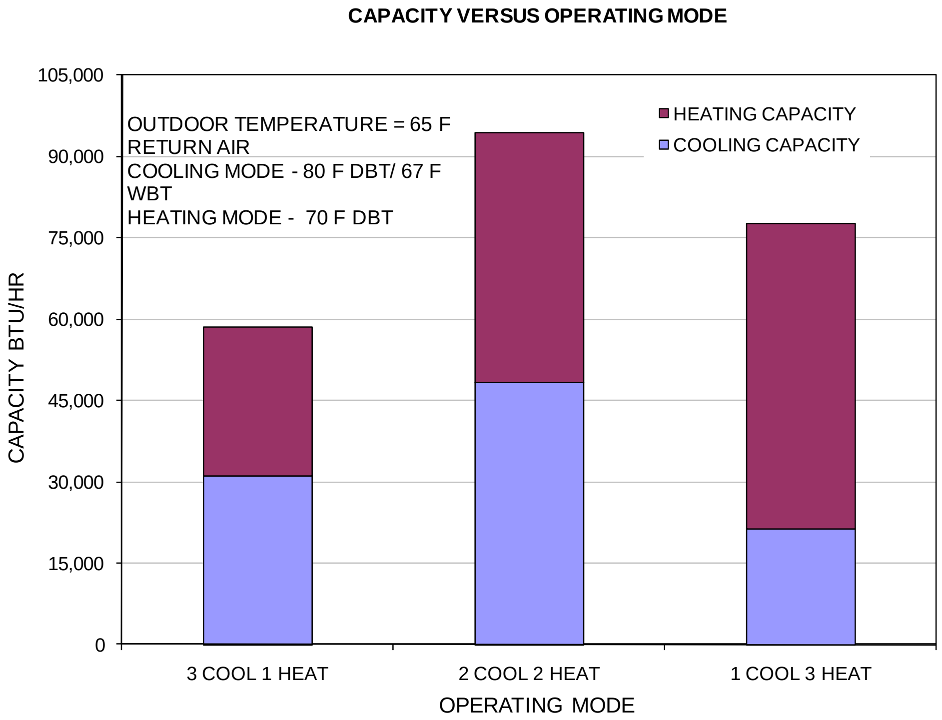


FIGURE 51. CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES (80/67)

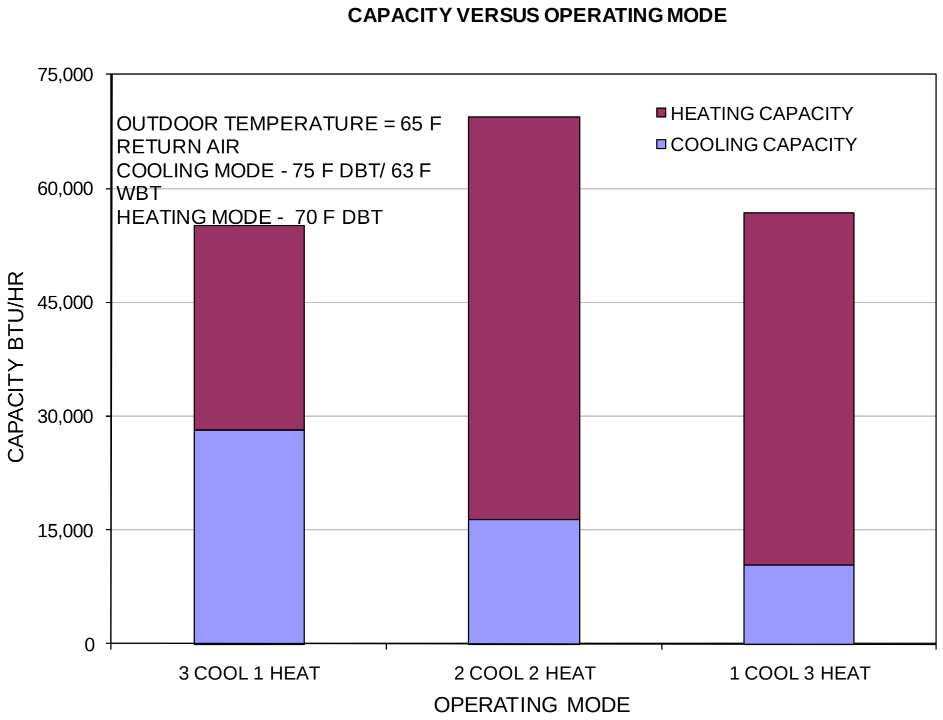


FIGURE 52 CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES (75/63)

Figure 51 and Figure 53 show capacity measurements similar to those in Figure 47 and Figure 49 but for an outdoor temperature of 65° F DBT. The overall trend in capacity at 65°F is very similar to the capacity measured at 75°F. It should be noted that the data for all units in cooling mode and all units in heating mode could not be obtained due to capacity limitation on the outdoor chamber. The higher capacity (Figure 51) when the return air is at 67°F WBT indicates that the system is in cooling based operation in '2 COOL 2 HEAT' mode (similar to 75° F OD-DBT). In Figure 52, the return air is at 63°F WBT and the system is in heating based operation. Figure 53 shows side-by-side comparison of data from 75°F OD-DBT and 65°F OD-DBT.

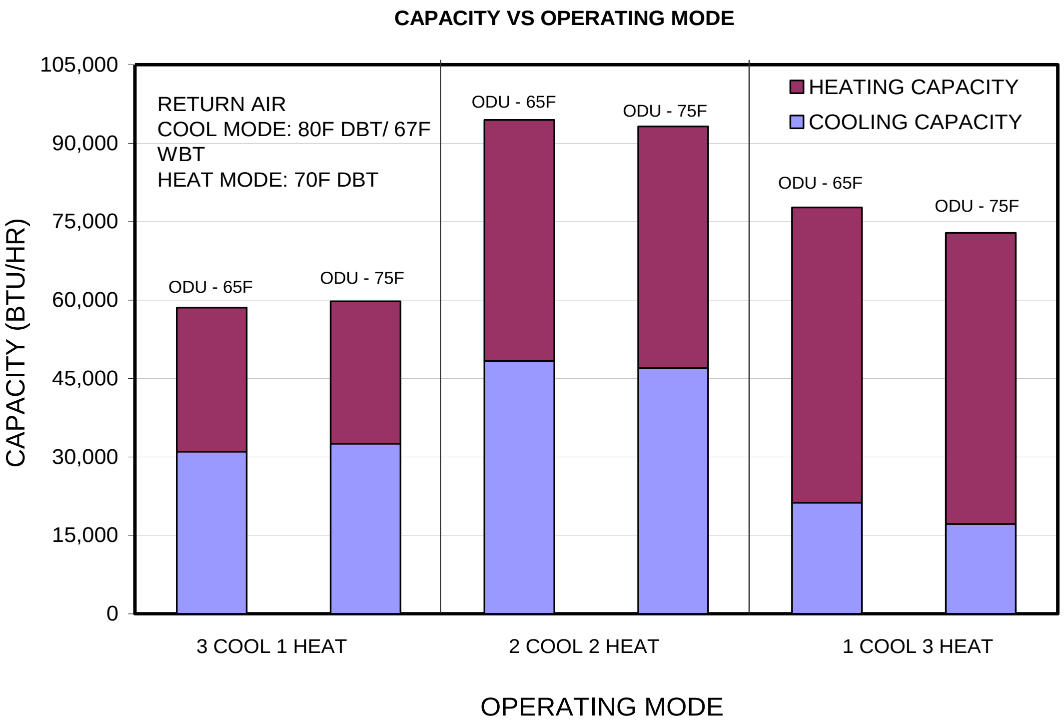


FIGURE 53. COMPARISON OF CAPACITY MEASUREMENTS AT 75°F AND 65°F OD-DBT

The outdoor temperature does not have a significant effect on capacity as shown in Figure 53. In SCH mode, the important parameter seems to be the RA-WBT for units that are operating in cooling mode. The RA-WBT effect can be seen in Figure 51 and Figure 52, where higher WBT (67°F) resulted in the higher cooling capacity in units operating in cooling mode. Similar results can also be seen in Figure 47 and Figure 49.

ANALYSIS OF TWO-PIPE SYSTEM DATA

A 2-pipe variable refrigerant flow heat recovery (VRF-HR) system was tested in EPRI's Thermal Environmental Lab. A 6-ton outdoor unit was coupled with four 2-ton ducted low static indoor units to provide a combination ratio of 133%. Table 6 lists the information of the equipment tested.

The overall trends in cooling mode match the trends in manufacturer data for cooling mode. The measured capacity in cooling mode is approximately 25% lower than the manufacturer published data when corrected for combination ratio, pipe length and outdoor dry bulb temperature. The power measurements are in-line with the manufacturer published numbers. The coefficient of performance (COP) is lower because of the reduced capacity. The manufacturer does not publish COP but the COP values can be deduced from capacity and power data.

TABLE 6 TWO PIPE EQUIPMENT DATA

	OUTDOOR UNIT	**INDOOR UNITS (4)**
	CITY-MULTI R2 Series	Ducted Low Static
Model #	PURY-P72THMU-A	PEFY-P24NMSU-E
Electrical	208-230V/60Hz/3 Ph	208-230V/60Hz/1 Ph
Capacity		
Cooling	72000 Btu/h	24000 Btu/h
Heating	80000 Btu/h	27000 Btu/h
Power Input		
Cooling	5.9kW (estimated)	0.8 kW
Heating	6.5kW (estimated)	0.8 kW
Refrigerant	R410a	N/A
Refrigerant Charge	n/a	N/A
Indoor Units (attached)	4	N/A
Airflow Max	6550 cfm	706 cfm

COOLING MODE ANALYSIS

Figure 54 shows capacity measurements from lab and the manufacturer's data with varying outdoor DBT and varying return air WBT. The return air DBT is fixed at 80°F.

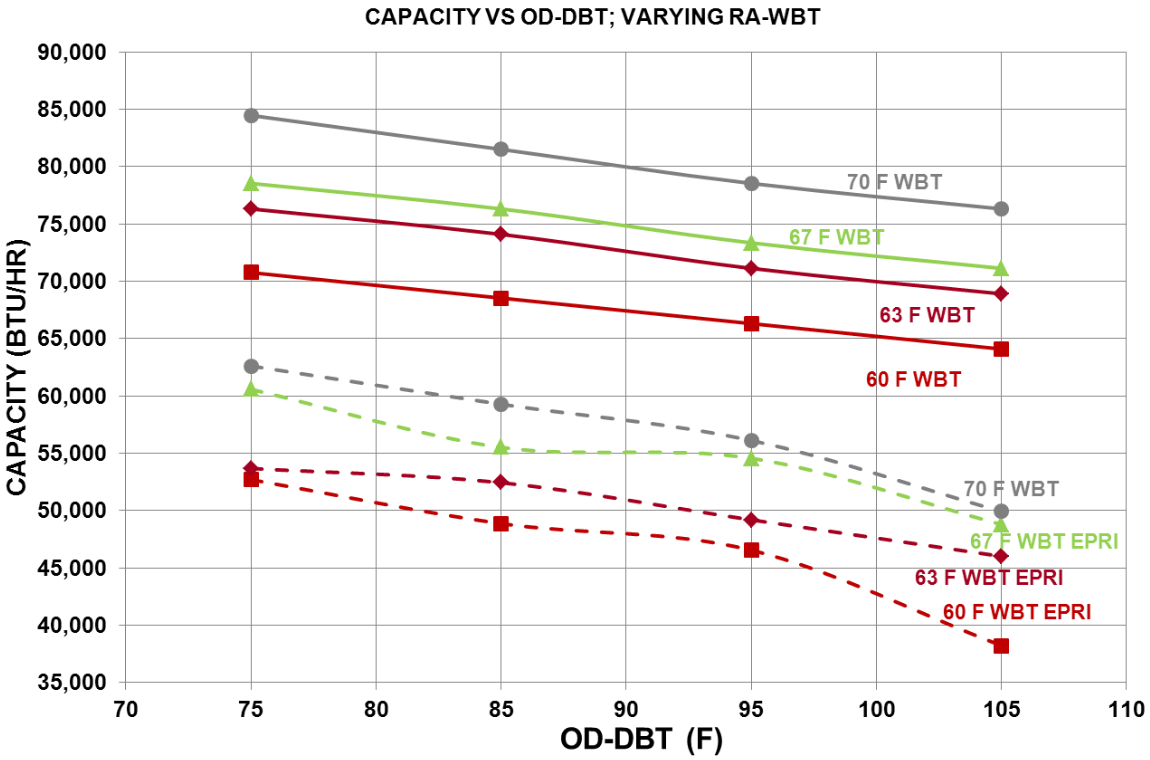


FIGURE 54. TWO-PIPE SYSTEM : COOLING CAPACITY, VARYING OD-DBT AND RA-WBT

The manufacturer data is calculated from capacity charts provided by the manufacturer. Appendix A includes the manufacturer charts and the procedure to calculate capacity and power for the system under test. At the AHRI rating point of 95°F OD-DBT and 80°F RA-DBT / 67°F RA-WBT the measured capacity is 25% less than the manufacturer published data. All the other data points revealed similar lower capacity throughout the tested envelope. The overall trend in capacity followed the trend of the published data from the manufacturer as seen in Figure 54. The cooling capacity is a function of the return air WBT and outdoor DBT. The cooling capacity decreases with increasing OD- DBT and increases with increasing RA-WBT.

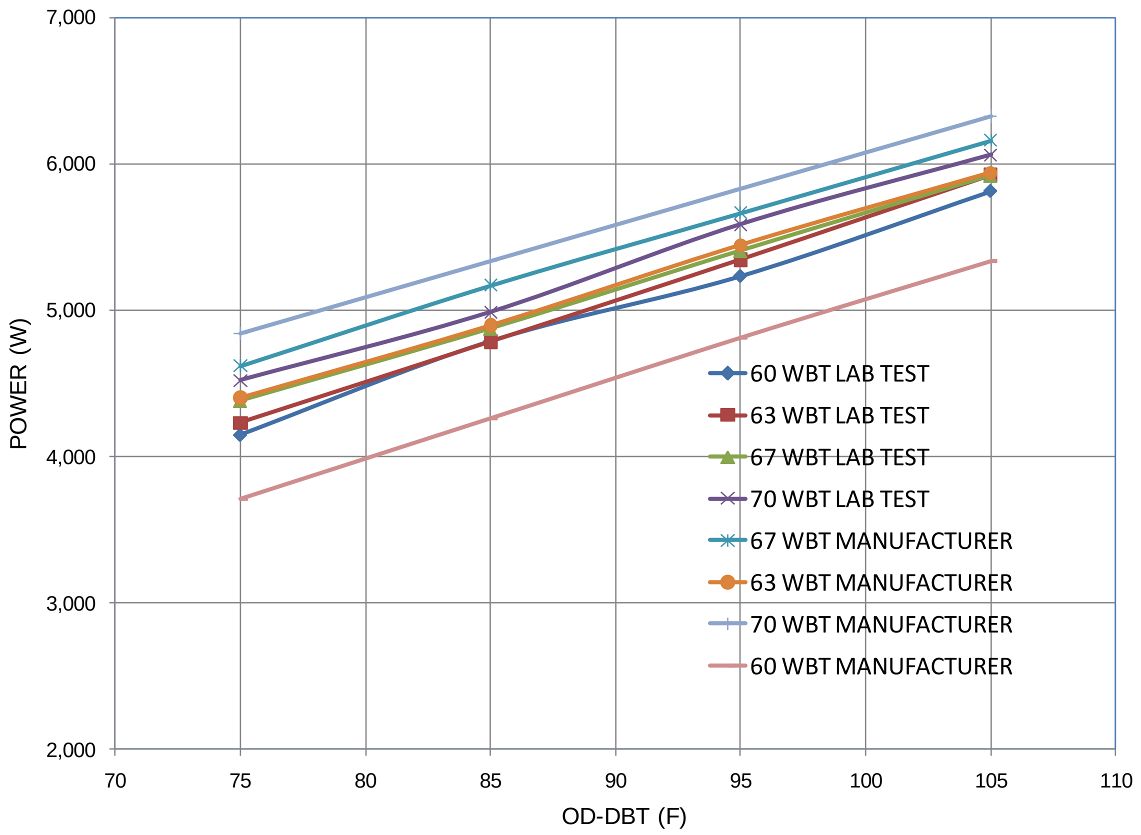


FIGURE 55 **COOLING MODE POWER DRAW, VARYING OD-DBT AND RA-WBT**

Figure 55 shows the power measurements for the same conditions that are shown in Figure 54. The power measurements are close to the manufacturers published data. The maximum difference of 10% is observed at lower return air WBT of 60°F. For all other data points, the difference in measured and published power is within 5%.

% IDU OPERATION (COOLING MODE)

In a multi-zone system, one or more zones might not be calling for cooling. The system test results for four, three, two and one indoor units in cooling mode are shown in Figure 56. The system was tested at outdoor condition of 95°F DBT and 80F RA-DBT / 67°F RA-WBT. After steady state was reached on all four units, one indoor unit was turned off and the other three indoor units were kept running at the same conditions. Once steady state was reached on the three indoor units, another indoor unit was shut off and so on. The corresponding steps in % IDU operation are 100%, 75%, 50% and 25%. Figure 56 shows results for the tests at RA-WBT of 67°F. The cooling capacity provided by the aggregate system decreases as the units are turned ‘OFF’. The power usage for the same conditions is shown in Figure 57.

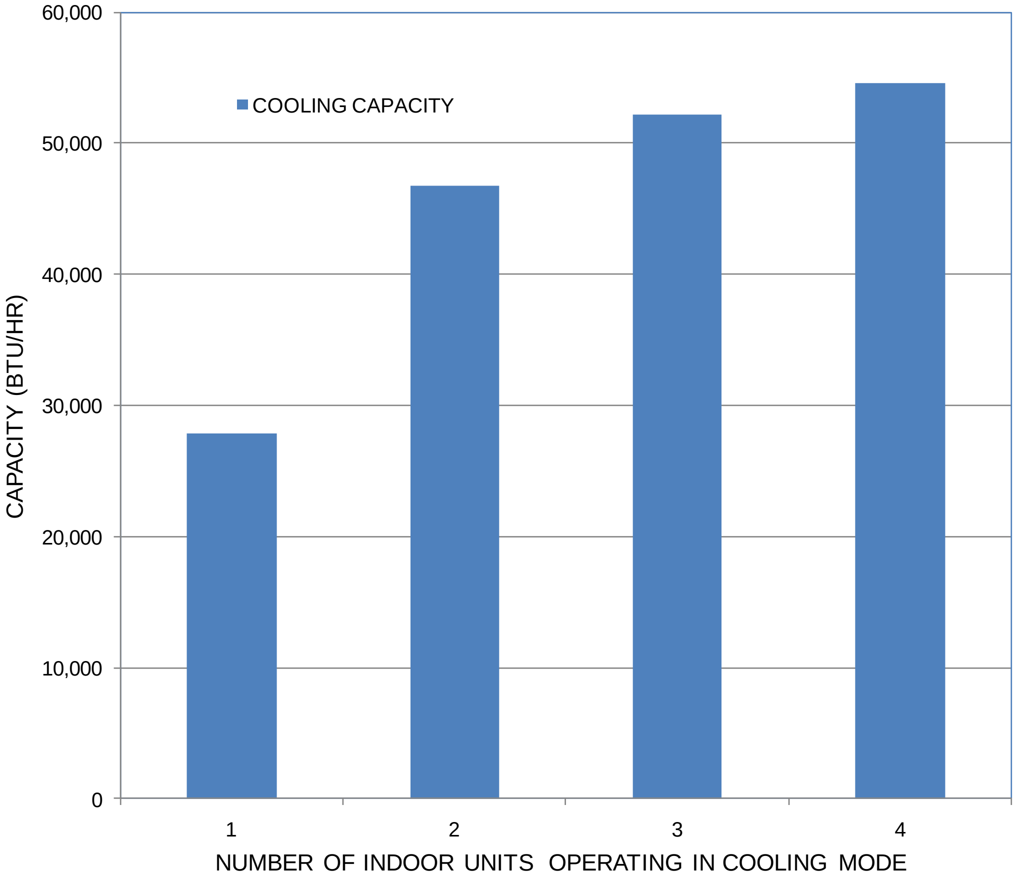


FIGURE 56 **COOLING CAPACITY MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION**

Starting with all four units operating, the total system capacity decreases as the number of indoor units are reduced. The individual capacity of each indoor unit increases the number of indoor units is reduced. As a result, the drop in total capacity from 4 units operating to 3 units operating to 2 units operating is not substantial. During the transition from 4 to 3 to 2 units, the compressor power is fairly constant as seen in Figure 57. The operating parameter that changes during this transition is the suction pressure. The suction pressure is controlled to a set pressure of 103 psig by the system. The compressor is running full speed until only one indoor unit is calling for cooling at which point the compressor speed reduces to attain the required suction and hence the reduction in power seen in Figure 57.

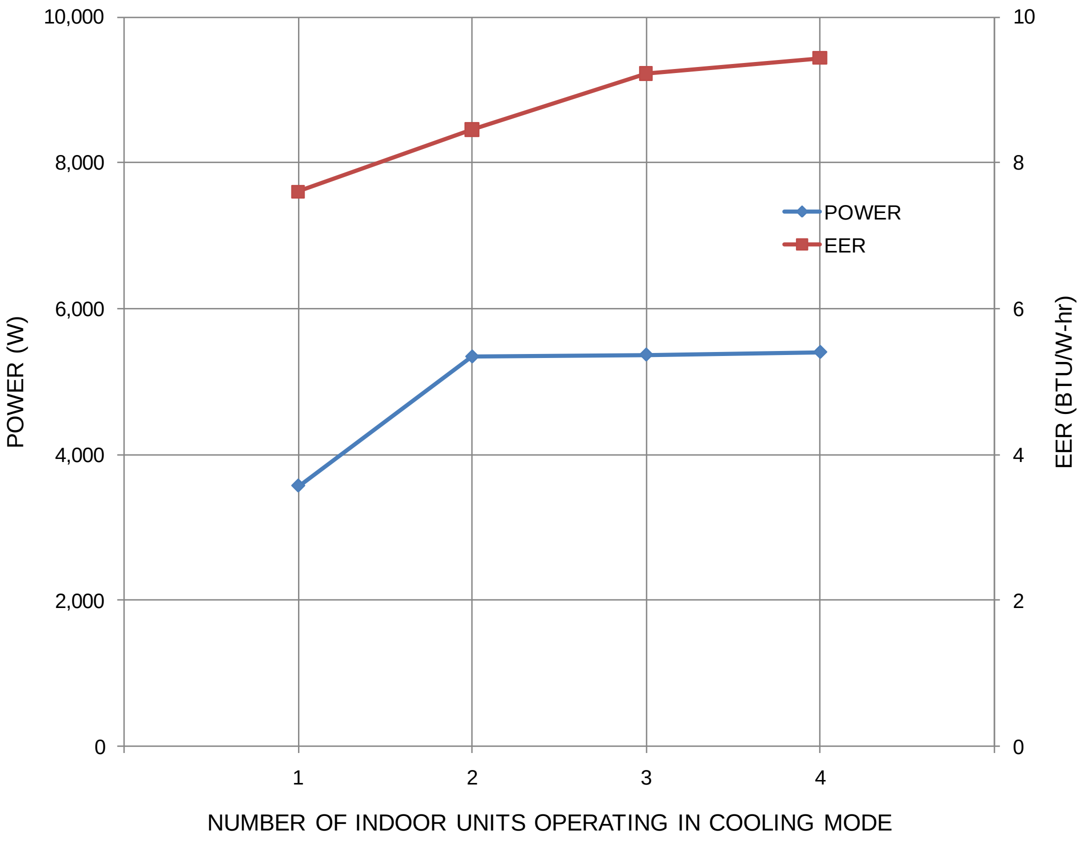


FIGURE 57 **POWER AND EER MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION**

HEATING PERFORMANCE – TEST RESULTS (2 PIPE)

Figure 58 shows the heating capacity measurements at various outdoor WBT and varying indoor RAT. The solid red line shows the manufacturer published data at 70F RAT with corrections applied for indoor capacity, outdoor WBT and piping length. The lab data follows the manufacturer's trend until a certain point. In the case of 70F RAT, the manufacturer's data shows that after a certain upper limit on the OD-WBT (37°F WBT) the capacity does not increase. In lab test though, the capacity increased linearly with increase in OD- WBT. For the period where the capacity increases with increasing WBT, the lab data follows the trends with a 15% lower capacity. The system does not show a flattening of capacity measurements as published by the manufacturer.

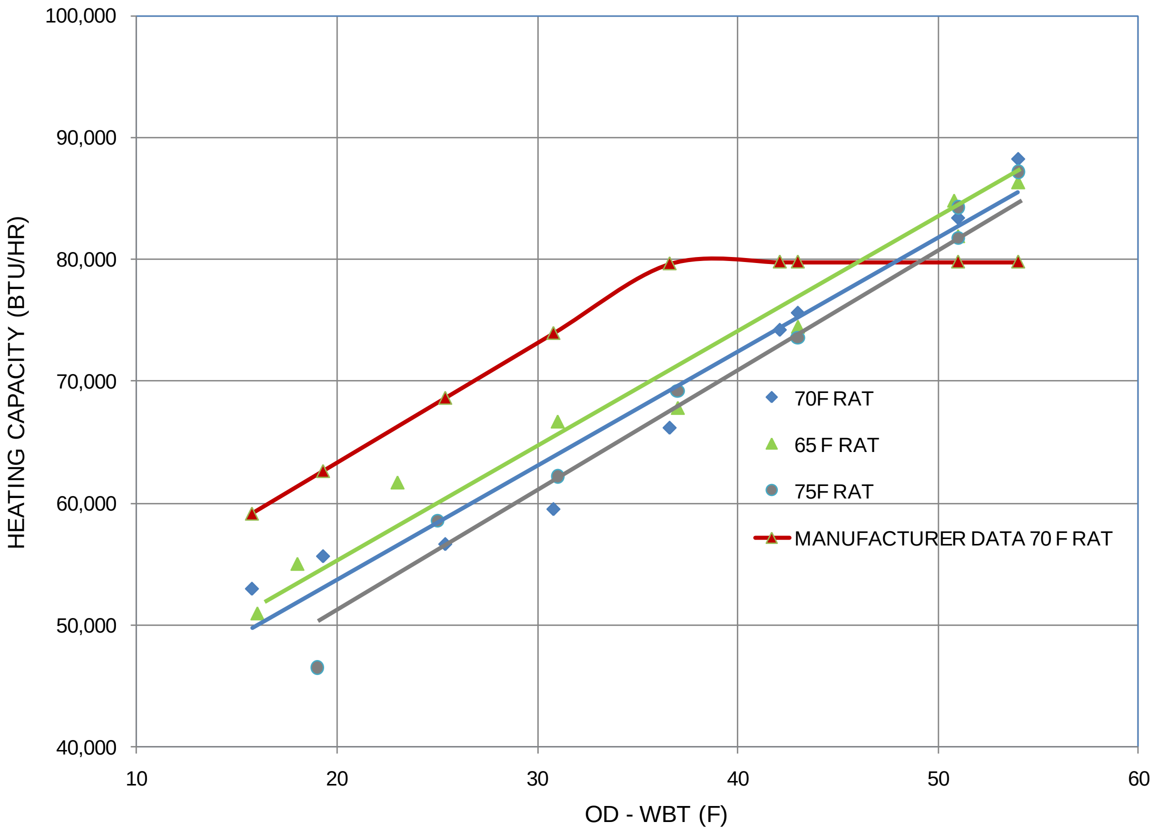


FIGURE 58 : HEATING CAPACITY, VARYING OD-WBT AND RA-DBT

The data looks very similar if the chart is plotted as a function of OD-DBT instead of OD-WBT. The OD-WBT was chosen because the manufacturer published the data in terms of OD-WBT. Figure 59 and Figure 60 show the power draw and the COP in heating mode. The power draw trends are different from the manufacturer published data. The red line in Figure 59 shows the manufacturer published power data for a 70°F RAT. From manufacturer's data, the power draw increases until about 38°F WBT and then decreases. The lab data shows a different characteristic in which the power draw actually decreases right around the 38°F WBT mark and then increases again as the WBT increases. The COP values are not published by the manufacturer. A linearly increasing trend in COP is observed in the COP chart (Figure 60).

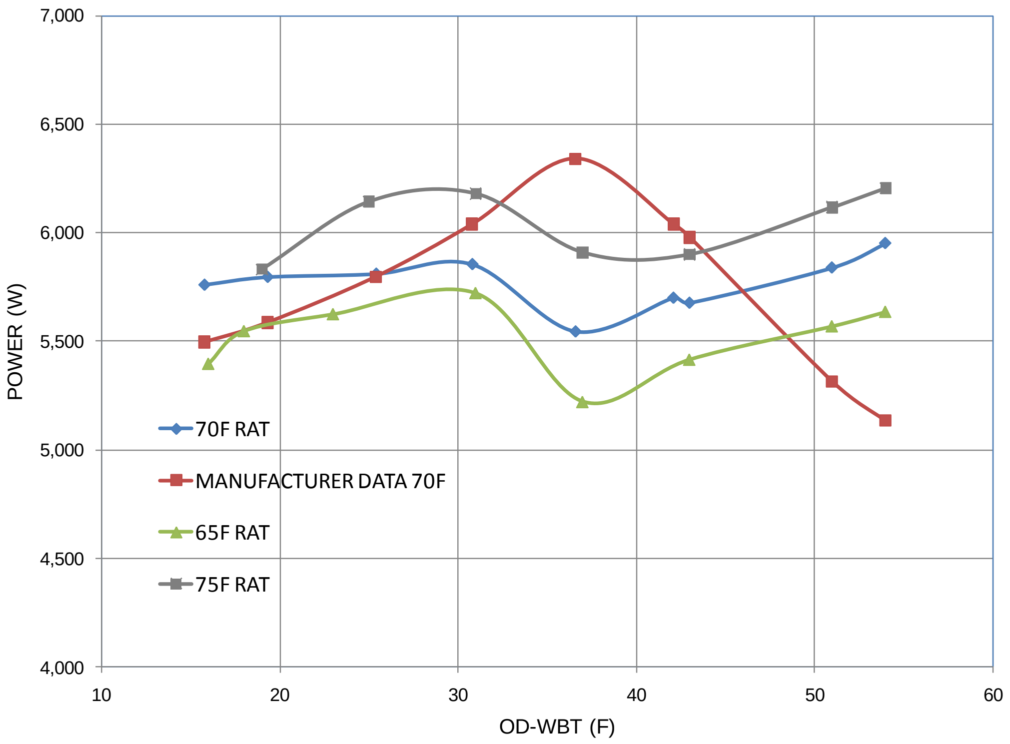


FIGURE 59 : HEATING MODE POWER DRAW, VARYING OD-WBT AND RA-DBT

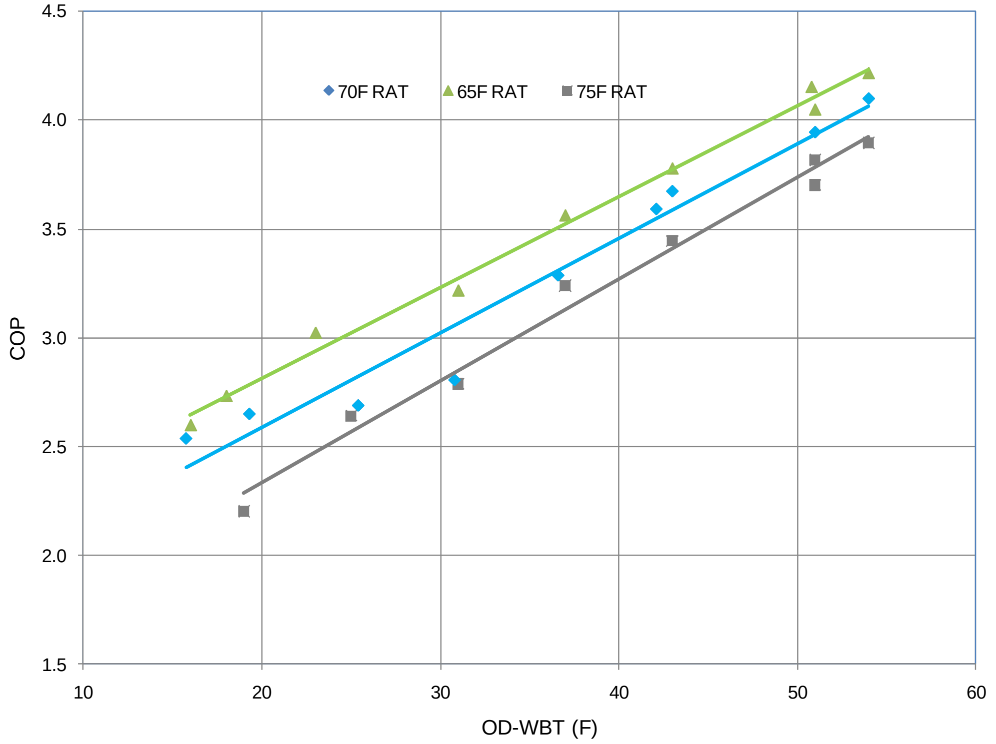


FIGURE 60 : HEATING MODE COP, VARYING OD-WBT AND RA-DBT

% IDU OPERATION (HEATING MODE)

In a multi-zone system, one or more zones might not be calling for heating. The systems test results for four, three, two and one indoor units in heating mode are shown in Figure 61. The system was tested with all four indoor units running at return air condition of 70°F DBT and outdoor condition of 47°F DBT / 43°F WBT.

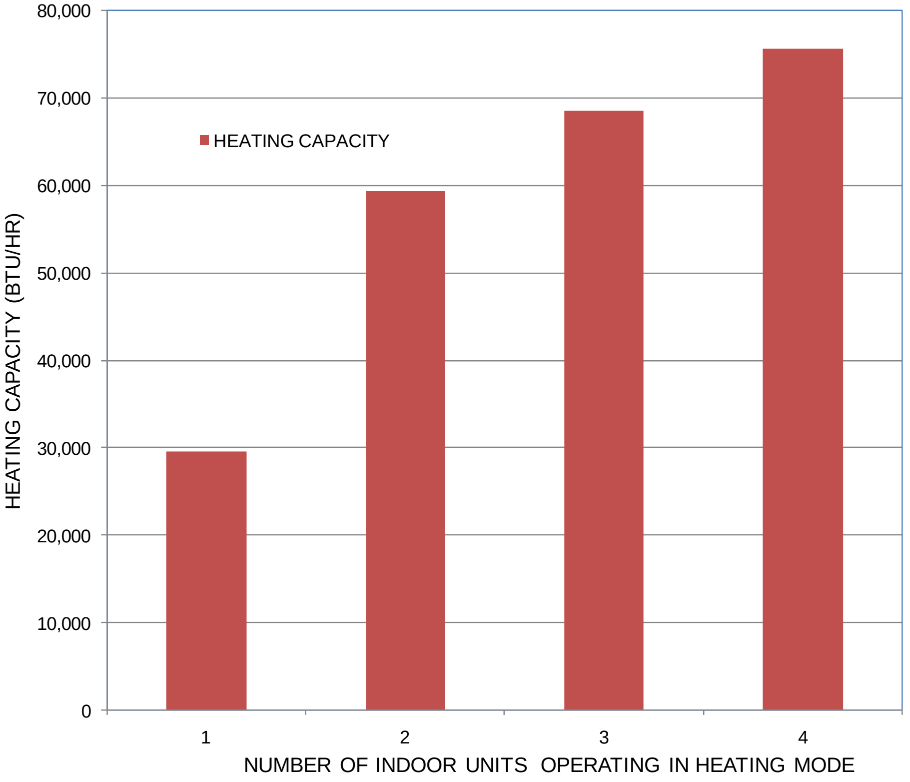


FIGURE 61 : HEATING CAPACITY MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION

After steady state was reached on all four indoor units, one indoor unit was turned off and the system was allowed to run with three indoor units. Once steady state with three indoor units was reached, the same procedure was followed to collect data for 2 and 1 unit operating in heating mode. The corresponding steps in % IDU operation are 100%, 75%, 50% and 25%. Figure 61 shows the total capacity increasing with increasing number of indoor units turned ‘ON’. The individual capacity of each unit decreases as the number of units turned ON increases. For example when two units are ON, the capacity is close to 60,000 Btu/hr but with three indoor units ON, the capacity only increases to 68,000 Btu/hr. This is because the compressor is running at maximum load and cannot provide any more output. This is further confirmed by the compressor power, which remains constant. In the case of only one unit running, the control system reduces the compressor speed to meet the high-pressure set point of 418 psig.

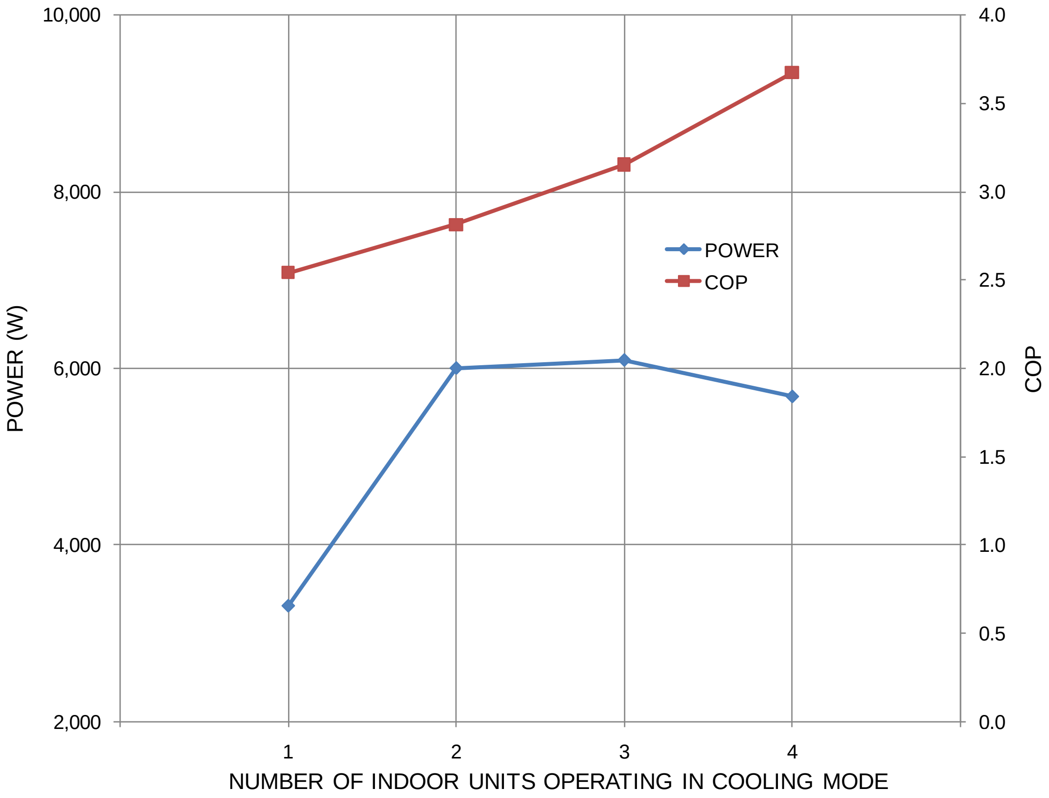


FIGURE 62 : POWER AND EER MEASUREMENTS WITH VARYING NUMBER OF INDOOR UNITS IN OPERATION

SIMULTANEOUS COOLING AND HEATING MODE (SCH)

In simultaneous heating and cooling modes, the system has the ability to deliver cooling or heating as required by each zone, independent of other zones. In this mode, one IDU can be in cooling mode while the other three can be in heating mode. An example of such an installation is an office building where the server room needs cooling even in winter months, whereas the office space needs heating. Another example is a building in which the east facing side of building has a higher heat load in morning, requiring cooling mode operation, whereas the west facing side or internal zones might require heating-mode operation. The ability of the system to redistribute energy from one zone to another without rejecting or absorbing all the energy from outdoor air results in tremendous energy savings.

To achieve this exchange of energy between individual zones, a branch connection (BC) controller is connected between the outdoor and the indoor units. With multiple solenoid valves and compact refrigerant-to-refrigerant heat exchangers, the BC controller can transfer liquid, hot gas and low-pressure gas amongst the IDUs and the ODU to satisfy the requirements of each zone. As a result, the ODU sees only the net requirement of the total system. This means if the system needs more cooling capacity than heating capacity, the ODU acts as a condenser providing only the difference between cooling and heating requirements. If the system needs more heating capacity than cooling capacity, the ODU acts as an evaporator providing the difference between the heating and cooling requirements.

In the two-pipe system that was tested, the refrigerant flow path is controlled by the BC controller. The outdoor unit has two pipe connections; one pipe is the refrigerant supply line and other is the refrigerant return line. These two pipes from the outdoor unit are connected to the BC controller. Each individual indoor unit is also connected to the BC controller with two pipes. The refrigerant flow circuit inside a BC controller is shown in Figure 63. A gas liquid separator separates out the liquid refrigerant from the vapor inside of the BC controller. The solenoid valve block and the check valve block together control the direction of refrigerant flow through each indoor unit. The two tube-in-tube heat exchangers (solid black U shaped components) control the sub cool and super heat depending on the mode the outdoor unit is operating in. The expansion valves LEV 1 and LEV 3 are controlling the amount of refrigerant flowing through each circuit. Multiple pressure sensors and thermistors incorporated within the BC box are used to determine state of refrigerant at each point and to control expansion and solenoid valves as determined by the control logic.

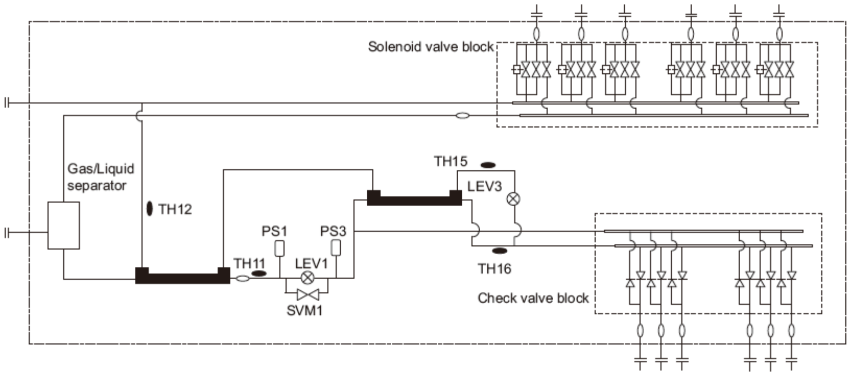


FIGURE 63. REFRIGERANT FLOW DIAGRAM BRANCH CONTROLLER BOX AND INDOOR UNITS (FROM MANUFACTURER)

The BC controller also has multiple strainers (not shown in flow diagram) as a safety mechanism for catching any debris in case of a failure. The BC controller that was installed in EPRI lab was a different model number than the one shown in this refrigerant flow diagram. The BC controller installed was capable of handling five indoor units instead of six shown in Figure 63.

In cooling main mode, the three solenoid valves connected to the outdoor unit heat exchanger are individually controlled to allow flow through each circuit. Depending on the cooling required, heat exchanger circuits are brought in or cut out. In cooling main mode, full capacity of the outdoor heat exchanger is not utilized to allow high temperature refrigerant to flow from the outdoor unit to the indoor units that are in heating mode. The outdoor unit fan is also modulated so that heat is not lost to the ambient air. In the BC controller (Figure 64) the hot gas flows through the solenoid block to the indoor units calling for heat. The hot gas is condensed by losing heat to the room air that flows over the heat exchanger. The liquid refrigerant flows back to the BC controller and is rerouted internally by the check valve block. This liquid refrigerant and the liquid refrigerant from the gas/liquid separator is sub cooled with the help of two tube in tube heat exchangers. The sub cooled liquid refrigerant is then routed back through the check valve block to the indoor units running in cooling mode. The low-pressure refrigerant from the indoor units in cooling mode returns back through the solenoid block into the BC controller and is routed back to the outdoor unit. In the outdoor unit, the low-pressure refrigerant flows back through the reversing valve to the accumulator and then into the compressor.

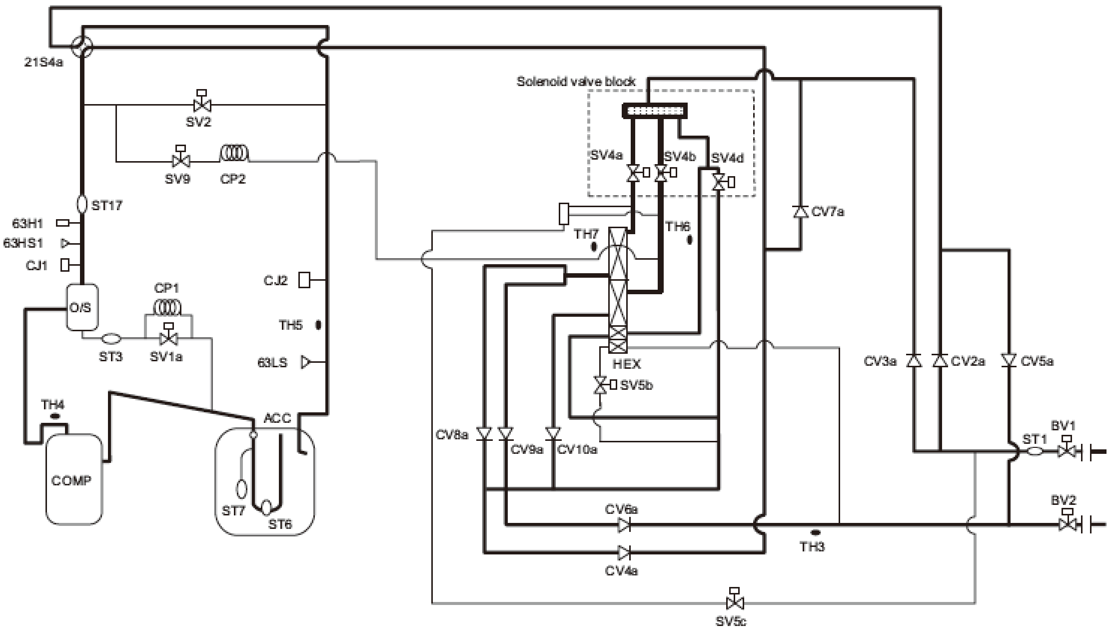


FIGURE 64. OUTDOOR UNIT REFRIGERANT FLOW DIAGRAM (FROM MANUFACTURER)

SIMULTANEOUS COOLING AND HEATING MODE PERFORMANCE MAPPING

The AHRI simultaneous cooling and heating test condition has a set outdoor condition of 47°F DBT, 43°F WBT. Since SCH mode is predominantly used in milder climates outdoor temperatures of 65°F and 75°F DBT were studied. For comparison with the data obtained in cooling mode tests additional outdoor temperatures of 85°F and 95°F were also evaluated. The system was tested using the following procedure:

- Outdoor temperature was maintained at 65°F, 75°F, 85°F and 95°F (four data sets)
- The return air conditions for units in cooling mode are 80°F DBT, 67°F WBT and 75°F DBT and 63°F WBT.
- Return air conditions for units in heating mode are 65°F, 70°F and 75ºF.
- The number of units in cooling mode and heating mode are varied to study the effect on capacity and power.

EFFECT OF CHANGING MODES ON CAPACITY AND POWER

Figure 65 shows the effect upon capacity of changing modes. The outdoor DBT in this case is 65°F and the return air in cooling mode is at 80°F DBT, 67°F WBT in cooling mode and 70°F in heating mode. In '4 COOL' mode each individual temperature controller is set in cooling mode and the resulting capacity and power is measured. After capturing data in steady state, one of the temperature controllers is set to heat mode with target temperature of 83°F DBT and the remaining three are in cooling mode.

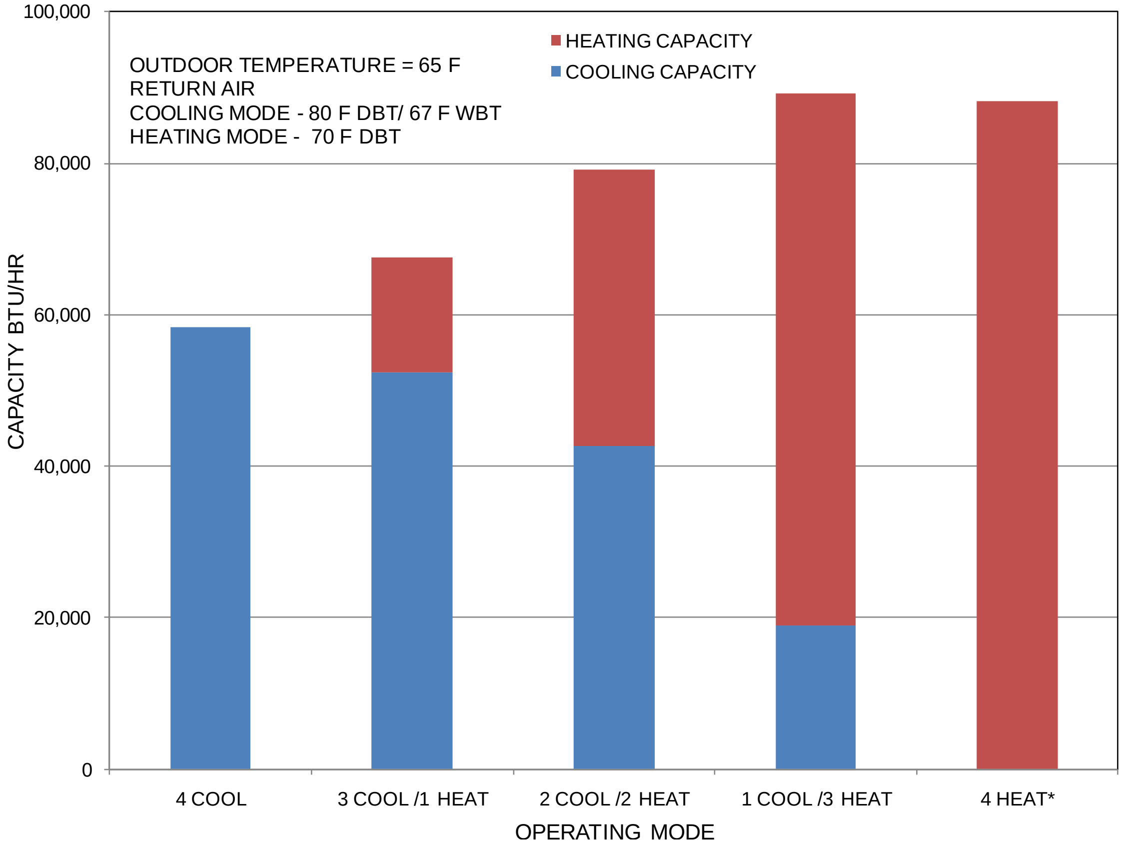


FIGURE 65. CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES (65°F)

In the "3 COOL/1 HEAT" mode the outdoor unit runs in a cooling main mode and in "1 COOL/3 HEAT" mode the outdoor unit runs in a heating main mode. The figure shows that as the units are turned in heating mode, the heating capacity starts increasing and the cooling capacity starts decreasing. The data point with all four units in heating mode is at 60ºF outdoor temperature. The power and EER of the system operating under various conditions is shown in Figure 66. The power draw is dependent on the operating mode of the outdoor unit. Figure 66 reveals some interesting characteristics of the two-pipe system.

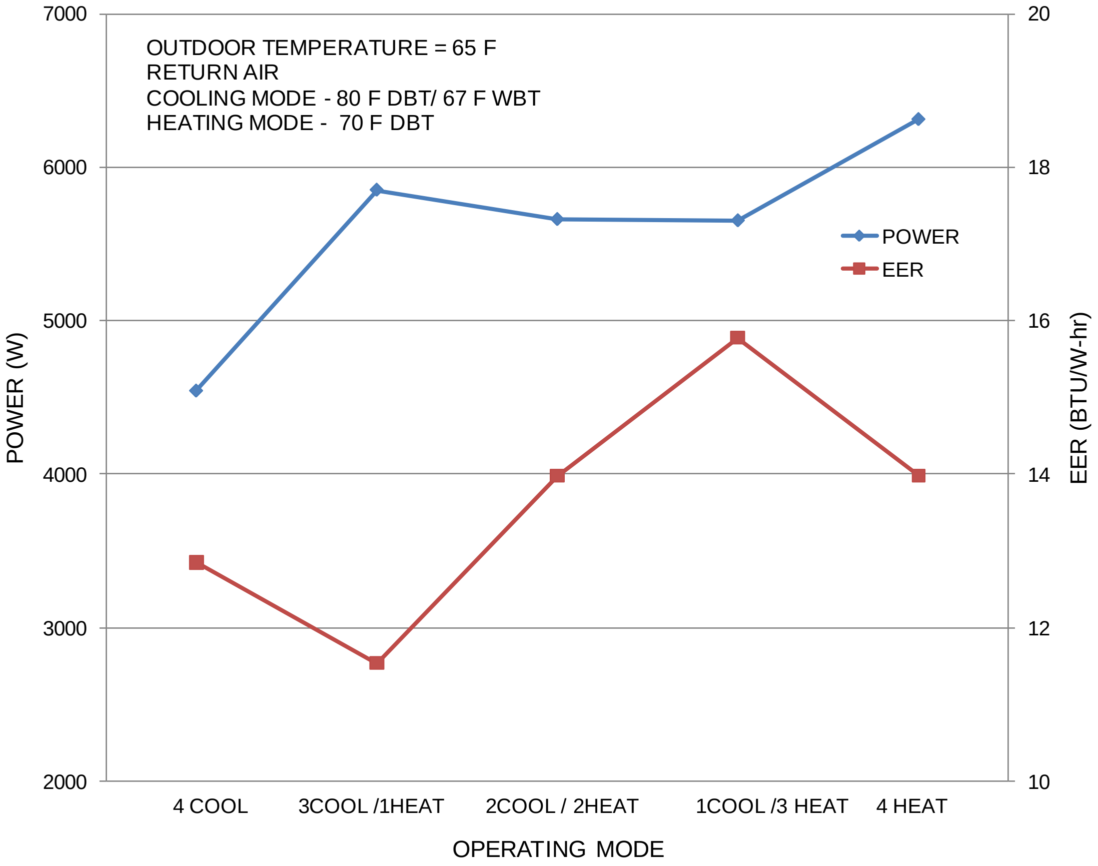


FIGURE 66. **POWER AND EER MEASUREMENTS FOR CHANGING OPERATING MODES (65F)**

The system when running in “4 COOL” mode, i.e., cooling only mode has a better EER due to lower power consumption. Once the unit is switched to 3 cool/1 heat mode the power draw increases and the EER reduces. This is counter intuitive to what a simultaneous cooling and heating mode is thought to be. Normal understanding of SCH is that in mixed mode the heat absorbed from one zone (units in cooling mode) can be rejected in other zones (units in heating mode) with a small penalty for refrigerant pumping from one zone to another. Further analysis of the diagnostic data from lab instrumentation and a thorough understanding of two-pipe system reveal some important characteristics of a two-pipe system.

In cooling only mode, the outdoor unit heat exchangers are utilized to provide liquid refrigerant to the BC controller. This liquid refrigerant is above the outdoor ambient temperature. The liquid refrigerant from the outdoor unit gets sub cooled in the BC controller. In cooling main mode, where there is heating load from one of the indoor units, the system encounters an issue. If the unit continues to operate in a similar way as in cooling only mode, the temperature of the refrigerant at the BC controller is not high enough to provide heating to any indoor unit. For example, in the case discussed above, at 65°F outdoor temperature and cooling only mode, the temperature of the refrigerant in the BC controller is 83°F. The refrigerant at 83°F is not hot enough to provide any heating to the zones calling for heating. The outdoor unit needs to transfer some hot refrigerant to the BC controller to satisfy the heating zones. This is achieved by increasing the refrigerant pressure and temperature at the outdoor unit by reducing the amount of heat exchanger area, reducing outdoor fan speed or modulating the compressor frequency. As the refrigerant pressure rises, the temperature rises too. This high pressure, high temperature refrigerant is then routed to the BC controller. A drawback of this method is that the system is unable to use the favorable ambient temperature (65°F) and the compressor has to work hard to provide the high pressure, high temperature refrigerant. The combined effect is increased outdoor unit power. This increased power consumption results in a reduced EER.

In 2 cool/ 2heat mode the outdoor unit is still operating in the cooling main mode. In the 2 cool / 2 heat mode the outdoor unit power decreases slightly because of fan speed and compressor modulation. The power draw is still higher than it was in “4 COOL” mode. The EER is higher because of the increased capacity. The overall energy balance in this case dictates that the outdoor unit be used as a condenser.

In 3 heat / 1 cool mode the outdoor unit operates in heating main mode and the outdoor heat exchanger acts as an evaporator. The reversing valve sends the high-pressure high temperature refrigerant from the compressor straight to the BC controller where the refrigerant is routed to the indoor units. The condensed liquid coming from the units in heating mode is sub cooled and sent the unit in cooling mode to provide cooling for that particular zone. The overall power consumption remains similar to the 2 cool / 2 heat case, but the refrigerant conditions at various points in the system change. The higher capacity results from the increased performance of 3 units in heating mode which also increases the system EER.

Figure 67 shows capacity measurements similar to Figure 65 except at a higher outdoor temperature of 75°F. The trends are similar to trends in capacity measurements from Figure 65. The data point for 4-heat mode is not available at 75°F because the system cannot operate in heating only mode beyond 73°F.

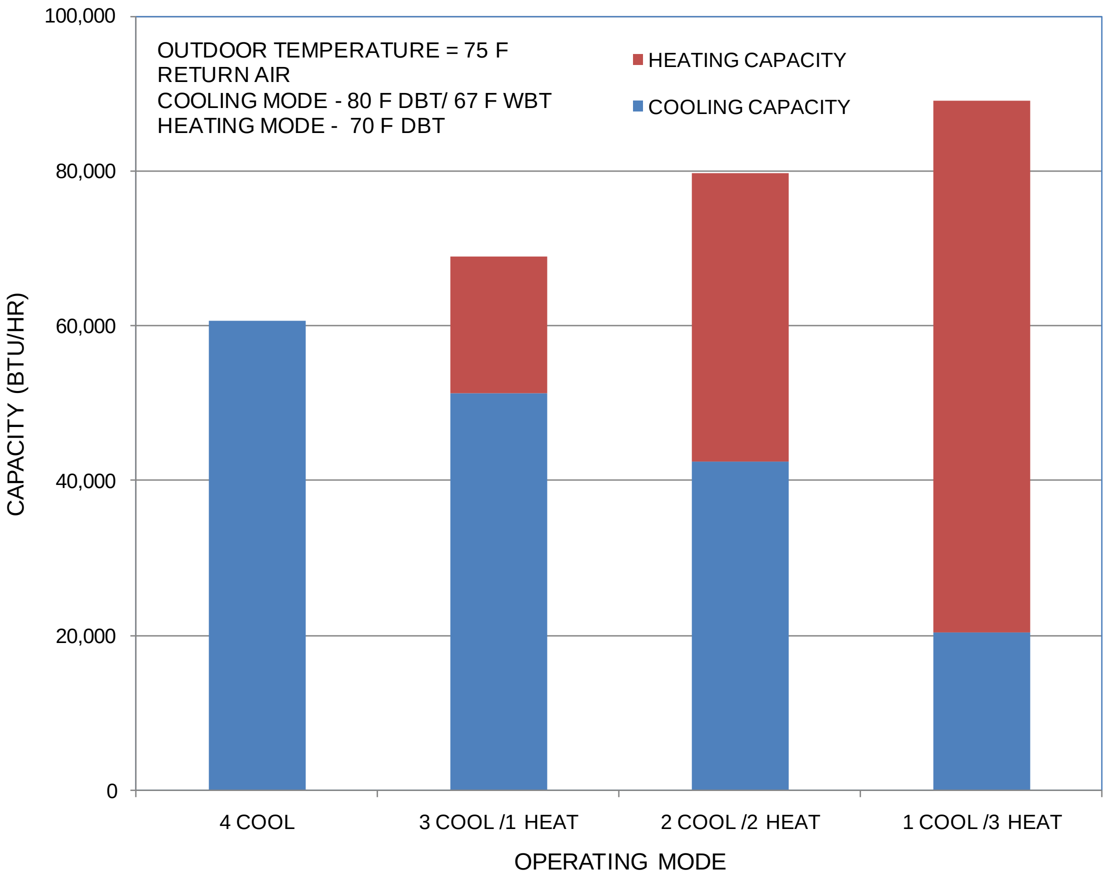


FIGURE 67 : CAPACITY MEASUREMENT FOR CHANGING OPERATING MODES (75F)

Figure 68 shows the power and EER measurements for simultaneous cooling and heating mode at 75°F outdoor temperature. Again, in this case the trends are very similar to the 65°F case. Although there is no data point in all heat mode in Figure 68, the figure can be compared to Figure 66without considering the all heat point.

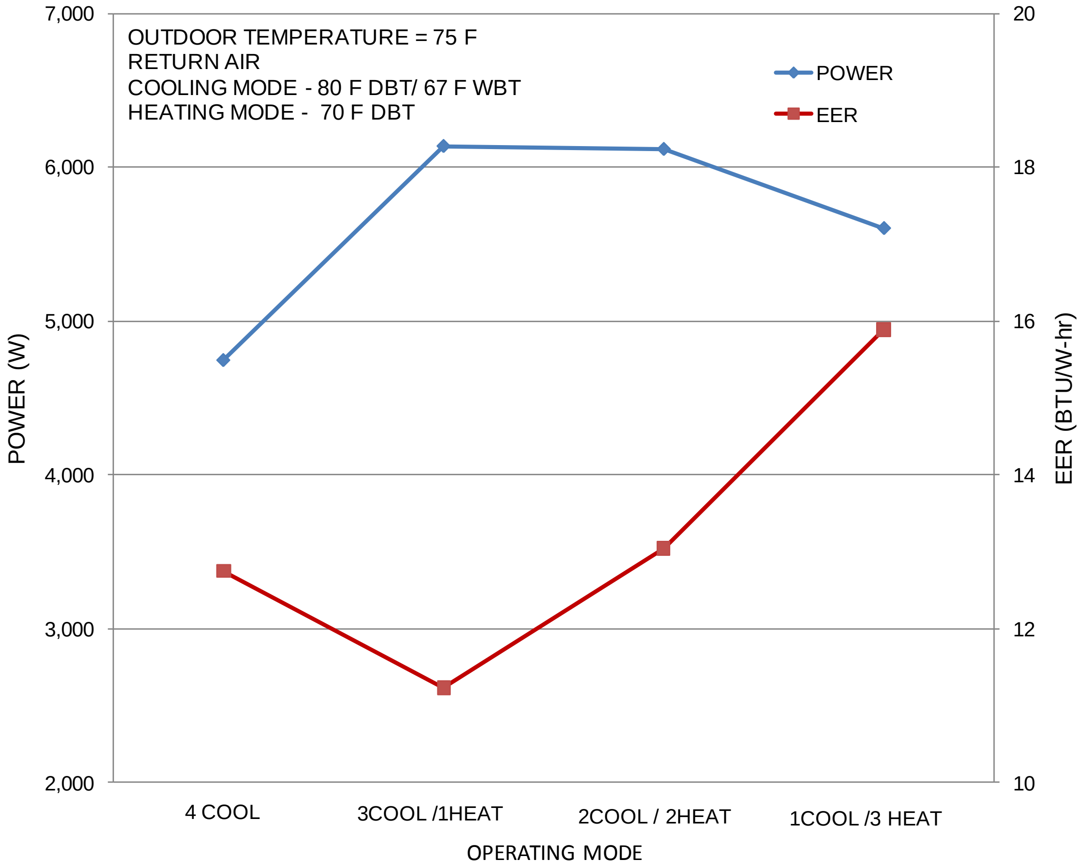


FIGURE 68 : POWER AND EER MEASUREMENTS FOR CHANGING OPERATING MODES (75F)

This effect of increasing power when switched from cooling only to simultaneous heating and cooling mode was studied at various temperatures to verify and understand the behavior. Figure 69 shows power draw with return air at 80°F DBT /60°F WBT in cooling mode and 70F DBT in heating mode for varying outdoor temperatures and operating modes. The trend is similar, though the power draw difference decreases with increasing outdoor temperature. This can be explained by the fact that the compressor is already working hard because of the higher outdoor temperature in 4 cooling mode. As the system is switched into 3 cool / 1 heat mode, the compressor doesn't have to work any harder and thus the power draw is not affected much. The effect is much prominent at milder ambient conditions and is important because the use of SCH mode might be more in milder conditions.

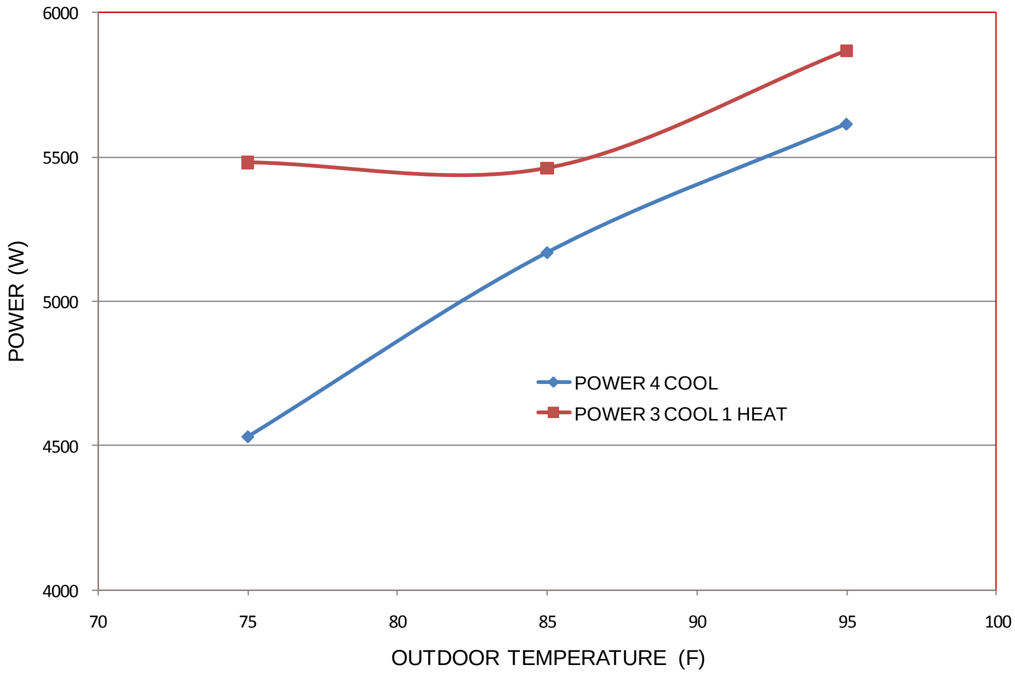


FIGURE 69. COMPARISON OF POWER DRAW FOR THREE DIFFERENT OUTDOOR TEMPERATURES

EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY

Outdoor temperature effect on capacity is studied in simultaneous cooling and heating mode to determine if trends seen in cooling only mode and heating only mode are applicable in SCH mode. In 2 cool / 2 heat (Figure 70) and 3 cool / 1 heat mode (Figure 71) the cooling capacity remains constant across the temperature range (from 65°F to 95°F). In these two cases, the outdoor unit is operating in cooling main mode and is utilizing the indoor units as condensers with little support from the outdoor heat exchanger. Since the return air on the units in heating mode is fixed at 70F, the outdoor temperature does not have significant impact on the capacity. In 1 cool / 3 heat (Figure 72) similar thing happens, the condensing pressure is determined by the return air in heating mode. The evaporator is the unit in cooling mode and the outdoor heat exchanger, which is seeing varying outdoor temperatures. The influence of the outdoor temperature is reduced to the percentage of the condensing / evaporating capacity used by the outdoor heat exchanger.

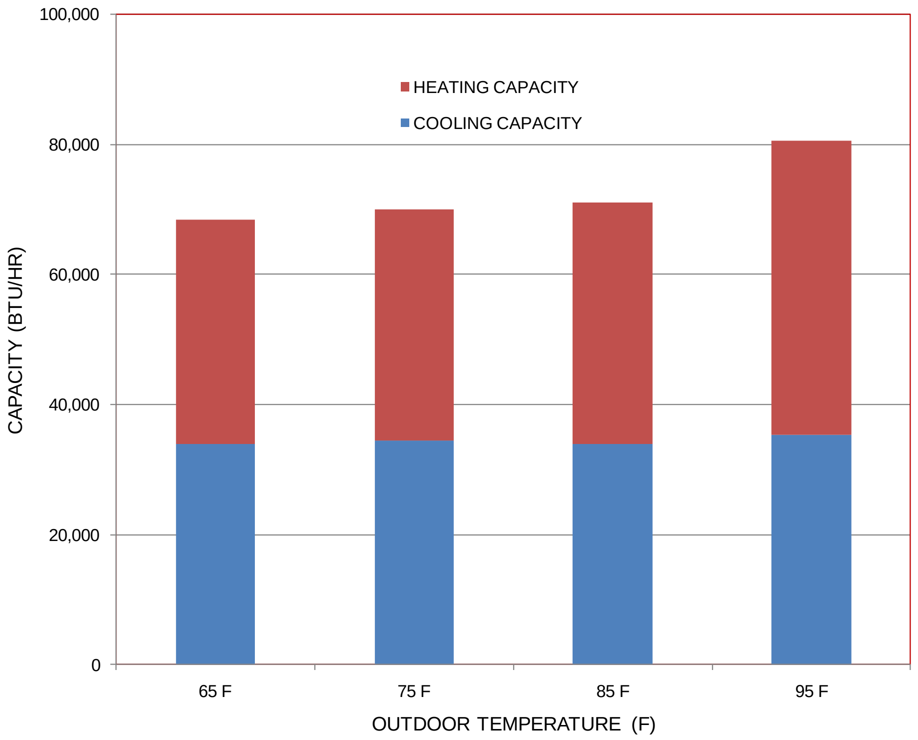


FIGURE 70 : EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY (2 COOL / 2 HEAT)

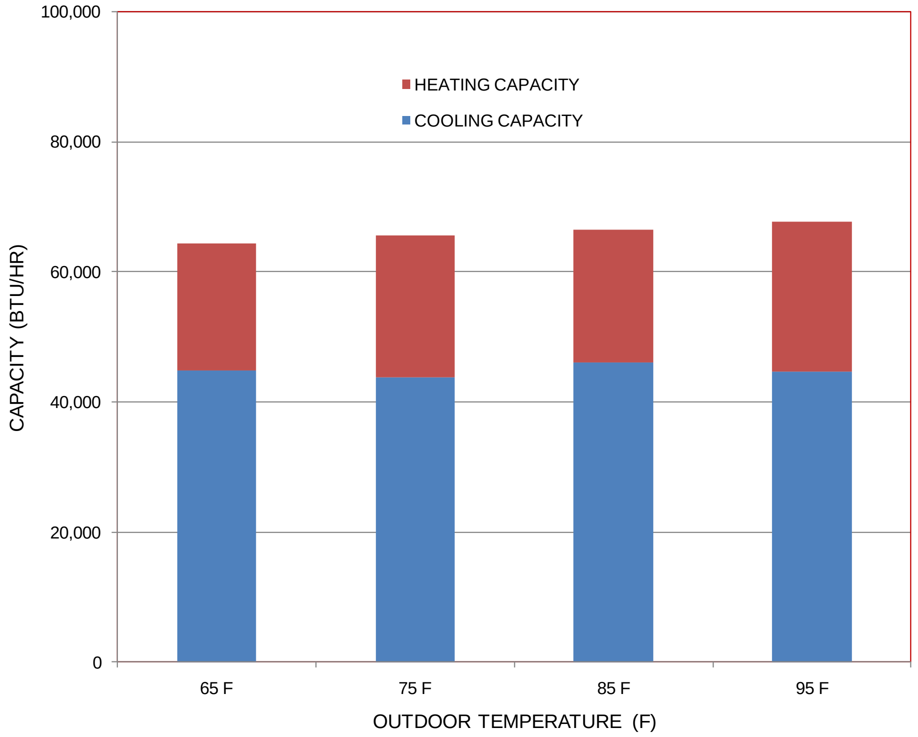


FIGURE 71 : EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY (3 COOL / 1 HEAT)

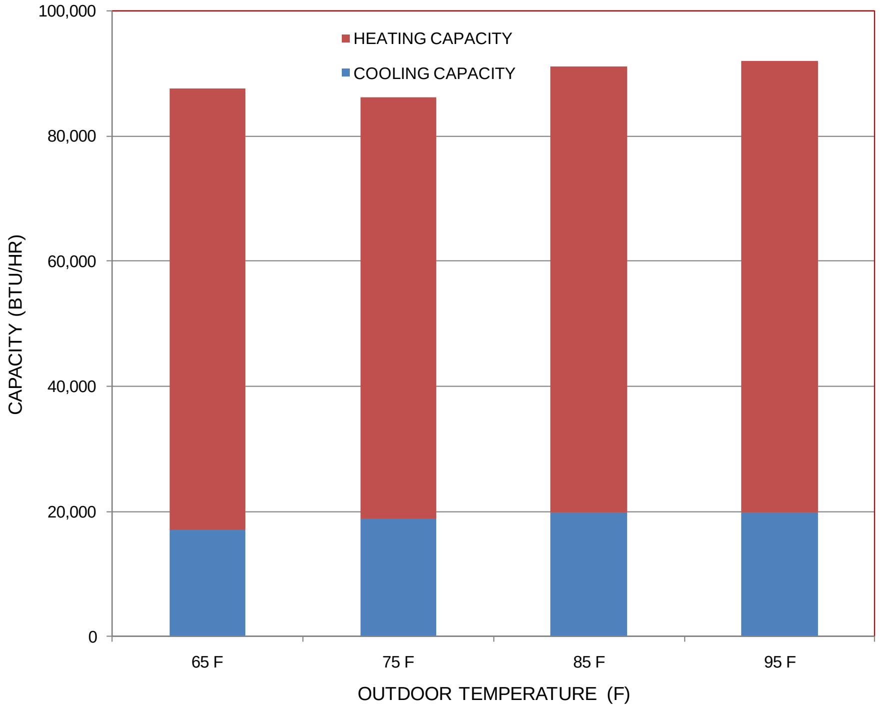


FIGURE 72 : EFFECT OF OUTDOOR TEMPERATURE ON CAPACITY (1 COOL / 3 HEAT)

CONCLUSIONS

The test stand design for testing variable refrigerant flow heat recovery (VRF-HR) systems completed construction and the laboratory data was collected for two VRF-HR systems. The data was shared with energy system modelers, where algorithm could be developed into their respective software. The performance map allows the parametric curve construction using least squares or another appropriate regression analysis method. The metrics included system power consumption and zonal heating and cooling capacity as delivered by the VRF-HR system. The equation set will be the basis for development of a VRF-HR module for use in building modeling software.

In observation of the measured laboratory data, the results differed from expectations. The published data was not replicable in the EPRI laboratory test setup and the test data for cooling capacity showed an average of 25 – 30% deficiency.

Issues that arose throughout the laboratory tests are listed below.

- Compressor speed was a challenge to measure
- Refrigerant side performance is impossible to measure with flooded suction line
- Control algorithm is proprietary to the respective manufacturer
- Override control of the systems are not available in lab or field
- Building owners get same performance as measured in the EPRI lab (i.e., no override)
- Manufacturer's data does not always show response "trend" when compared to lab data.
- These tests are time consuming and as a result costly.

Additionally, the area of codes and standards needs to be carefully evaluated, including ASHRAE Standard 15, ASHRAE Standard 34 and ASRAE Standard 62.1:

- Standard 15 addresses the Refrigerant Concentration Limit (RCL) in a direct system. A direct system per Standard 15 is one in which the evaporator or condenser of the refrigerating system is in direct contact with the air or other substances to be cooled or heated. A VRF system falls under the "Direct System" classification and hence is subject to the RCL.
- ASHRAE Standard 34-2010 assigns safety classifications and refrigerant concentration limits based on toxicity and flammability data. Most of the VRF systems on the market use R410A as a refrigerant. R410A has an A1 safety group classification per Standard 34 that means R410A is a lower toxicity and has no flame propagation potential.
- ASHRAE Standard 62.1 2010 "Ventilation for Acceptable Indoor Air Quality" specifies minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects. The absence of ductwork in a VRF system poses a challenge for moving air from conditioned space to outdoors and vice-versa.

RECOMMENDATIONS

These future activities are recommended to further assess VRF and VRF-HR systems:

Perform Additional Laboratory Testing: Additional laboratory testing will allow for a more comprehensive performance map to assist software vendors.

Perform Field Testing: Data from additional VRF-HR products and applications will further support this research.

Develop VRF Models for Energy Modeling Tools: Enhance the current capabilities of building energy simulation tools like eQuest, Energy Plus, DOE-2 and others to model VRF systems.

Perform Field Testing: Data from additional VRF-HR products and applications will further support this research.

Integrate VRF with Outside Air and Economizer Systems: Currently, ventilation systems used in conjunction with VRF systems are engineered separately on a case-by-case basis. Manufacturers are evaluating potential approaches for an integrated solution, incorporating controls to ensure adequate outside air for ventilation and economizing, while optimizing overall performance.

APPENDIX A – CAPACITY AND POWER CORRECTION TABLES

To determine the expected capacity and power input for a particular VRF installation, correction factors need to be applied to the published capacity and power data. Every manufacturer has a different way of providing this data. For the two-pipe system tested in the lab, correction factors were provided in the form of charts. The first correction factor is based on the total installed indoor capacity as seen in Figure 73. The total indoor capacity for the system in cooling mode is 96,000 Btu/hr and the nominal capacity for the outdoor unit is 72,000 Btu/hr. In Figure 73, this correlates to a rated capacity of 78,000 Btu/h and a power input of 5.5 kW in cooling mode. The same chart is also applicable for heating mode.

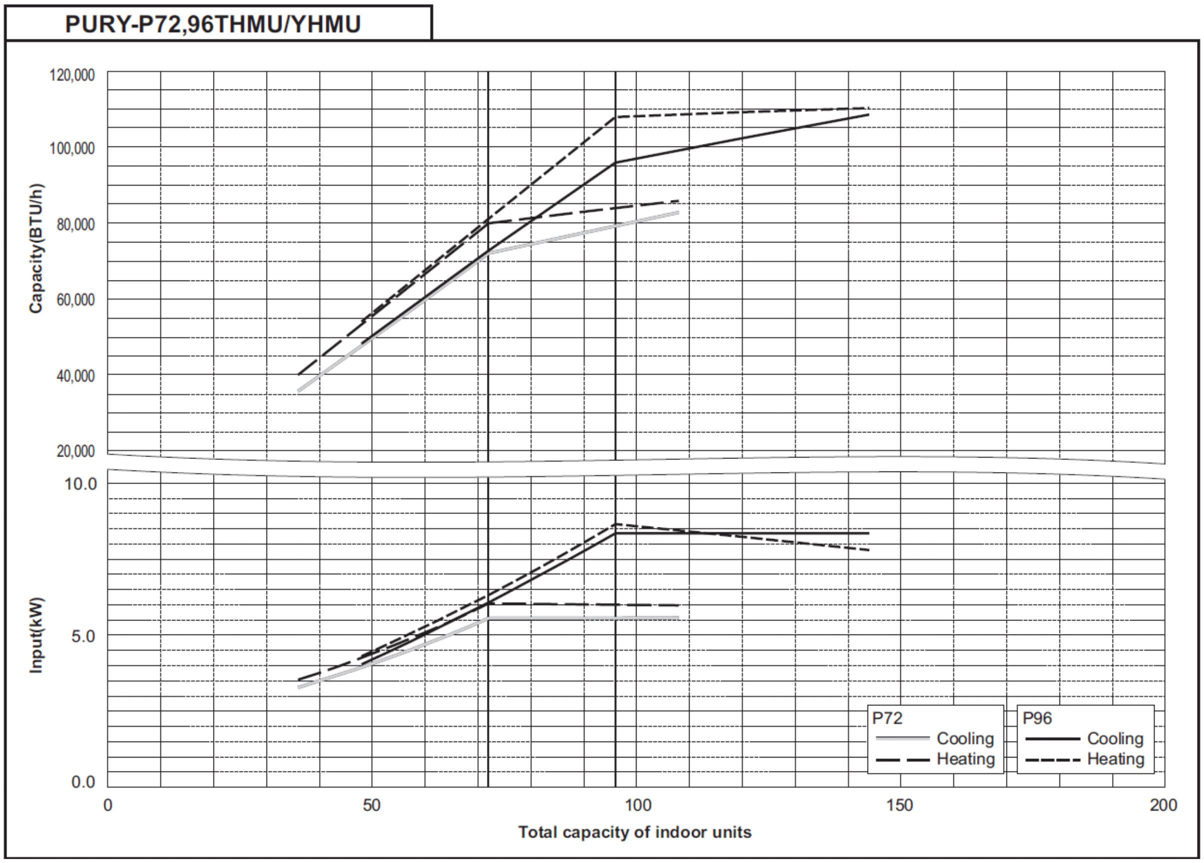


FIGURE 73. CAPACITY AND POWER CORRECTION BASED ON TOTAL INDOOR CAPACITY (FROM MANUFACTURER)

In Figure 74 and Figure 75, for cooling mode and heating mode respectively, a second correction based on indoor and outdoor air temperature can be determined and used to scale the capacity and power obtained from Figure 73. If the system were operating in cooling mode, correction factors for capacity and power input could be found from Figure 74 The solid black lines in Figure 74 represent constant WBT, and the x-axis represents OD-DBT. If the air conditions were 95°F DBT for outdoor air and 67°F WBT indoor air, the corresponding capacity and power correction ratios would be approximately 0.99 and 1.1 respectively. If the system were operating in heating mode, similar steps could be taken with Figure 75.

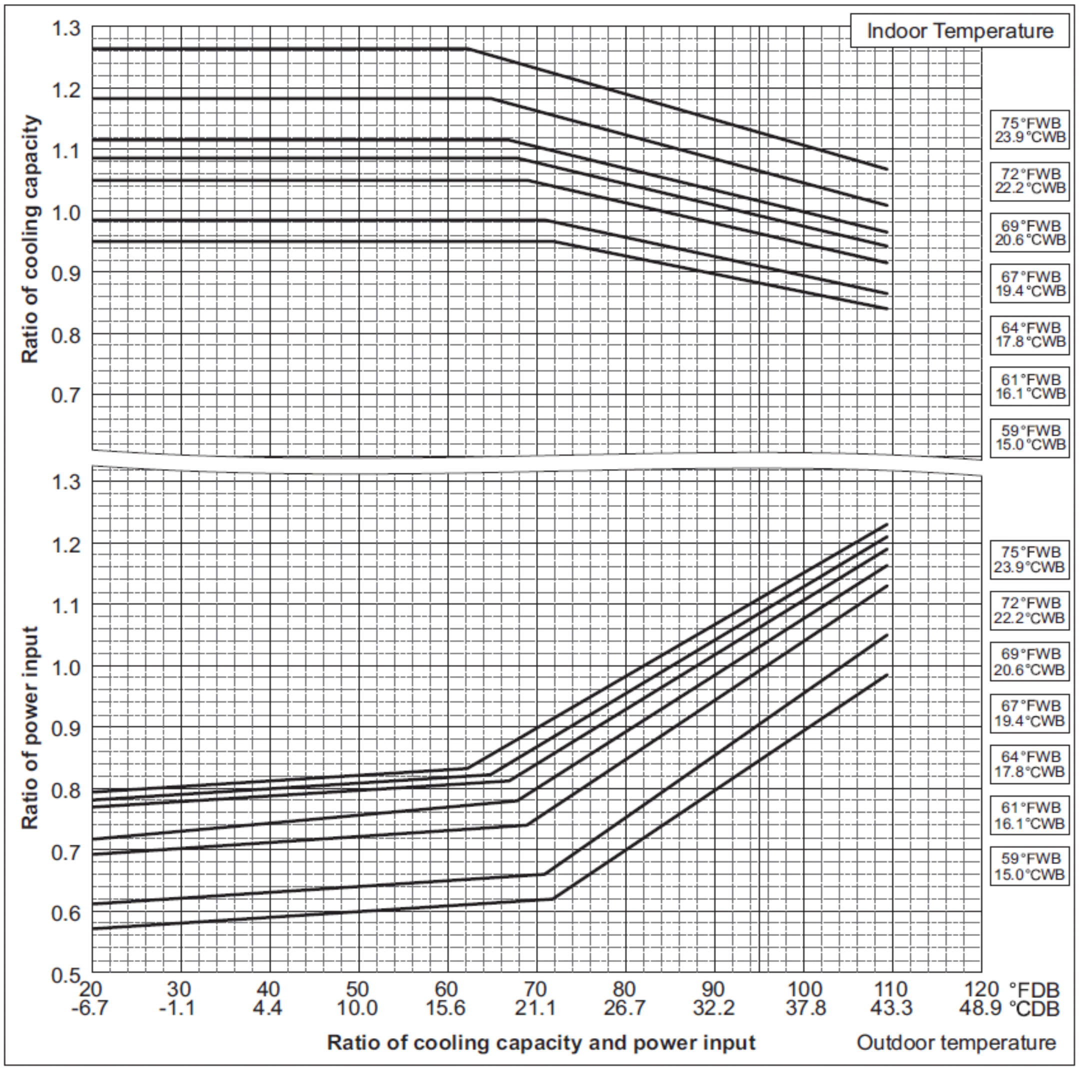


FIGURE 74. CAPACITY AND POWER CORRECTION BY TEMPERATURE CONDITIONS IN COOLING MODE (FROM MANUFACTURER)

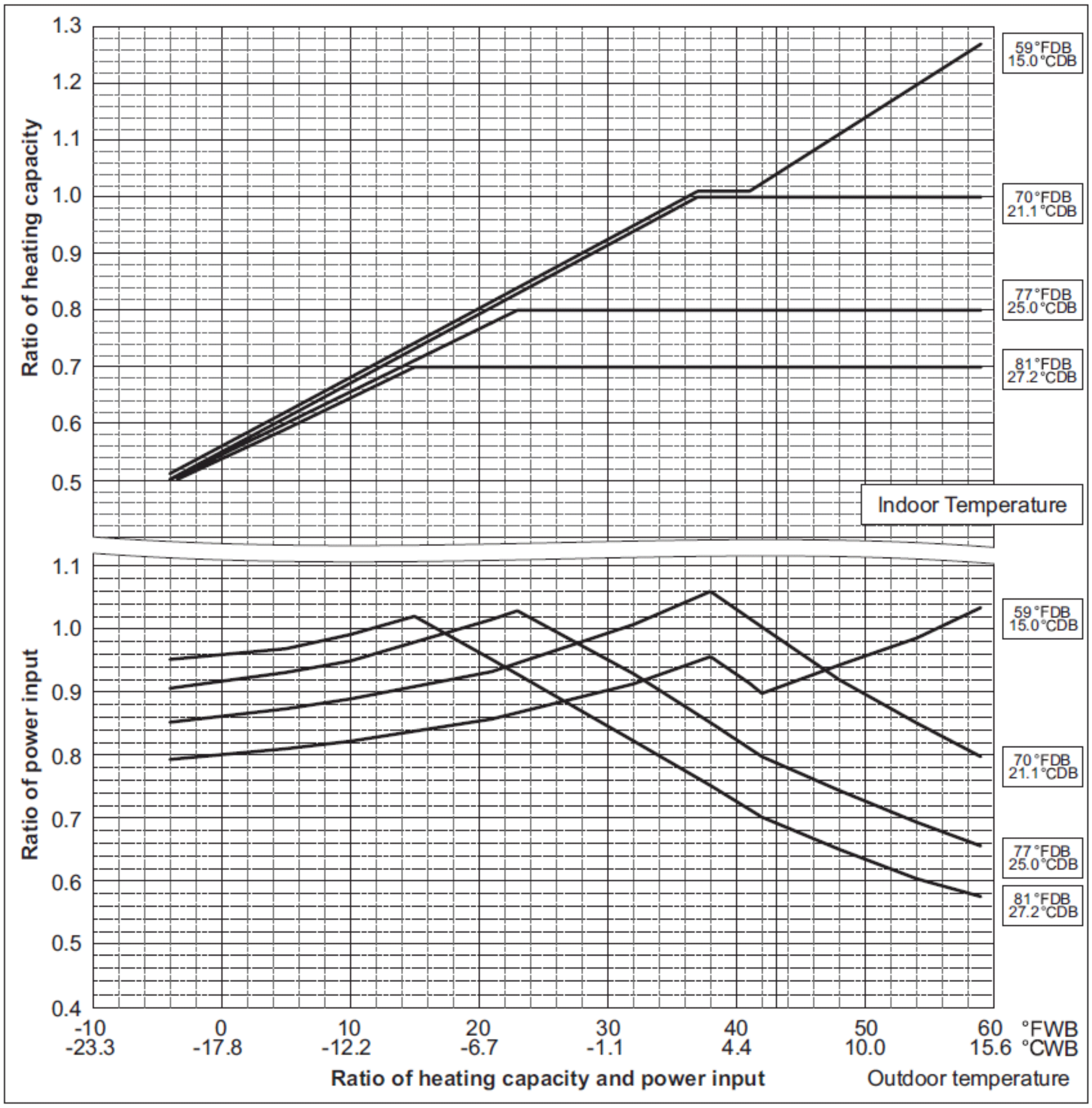


Figure 75. Capacity and Power Correction by Temperature Conditions in Heating Mode (from manufacturer)

The third correction is based on refrigerant piping length as seen in Figure 76. The equivalent piping length for the VRF setup was determined to be 55 feet, which corresponds to a correction factor of 0.95 from Figure 76. Correction factors are multiplied to the capacity and power input obtained from Figure 76. Using the correction factors for indoor and outdoor temperature conditions and refrigerant piping length, the expected cooling capacity was determined to be 73,359 Btu/h under the specified conditions. Power input is not affected by refrigerant length, and therefore expected power is based only on a temperature correction. The expected power input was determined to be 6.05 kW.

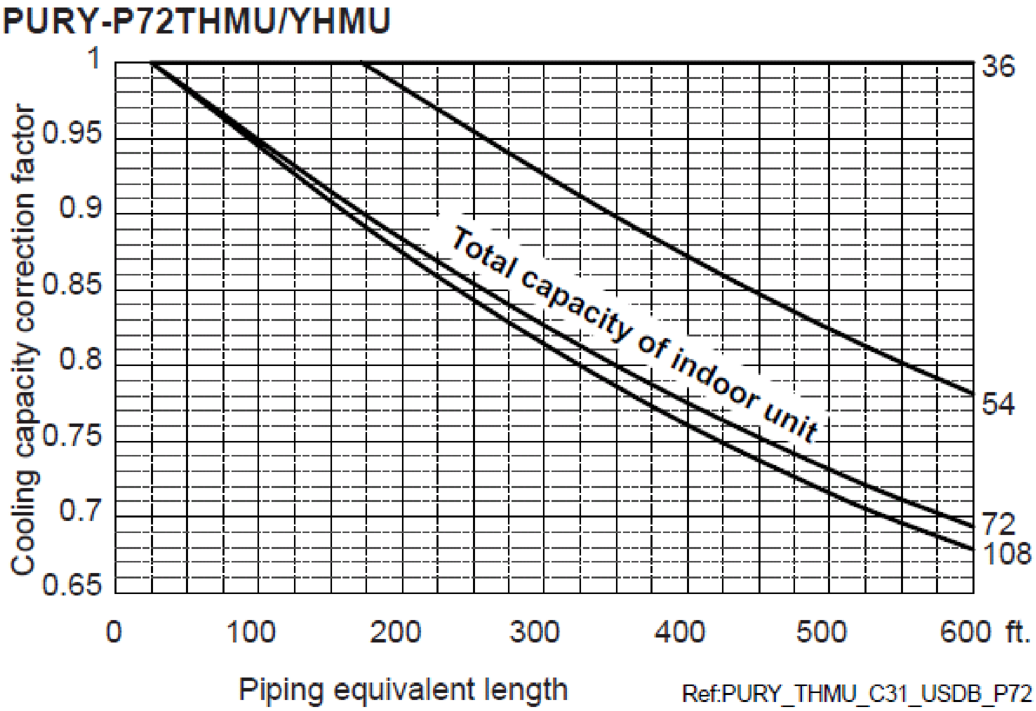


FIGURE 76. CORRECTION FOR REFRIGERANT PIPING LENGTH (FROM MANUFACTURER)

In heating mode, a correction factor is also applied for defrost, but for this analysis defrost was not used to de-rate the equipment.

APPENDIX B – LAB DATA

The following is raw data captured from the LABview system and formatted for clarity. The laboratory data follows the test matrix for testing VRF-HR system as shown in Table 2.

TABLE 7. 100% COOLING MODE LAB TEST

100 % IDU OPERATION - COOLING MODE									
INDOOR		OUTDOOR	CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	WBT	DBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
75	60	75	13,048	12,806	12,659	12,863	51,376	4,555	11.28	3.31
75	60	85	12,869	12,241	12,229	12,427	49,766	5,206	9.56	2.80
75	60	95	11,940	11,600	11,495	11,634	46,669	5,681	8.22	2.41
75	60	105	10,689	10,411	10,443	10,438	41,982	6,192	6.78	1.99
75	63	75	14,774	14,404	13,155	13,767	56,101	4,628	12.12	3.55
75	63	85	14,147	13,926	12,889	13,261	54,222	5,214	10.40	3.05
75	63	95	12,660	12,438	11,667	12,119	48,883	5,665	8.63	2.53
75	63	105	9,783	9,578	9,620	9,899	38,880	6,093	6.38	1.87
75	67	75	16,008	15,845	14,382	15,599	61,834	4,752	13.01	3.81
75	67	85	14,928	15,220	13,206	14,423	57,777	5,283	10.94	3.21
75	67	95	14,279	14,365	12,413	13,880	54,938	5,788	9.49	2.78
75	67	105	13,094	12,422	11,485	12,036	49,037	6,408	7.65	2.24
80	60	75	13,391	13,363	12,822	13,126	52,702	4,530	11.63	3.41
80	60	85	12,333	12,057	12,152	12,329	48,871	5,169	9.45	2.77
80	60	95	11,870	11,758	11,582	11,342	46,553	5,615	8.29	2.43
80	60	105	9,454	9,205	9,732	9,834	38,225	6,193	6.17	1.81
80	63	75	13,540	13,233	13,237	13,672	53,683	4,611	11.64	3.41
80	63	85	13,330	13,237	12,873	13,002	52,443	5,167	10.15	2.97
80	63	95	12,700	12,180	12,055	12,263	49,198	5,726	8.59	2.52
80	63	105	11,747	11,330	11,395	11,543	46,014	6,302	7.30	2.14
80	67	65	16,089	14,467	13,309	14,572	58,437	4,547	12.85	3.77
80	67	68	15,726	15,038	13,729	14,802	59,296	4,562	13.00	3.81
80	67	75	15,901	15,549	14,257	14,875	60,581	4,750	12.75	3.74
80	67	85	14,859	14,049	12,880	13,734	55,521	5,244	10.59	3.10
80	67	95	14,482	13,689	12,953	13,444	54,568	5,781	9.44	2.77
80	67	105	12,821	12,458	11,516	12,000	48,795	6,295	7.75	2.27
80	70	75	16,326	15,900	14,328	16,064	62,618	4,893	12.80	3.75
80	70	85	15,418	15,002	13,752	15,110	59,282	5,360	11.06	3.24
80	70	95	15,135	14,431	12,768	13,790	56,125	5,959	9.42	2.76
80	70	105	12,840	12,873	11,407	12,804	49,924	6,433	7.76	2.27
85	63	75	14,440	14,327	13,926	14,269	56,962	4,652	12.24	3.59
85	63	85	13,764	13,632	13,278	13,561	54,236	5,334	10.17	2.98
85	63	95	13,333	13,162	12,766	12,994	52,256	5,733	9.11	2.67
85	63	105	12,357	12,030	11,670	12,174	48,230	6,354	7.59	2.22
85	67	75	15,258	14,654	13,951	14,810	58,673	4,695	12.50	3.66
85	67	85	13,724	13,409	13,121	13,426	53,681	5,146	10.43	3.06
85	67	95	12,883	12,582	12,435	12,594	50,494	5,675	8.90	2.61
85	67	105	11,939	11,755	11,595	11,900	47,189	6,286	7.51	2.20
85	70	75	16,050	15,519	14,348	15,682	61,598	4,702	13.10	3.84
85	70	85	15,228	14,890	13,842	14,835	58,794	5,352	10.99	3.22
85	70	95	14,137	13,793	12,933	14,047	54,910	5,793	9.48	2.78
85	70	105	13,026	12,425	11,869	12,908	50,228	6,361	7.90	2.31

TABLE 8. 75% COOLING MODE LAB TEST RESULTS

75 % IDU OPERATION - COOLING MODE										
INDOOR		OUTDOOR	CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	WBT	DBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
75	67	75	0	19,714	17,922	20,122	57,758	4,583	12.60	3.69
75	67	85	0	19,545	16,900	18,949	55,395	5,221	10.61	3.11
75	67	95	0	18,021	15,890	17,561	51,471	5,710	9.01	2.64
75	67	105	0	15,644	14,193	16,257	46,094	6,264	7.36	2.16
80	60	75		16,814	16,671	16,871	50,356	4,542	11.09	3.25
80	60	85	0	16,028	15,939	16,283	48,251	5,079	9.50	2.78
80	60	95	0	15,720	15,620	15,493	46,833	5,644	8.30	2.43
80	60	105	0	13,148	13,259	13,459	39,866	6,064	6.57	1.93
80	63	75	0	15,586	15,744	16,158	47,489	4,403	10.79	3.16
80	63	85	0	16,683	16,622	17,116	50,421	5,149	9.79	2.87
80	63	95	0	15,525	15,700	15,484	46,709	5,597	8.34	2.45
80	63	105	0	14,110	14,600	14,733	43,443	6,188	7.02	2.06
80	67	75	0	19,639	18,122	19,019	56,781	4,682	12.13	3.55
80	67	85	0	17,893	16,919	19,483	54,295	5,109	10.63	3.11
80	67	95	0	17,404	16,697	18,085	52,186	5,655	9.23	2.70
80	67	105	0	15,651	14,498	15,430	45,579	6,166	7.39	2.17
80	70	75	0	20,607	18,447	20,946	59,999	4,758	12.61	3.70
80	70	85	0	19,149	18,041	20,771	57,962	5,284	10.97	3.21
80	70	95	0	17,617	16,411	18,470	52,498	5,580	9.41	2.76
80	70	105	0	16,293	14,523	16,053	46,869	6,246	7.50	2.20
85	67	75	0	18,861	17,524	19,644	56,030	4,555	12.30	3.61
85	67	85	0	17,826	17,506	18,340	53,672	5,212	10.30	3.02
85	67	95	0	16,482	16,368	17,219	50,069	5,604	8.93	2.62
85	67	105	0	14,938	14,670	15,200	44,808	6,154	7.28	2.13

TABLE 9. 50% COOLING MODE LAB TEST RESULTS

50 % IDU OPERATION - COOLING MODE										
INDOOR		OUTDOOR	CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	WBT	DBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
75	67	75	0	0	21,990	24,895	46,885	4,589	10.22	2.99
75	67	85	0	0	21,104	24,062	45,166	4,833	9.35	2.74
75	67	95	0	0	21,889	23,779	45,669	5,539	8.25	2.42
75	67	105	0	0	20,204	22,262	42,466	6,123	6.94	2.03
80	60	75	0	0	20,223	20,347	40,571	4,267	9.51	2.79
80	60	85	0	0	20,094	20,311	40,405	4,713	8.57	2.51
80	60	95	0	0	19,602	19,546	39,148	5,296	7.39	2.17
80	60	105	0	0	18,511	18,261	36,772	6,054	6.07	1.78
80	63	75	0	0	21,151	22,630	43,781	4,434	9.87	2.89
80	63	85	0	0	21,485	21,985	43,471	4,962	8.76	2.57
80	63	95	0	0	21,000	21,789	42,789	5,466	7.83	2.29
80	63	105	0	0	19,375	19,848	39,223	6,077	6.45	1.89
80	67	75	0	0	22,179	24,730	46,909	4,588	10.22	3.00
80	67	85	0	0	22,008	24,768	46,776	4,858	9.63	2.82
80	67	95	0	0	22,061	24,747	46,808	5,535	8.46	2.48
80	67	105	0	0	20,324	21,339	41,663	6,078	6.85	2.01
80	70	75	0	0	20,577	23,936	44,513	4,482	9.93	2.91
80	70	85	0	0	21,700	24,818	46,518	5,154	9.03	2.65
80	70	95	0	0	21,157	23,992	45,149	5,517	8.18	2.40
80	70	105	0	0	20,648	22,962	43,610	6,054	7.20	2.11
85	67	75	0	0	21,416	24,307	45,723	4,707	9.71	2.85
85	67	85	0	0	20,822	23,672	44,494	5,102	8.72	2.56
85	67	95	0	0	20,291	22,529	42,820	5,711	7.50	2.20
85	67	105	0	0	19,775	21,388	41,162	6,080	6.77	1.98

TABLE 10. 25% COOLING MODE LAB TEST RESULTS

25 % IDU OPERATION - COOLING MODE										
INDOOR		OUTDOOR	CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	WBT	DBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
75	67	75	0	0	0	26,606	26,606	2,759	9.64	2.83
75	67	85	0	0	0	27,226	27,226	3,230	8.43	2.47
75	67	95	0	0	0	27,879	27,879	3,493	7.98	2.34
75	67	105	0	0	0	27,542	27,542	4,613	5.97	1.75
80	60	75	0	0	0	22,634	22,634	2,439	9.28	2.72
80	60	85	0	0	0	22,505	22,505	2,706	8.32	2.44
80	60	95	0	0	0	21,893	21,893	3,052	7.17	2.10
80	60	105	0	0	0	21,809	21,809	3,763	5.80	1.70
80	63	75	0	0	0	25,239	25,239	2,547	9.91	2.90
80	63	85	0	0	0	24,547	24,547	3,093	7.94	2.33
80	63	95	0	0	0	25,025	25,025	3,434	7.29	2.14
80	63	105	0	0	0	24,878	24,878	4,093	6.08	1.78
80	67	75	0	0	0	26,711	26,711	2,694	9.91	2.91
80	67	85	0	0	0	27,251	27,251	3,056	8.92	2.61
80	67	95	0	0	0	27,817	27,817	3,658	7.61	2.23
80	67	105	0	0	0	27,679	27,679	4,554	6.08	1.78
80	70	75	0	0	0	27,483	27,483	2,572	10.69	3.13
80	70	85	0	0	0	27,930	27,930	3,282	8.51	2.49
80	70	95	0	0	0	27,510	27,510	3,932	7.00	2.05
80	70	105	0	0	0	28,695	28,695	4,570	6.28	1.84
85	67	75	0	0	0	26,336	26,336	2,567	10.26	3.01
85	67	85	0	0	0	26,782	26,782	3,012	8.89	2.61
85	67	95	0	0	0	26,685	26,685	3,666	7.28	2.13
85	67	105	0	0	0	27,276	27,276	4,432	6.15	1.80

TABLE 11. 100% HEATING MODE LAB TEST RESULTS

100 % IDU OPERATION - HEATING MODE										
INDOOR	OUTDOOR		CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	DBT	WBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
65	17	16	13,137	12,817	12,543	12,516	51,014	5,758	8.86	2.60
65	21	18	14,140	13,668	13,503	13,759	55,069	5,909	9.32	2.73
65	28	23	15,775	15,327	14,975	15,652	61,728	5,987	10.31	3.02
65	34	31	16,991	16,719	16,154	16,851	66,716	6,080	10.97	3.22
65	41	37	17,429	17,110	16,541	16,755	67,835	5,583	12.15	3.56
65	47	43	19,100	18,901	18,493	17,981	74,475	5,779	12.89	3.78
65	55	51	21,008	20,777	20,327	19,778	81,890	5,929	13.81	4.05
65	60	50.8	21,842	21,353	21,088	20,520	84,803	5,986	14.17	4.15
65	60	54	22,200	21,836	21,549	20,714	86,298	5,999	14.38	4.22
70	17	15.75	13,584	13,320	13,060	13,036	53,000	6,119	8.66	2.54
70	21	19.3	14,142	13,988	13,891	13,649	55,670	6,154	9.05	2.65
70	28	25.4	14,288	14,276	14,039	14,061	56,663	6,173	9.18	2.69
70	34	30.8	15,068	15,166	14,619	14,680	59,534	6,215	9.58	2.81
70	40.5	36.6	16,881	16,841	16,285	16,204	66,211	5,903	11.22	3.29
70	47	42.1	18,764	18,921	18,385	18,178	74,247	6,057	12.26	3.59
70	47	43	18,877	19,120	18,947	18,705	75,649	6,035	12.54	3.67
70	55	51	21,166	21,158	20,557	20,550	83,431	6,198	13.46	3.95
70	60	54	22,468	22,348	21,806	21,644	88,266	6,310	13.99	4.10
75	21	19	12,247	12,101	10,861	11,322	46,531	6,189	7.52	2.20
75	28	25	14,914	14,708	14,628	14,336	58,585	6,500	9.01	2.64
75	34	31	15,941	15,778	15,338	15,162	62,219	6,540	9.51	2.79
75	41	37	17,946	17,460	17,184	16,646	69,236	6,265	11.05	3.24
75	47	43	18,453	18,504	18,055	18,549	73,561	6,257	11.76	3.45
75	55	51	20,789	20,820	20,157	20,030	81,797	6,476	12.63	3.70
75	60	51	21,532	21,160	20,977	20,613	84,281	6,472	13.02	3.82
75	60	54	22,296	22,152	21,556	21,188	87,192	6,561	13.29	3.90

TABLE 12. 75% HEATING MODE LAB TEST RESULTS

75 % IDU OPERATION - HEATING MODE										
INDOOR	**OUTDOOR**		**CAP 1**	**CAP 2**	**CAP 3**	**CAP 4**	**TOTAL**	**POWER**	**EER**	**COP**
DBT	**DBT**	**WBT**								
°F	**°F**	**°F**	**BTU/HR**	**BTU/HR**	**BTU/HR**	**BTU/HR**	**BTU/HR**	**W**	**BTU/W-HR**	
65	17	16	16,345	16,157	15,633	0	48,135	5,908	8.15	2.39
65	21	19	17,627	17,232	16,719	0	51,579	6,061	8.51	2.49
65	28	25	18,654	18,302	17,738	0	54,694	6,120	8.94	2.62
65	34	31	21,185	20,767	20,238	0	62,190	6,315	9.85	2.89
65	41	37	21,441	21,028	20,514	0	62,983	5,863	10.74	3.15
65	47	43		23,390	23,056	22,285	68,731	6,097	11.27	3.30
65	55	51		26,269	26,050	25,265	77,583	6,389	12.14	3.56
65	60	54		28,320	28,061	27,294	83,675	6,548	12.78	3.75
70	19	17		12,222	12,185	12,051	36,458	5,727	6.37	1.87
70	28	25	0	17,741	17,457	17,355	52,553	6,359	8.26	2.42
70	34	31	0	20,836	20,581	20,369	61,786	6,651	9.29	2.72
70	41	37	0	21,746	21,559	21,237	64,542	6,208	10.40	3.05
70	47	43	0	23,163	22,887	22,459	68,508	6,363	10.77	3.16
70	56	51	0	26,081	25,816	26,097	77,995	6,673	11.69	3.43
70	60	54	0	28,375	27,994	27,733	84,102	6,894	12.20	3.58
75	21	19	0	14,297	13,843	13,813	41,954	6,227	6.74	1.97
75	28	25	0	18,125	17,662	17,641	53,427	6,644	8.04	2.36
75	34	31	0	18,565	18,306	17,894	54,765	6,666	8.22	2.41
75	41	37	0	21,440	21,280	20,580	63,300	6,489	9.76	2.86
75	47	43	0	23,421	22,826	23,140	69,386	6,669	10.40	3.05
75	55	51		25,939	25,515	25,206	76,660	6,555	11.69	3.43
75	60	51	0	25,773	25,782	25,255	76,810	6,475	11.86	3.48
75	60	54	0	26,021	25,603	25,228	76,852	6,379	12.05	3.53

TABLE 13. 50% HEATING MODE LAB TEST RESULTS

50 % IDU OPERATION - HEATING MODE										
INDOOR	OUTDOOR		CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	DBT	WBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
65	17	16	0	22,967	22,099	0	45,066	6,354	7.09	2.08
65	21	19	0	24,262	23,255	0	47,517	6,479	7.33	2.15
65	28	25	0	27,621	26,419	0	54,039	6,857	7.88	2.31
65	34	31	0	28,024	27,805	0	55,830	6,944	8.04	2.36
65	41	37	30,589	29,858	0	0	60,447	6,614	9.14	2.68
65	47	43	0	32,558	32,365	0	64,923	6,931	9.37	2.75
65	55	50	0	0	32,561	31,516	64,077	6,274	10.21	2.99
65	60	53	0	0	32,712	31,597	64,310	6,161	10.44	3.06
			0	0						
70	17	16	0	0	22,024	21,531	43,555	6,607	6.59	1.93
70	28	25	0	0	23,976	23,365	47,341	6,811	6.95	2.04
70	34	31	0	0	28,862	28,260	57,122	7,371	7.75	2.27
70	41	37	0	0	29,960	29,338	59,298	6,782	8.74	2.56
70	47	43	0	0	30,034	29,323	59,358	6,183	9.60	2.81
70	55	50	0	0	29,969	29,816	59,785	5,894	10.14	2.97
70	60	54	0	0	30,018	29,504	59,522	5,688	10.46	3.07
			0	0						
75	21	19	0	0	18,117	18,071	36,188	6,414	5.64	1.65
75	28	25	0	0	24,334	23,791	48,125	7,130	6.75	1.98
75	33	31	0	0	27,236	26,429	53,665	7,153	7.50	2.20
75	41	37	0	0	27,167	26,193	53,360	6,298	8.47	2.48
75	47	43	0	0	27,182	27,379	54,561	5,668	9.63	2.82
75	55	51	0	0	27,229	26,741	53,970	5,275	10.23	3.00
75	60	51	0	0	27,546	26,404	53,950	5,251	10.27	3.01
75	60	54	0	0	27,213	26,779	53,992	5,293	10.20	2.99

TABLE 14. 25% HEATING MODE LAB TEST RESULTS

25 % IDU OPERATION - HEATING MODE										
INDOOR	OUTDOOR		CAP 1	CAP 2	CAP 3	CAP 4	TOTAL	POWER	EER	COP
DBT	DBT	WBT								
°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
65	17	16	0	0	32,108	0	32,108	6,030	5.32	1.56
65	21	19	0	0	31,132	0	31,132	5,494	5.67	1.66
65	28	25	0	0	32,323	0	32,323	5,061	6.39	1.87
65	34	31	0	0	31,913	0	31,913	4,702	6.79	1.99
65	41	37	0	0	32,482	0	32,482	3,871	8.39	2.46
65	47	43	0	0	0	32,081	32,081	3,605	8.90	2.61
65	56	52	0	0	0	31,915	31,915	3,397	9.39	2.75
65	60	53	0	0	0	32,419	32,419	3,409	9.51	2.79
70	28	25	0	0	0	28,770	28,770	5,033	5.72	1.68
70	34	31	0	0	0	29,315	29,315	4,373	6.70	1.96
70	41	37	0	0	0	29,615	29,615	3,434	8.62	2.53
70	47	43	0	0	0	29,520	29,520	3,403	8.68	2.54
70	55	51	0	0	0	30,250	30,250	3,278	9.23	2.70
70	60	54	0	0	0	29,839	29,839	3,082	9.68	2.84
75	28	25	0	0	0	26,775	26,775	4,646	5.76	1.69
75	36	34	0	0	0	26,230	26,230	3,885	6.75	1.98
75	41	37	0	0	0	26,467	26,467	3,205	8.26	2.42
75	47	43	0	0	0	27,213	27,213	3,129	8.70	2.55
75	55	51	0	0	0	26,642	26,642	2,915	9.14	2.68
75	60	51	0	0	0	26,476	26,476	2,919	9.07	2.66
75	60	54	0	0	0	26,740	26,740	2,844	9.40	2.76

TABLE 15. SCH MODE LAB TEST RESULTS – 75% COOLING, 25% HEATING

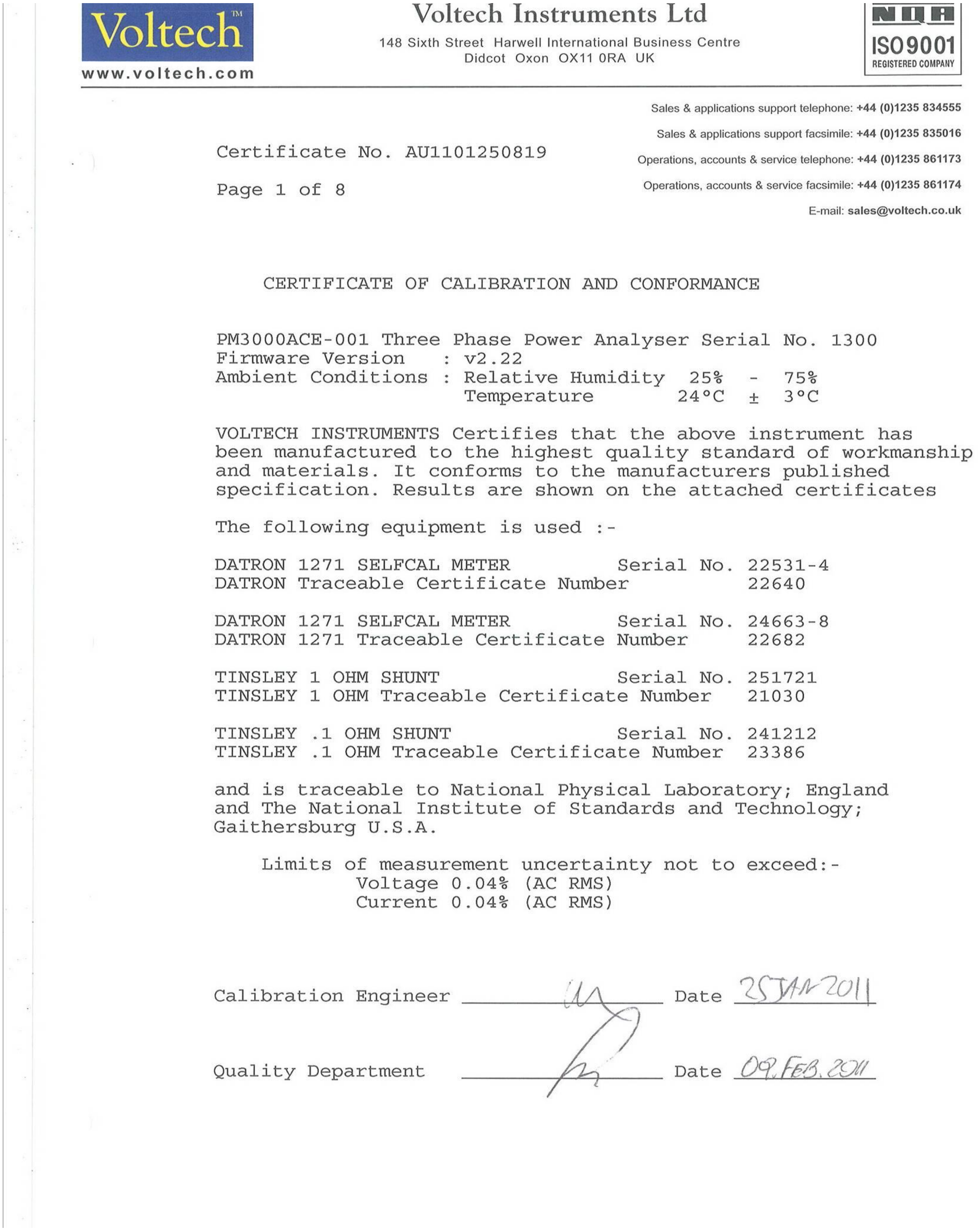
SYSTEM B: SIMULTANEOUS COOLING AND HEATING 75% COOL - 25% HEAT									
INDOOR COOL		INDOOR HEAT	OUTDOOR	CAPACITY		CAPACITY	POWER	EER	COP
DBT	WBT	DBT	DBT	COOL	HEAT	TOTAL			
°F	°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
75	63	65	65	50,281	19,843	70,124	5,832	12.02	3.52
80	63	65	65	44,301	24,460	68,761	5,403	12.73	3.73
80	59	65	65	42,099	27,726	69,825	5,531	12.62	3.70
75	63	70	65	48,859	19,445	68,304	5,809	11.76	3.45
75	63	70	65	47,891	20,647	68,538	5,979	11.46	3.36
80	67	70	64	52,430	15,090	67,520	5,852	11.54	3.38
80	60	70	65	44,822	19,611	64,433	5,882	10.96	3.21
80	63	70	66	46,317	21,708	68,026	5,854	11.62	3.41
75	63	65	75	49,213	21,059	70,271	5,983	11.74	3.44
80	62	65	75	44,203	23,956	68,158	5,398	12.63	3.70
80	60	65	75	44,617	22,979	67,596	5,468	12.36	3.62
80	66	66	74	51,299	18,451	69,751	6,083	11.47	3.36
75	63	70	76	47,915	18,497	66,411	5,963	11.14	3.26
80	63	70	75	47,631	19,103	66,734	6,044	11.04	3.24
80	60	70	75	43,792	21,759	65,551	5,481	11.96	3.51
80	67	70	74	51,285	17,639	68,924	6,136	11.23	3.29
75	63	65	85	45,516	22,121	67,636	5,619	12.04	3.53
80	63	65	85	46,026	25,054	71,080	5,480	12.97	3.80
80	60	65	85	46,400	22,010	68,410	5,515	12.40	3.64
75	63	70	85	44,575	19,988	64,563	5,733	11.26	3.30
80	60	70	85	46,045	20,518	66,563	5,462	12.19	3.57
80	63	70	85	44,479	24,720	69,200	5,674	12.20	3.57
75	63	65	95	44,923	23,056	67,979	5,829	11.66	3.42
80	60	65	95	45,108	24,985	70,093	5,777	12.13	3.56
80	63	65	95	44,366	27,491	71,857	5,741	12.52	3.67
75	63	70	95	43,662	21,612	65,274	5,833	11.19	3.28
80	63	70	95	43,508	26,074	69,583	5,796	12.01	3.52
80	60	70	95	44,708	22,991	67,699	5,868	11.54	3.38

TABLE 16. SCH MODE LAB TEST RESULTS – 50% COOLING, 50% HEATING

SYSTEM B: SIMULTANEOUS COOLING AND HEATING 50% COOL - 50% HEAT									
INDOOR COOL		INDOOR HEAT	OUTDOOR	CAPACITY		CAPACITY	POWER	EER	COP
DBT	WBT	DBT	DBT	COOL	HEAT	TOTAL			
°F	°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
75	63	65	65	38,915	37,578	76,493	5,327	14.36	4.21
80	63	65	65	41,522	36,338	77,860	5,531	14.08	4.13
80	60	65	65	34,543	38,831	73,374	5,665	12.95	3.80
80	67	65	65	40,978	37,086	78,064	5,609	13.92	4.08
75	62	70	65	38,927	33,543	72,470	5,640	12.85	3.77
80	63	70	65	41,508	32,348	73,856	5,824	12.68	3.72
80	60	70	65	34,022	34,348	68,370	5,188	13.18	3.86
80	67	70	65	42,674	36,453	79,127	5,661	13.98	4.10
75	62	65	75	40,807	39,715	80,522	5,810	13.86	4.06
80	60	65	75	35,063	39,711	74,774	5,625	13.29	3.90
80	63	65	75	36,917	42,324	79,241	5,592	14.17	4.15
80	67	65	75	41,862	42,465	84,326	5,749	14.67	4.30
75	63	70	75	39,995	39,499	79,495	5,688	13.98	4.10
80	67	70	75	42,428	37,371	79,799	6,117	13.05	3.82
80	63	70	75	40,841	37,493	78,334	5,770	13.58	3.98
80	59	70	75	34,428	35,589	70,017	5,524	12.67	3.71
75	63	65	85	39,277	43,419	82,696	5,693	14.53	4.26
80	59	65	85	34,622	41,815	76,437	5,462	14.00	4.10
80	63	65	85	36,342	42,350	78,692	5,908	13.32	3.90
75	62	70	85	39,379	39,098	78,477	5,967	13.15	3.85
80	59	70	85	33,926	37,112	71,039	5,480	12.96	3.80
80	63	70	85	39,185	39,136	78,321	6,322	12.39	3.63
80	66	70	85	42,100	48,195	90,294	5,463	16.53	4.84
75	63	65	95	38,974	50,092	89,067	5,423	16.42	4.81
79	64	65	95	39,177	50,370	89,547	5,270	16.99	4.98
80	60	65	95	35,080	44,839	79,919	5,821	13.73	4.02
80	63	65	95	34,984	50,199	85,184	5,312	16.04	4.70
75	63	70	95	38,487	47,909	86,396	5,417	15.95	4.67
80	59	70	95	35,272	45,300	80,572	5,383	14.97	4.39
80	66	70	95	41,371	47,274	88,645	5,436	16.31	4.78
80	63	70	95	38,997	46,888	85,884	5,431	15.81	4.63

TABLE 17. SCH MODE LAB TEST RESULTS – 25% COOLING, 75% HEATING

SYSTEM B: SIMULTANEOUS COOLING AND HEATING 25% COOL - 75% HEAT									
INDOOR COOL		INDOOR HEAT	OUTDOOR	CAPACITY		CAPACITY	POWER	EER	COP
DBT	WBT	DBT	DBT	COOL	HEAT	TOTAL			
°F	°F	°F	°F	BTU/HR	BTU/HR	BTU/HR	W	BTU/W-HR	
80	63	65	65	17,192	71,444	88,636	5,446	16.28	4.77
75	63	65	65	17,901	70,098	87,999	5,380	16.36	4.79
80	67	65	65	19,868	72,655	92,523	5,463	16.94	4.96
80	59	65	65	14,424	78,254	92,678	5,831	15.89	4.66
80	60	70	65	14,710	75,336	90,047	5,972	15.08	4.42
80	66	70	65	18,896	70,298	89,194	5,653	15.78	4.62
75	63	70	65	15,224	71,813	87,037	5,769	15.09	4.42
80	63	70	65	16,971	70,584	87,555	5,718	15.31	4.49
80	59	65	75	14,737	75,895	90,632	5,682	15.95	4.68
80	67	65	75	20,145	72,842	92,987	5,451	17.06	5.00
75	63	65	75	16,853	71,951	88,804	5,445	16.31	4.78
80	63	65	75	17,771	71,499	89,270	5,398	16.54	4.85
80	63	70	75	18,758	67,496	86,254	5,596	15.41	4.52
80	66	70	75	20,392	68,679	89,071	5,605	15.89	4.66
80	60	70	75	14,752	74,787	89,539	5,917	15.13	4.43
75	63	70	75	15,795	69,358	85,153	5,683	14.98	4.39
80	63	65	85	20,453	68,676	89,129	5,467	16.30	4.78
75	62	65	85	20,648	67,182	87,831	5,637	15.58	4.57
80	60	65	85	18,337	66,761	85,098	5,486	15.51	4.55
80	63	70	85	19,924	71,209	91,134	5,810	15.68	4.60
80	60	70	85	19,040	67,132	86,172	5,689	15.15	4.44
75	63	70	85	18,825	70,222	89,048	5,710	15.60	4.57
80	67	70	85	19,766	67,465	87,232	5,602	15.57	4.56
79	64	65	95	20,583	66,131	86,714	5,400	16.06	4.71
80	63	65	95	19,813	70,642	90,455	5,548	16.30	4.78
75	62	65	95	21,069	65,348	86,417	5,401	16.00	4.69
80	60	65	95	17,998	68,618	86,616	5,513	15.71	4.60
80	67	70	95	19,853	70,782	90,635	5,711	15.87	4.65
80	63	70	95	19,851	72,163	92,015	5,855	15.72	4.61
80	60	70	95	18,591	68,790	87,381	5,756	15.18	4.45
75	62	70	95	18,460	72,475	90,934	5,787	15.71	4.61



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Certificate No. AU1101250819

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CERTIFICATE OF CALIBRATION AND CONFORMANCE

PM3000ACE-001 Three Phase Power Analyser Serial No. 1300
Firmware Version : v2.22
Ambient Conditions : Relative Humidity 25% - 75%
Temperature 24°C ± 3°C

VOLTECH INSTRUMENTS Certifies that the above instrument has been manufactured to the highest quality standard of workmanship and materials. It conforms to the manufacturers published specification. Results are shown on the attached certificates

The following equipment is used :-

DATRON 1271 SELFCAL METER Serial No. 22531-4
DATRON Traceable Certificate Number 22640

DATRON 1271 SELFCAL METER Serial No. 24663-8
DATRON 1271 Traceable Certificate Number 22682

TINSLEY 1 OHM SHUNT Serial No. 251721
TINSLEY 1 OHM Traceable Certificate Number 21030

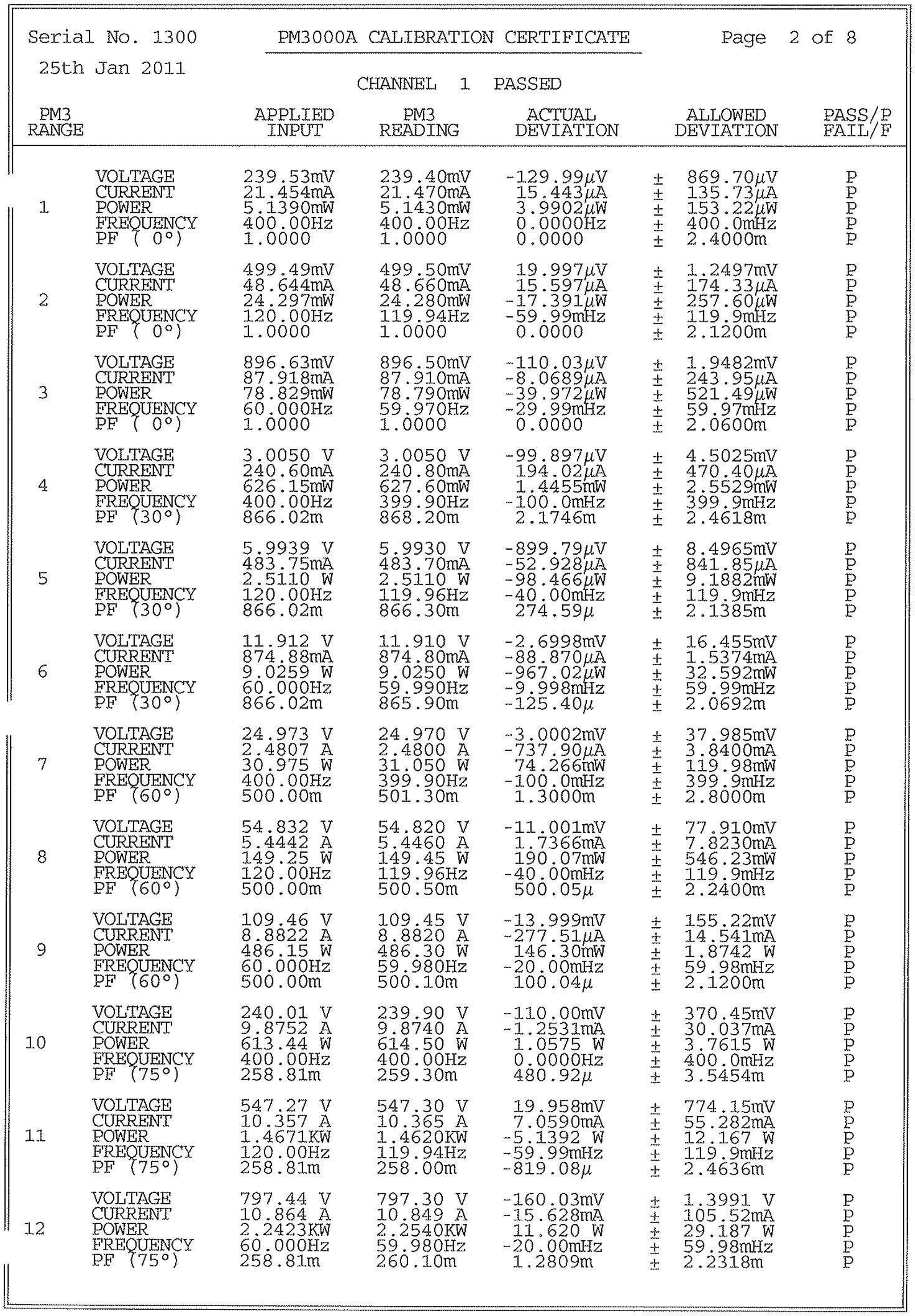
TINSLEY .1 OHM SHUNT Serial No. 241212
TINSLEY .1 OHM Traceable Certificate Number 23386

and is traceable to National Physical Laboratory; England and The National Institute of Standards and Technology; Gaithersburg U.S.A.

Limits of measurement uncertainty not to exceed:-
Voltage 0.04% (AC RMS)
Current 0.04% (AC RMS)

Calibration Engineer ____________ Date 25 JAN 2011

Quality Department ____________ Date 09.FEB.2011



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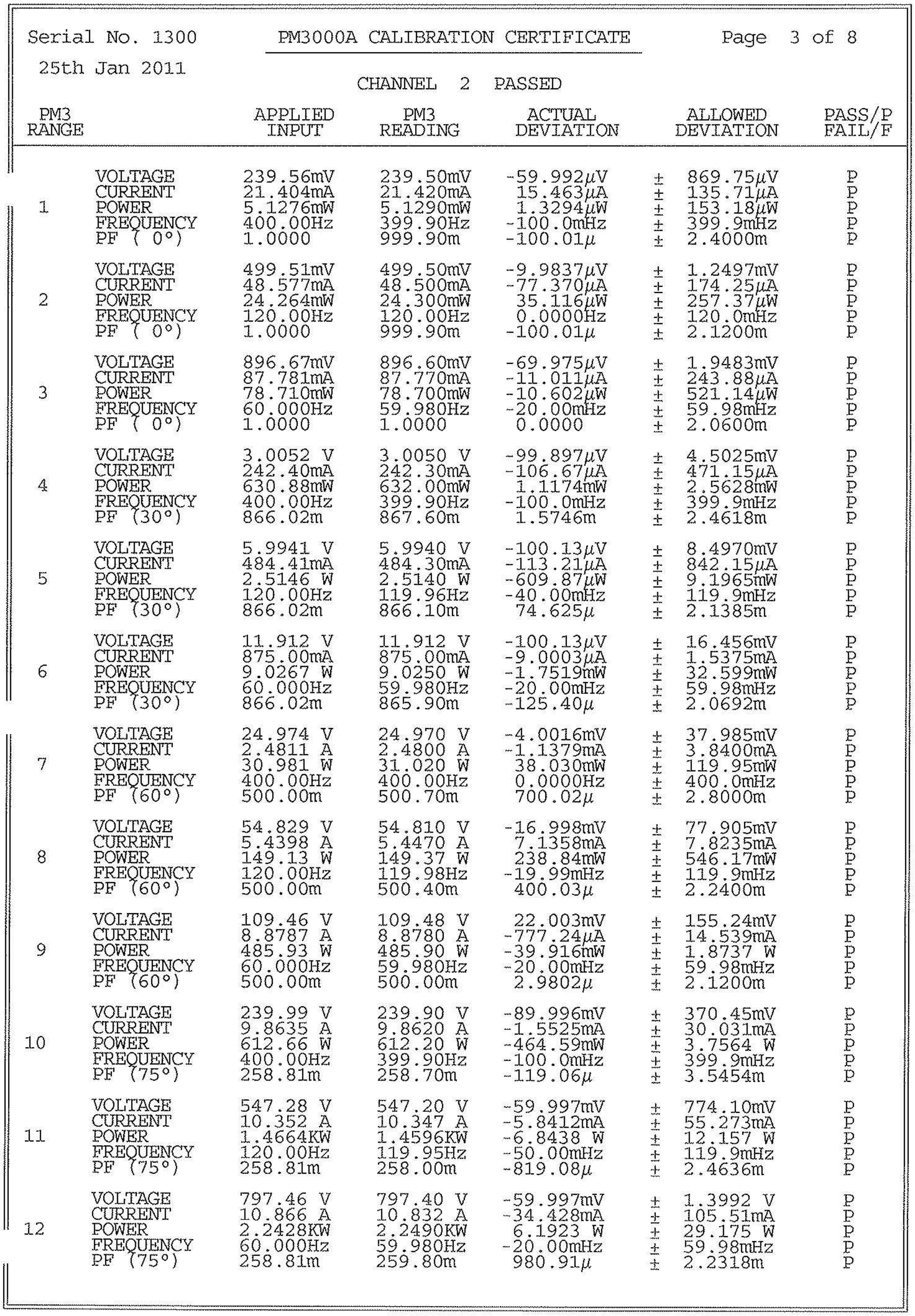
25th Jan 2011

CHANNEL 1 PASSED

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION	ALLOWED DEVIATION	PASS/P FAIL/F
1	VOLTAGE	239.53mV	239.40mV	-129.99μV	± 869.70μV	P
	CURRENT	21.454mA	21.470mA	15.443μA	± 135.73μA	P
	POWER	5.1390mW	5.1430mW	3.9902μW	± 153.22μW	P
	FREQUENCY	400.00Hz	400.00Hz	0.0000Hz	± 400.0mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.4000m	P
2	VOLTAGE	499.49mV	499.50mV	19.997μV	± 1.2497mV	P
	CURRENT	48.644mA	48.660mA	15.597μA	± 174.33μA	P
	POWER	24.297mW	24.280mW	-17.391μW	± 257.60μW	P
	FREQUENCY	120.00Hz	119.94Hz	-59.99mHz	± 119.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.1200m	P
3	VOLTAGE	896.63mV	896.50mV	-110.03μV	± 1.9482mV	P
	CURRENT	87.918mA	87.910mA	-8.0689μA	± 243.95μA	P
	POWER	78.829mW	78.790mW	-39.972μW	± 521.49μW	P
	FREQUENCY	60.000Hz	59.970Hz	-29.99mHz	± 59.97mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.0600m	P
4	VOLTAGE	3.0050 V	3.0050 V	-99.897μV	± 4.5025mV	P
	CURRENT	240.60mA	240.80mA	194.02μA	± 470.40μA	P
	POWER	626.15mW	627.60mW	1.4455mW	± 2.5529mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (30°)	866.02m	868.20m	2.1746m	± 2.4618m	P
5	VOLTAGE	5.9939 V	5.9930 V	-899.79μV	± 8.4965mV	P
	CURRENT	483.75mA	483.70mA	-52.928μA	± 841.85μA	P
	POWER	2.5110 W	2.5110 W	-98.466μW	± 9.1882mW	P
	FREQUENCY	120.00Hz	119.96Hz	-40.00mHz	± 119.9mHz	P
	PF (30°)	866.02m	866.30m	274.59μ	± 2.1385m	P
6	VOLTAGE	11.912 V	11.910 V	-2.6998mV	± 16.455mV	P
	CURRENT	874.88mA	874.80mA	-88.870μA	± 1.5374mA	P
	POWER	9.0259 W	9.0250 W	-967.02μW	± 32.592mW	P
	FREQUENCY	60.000Hz	59.990Hz	-9.998mHz	± 59.99mHz	P
	PF (30°)	866.02m	865.90m	-125.40μ	± 2.0692m	P
7	VOLTAGE	24.973 V	24.970 V	-3.0002mV	± 37.985mV	P
	CURRENT	2.4807 A	2.4800 A	-737.90μA	± 3.8400mA	P
	POWER	30.975 W	31.050 W	74.266mW	± 119.98mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (60°)	500.00m	501.30m	1.3000m	± 2.8000m	P
8	VOLTAGE	54.832 V	54.820 V	-11.001mV	± 77.910mV	P
	CURRENT	5.4442 A	5.4460 A	1.7366mA	± 7.8230mA	P
	POWER	149.25 W	149.45 W	190.07mW	± 546.23mW	P
	FREQUENCY	120.00Hz	119.96Hz	-40.00mHz	± 119.9mHz	P
	PF (60°)	500.00m	500.50m	500.05μ	± 2.2400m	P
9	VOLTAGE	109.46 V	109.45 V	-13.999mV	± 155.22mV	P
	CURRENT	8.8822 A	8.8820 A	-277.51μA	± 14.541mA	P
	POWER	486.15 W	486.30 W	146.30mW	± 1.8742 W	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (60°)	500.00m	500.10m	100.04μ	± 2.1200m	P
10	VOLTAGE	240.01 V	239.90 V	-110.00mV	± 370.45mV	P
	CURRENT	9.8752 A	9.8740 A	-1.2531mA	± 30.037mA	P
	POWER	613.44 W	614.50 W	1.0575 W	± 3.7615 W	P
	FREQUENCY	400.00Hz	400.00Hz	0.0000Hz	± 400.0mHz	P
	PF (75°)	258.81m	259.30m	480.92μ	± 3.5454m	P
11	VOLTAGE	547.27 V	547.30 V	19.958mV	± 774.15mV	P
	CURRENT	10.357 A	10.365 A	7.0590mA	± 55.282mA	P
	POWER	1.4671KW	1.4620KW	-5.1392 W	± 12.167 W	P
	FREQUENCY	120.00Hz	119.94Hz	-59.99mHz	± 119.9mHz	P
	PF (75°)	258.81m	258.00m	-819.08μ	± 2.4636m	P
12	VOLTAGE	797.44 V	797.30 V	-160.03mV	± 1.3991 V	P
	CURRENT	10.864 A	10.849 A	-15.628mA	± 105.52mA	P
	POWER	2.2423KW	2.2540KW	11.620 W	± 29.187 W	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (75°)	258.81m	260.10m	1.2809m	± 2.2318m	P



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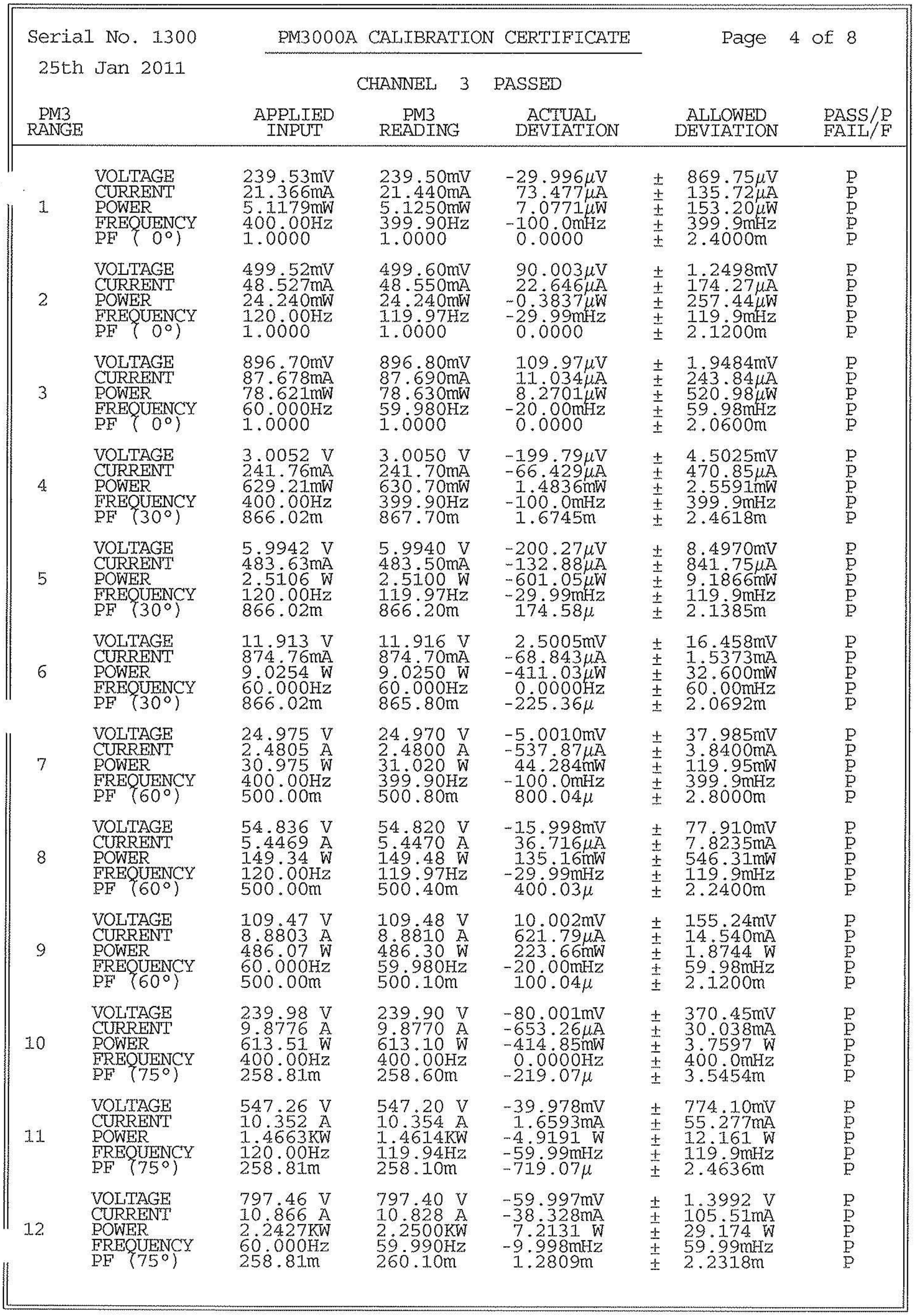
25th Jan 2011

CHANNEL 2 PASSED

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION	ALLOWED DEVIATION	PASS/P FAIL/F
1	VOLTAGE	239.56mV	239.50mV	-59.992µV	± 869.75µV	P
	CURRENT	21.404mA	21.420mA	15.463µA	± 135.71µA	P
	POWER	5.1276mW	5.1290mW	1.3294µW	± 153.18µW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (0°)	1.0000	999.90m	-100.01µ	± 2.4000m	P
2	VOLTAGE	499.51mV	499.50mV	-9.9837µV	± 1.2497mV	P
	CURRENT	48.577mA	48.500mA	-77.370µA	± 174.25µA	P
	POWER	24.264mW	24.300mW	35.116µW	± 257.37µW	P
	FREQUENCY	120.00Hz	120.00Hz	0.0000Hz	± 120.0mHz	P
	PF (0°)	1.0000	999.90m	-100.01µ	± 2.1200m	P
3	VOLTAGE	896.67mV	896.60mV	-69.975µV	± 1.9483mV	P
	CURRENT	87.781mA	87.770mA	-11.011µA	± 243.88µA	P
	POWER	78.710mW	78.700mW	-10.602µW	± 521.14µW	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.0600m	P
4	VOLTAGE	3.0052 V	3.0050 V	-99.897µV	± 4.5025mV	P
	CURRENT	242.40mA	242.30mA	-106.67µA	± 471.15µA	P
	POWER	630.88mW	632.00mW	1.1174mW	± 2.5628mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (30°)	866.02m	867.60m	1.5746m	± 2.4618m	P
5	VOLTAGE	5.9941 V	5.9940 V	-100.13µV	± 8.4970mV	P
	CURRENT	484.41mA	484.30mA	-113.21µA	± 842.15µA	P
	POWER	2.5146 W	2.5140 W	-609.87µW	± 9.1965mW	P
	FREQUENCY	120.00Hz	119.96Hz	-40.00mHz	± 119.9mHz	P
	PF (30°)	866.02m	866.10m	74.625µ	± 2.1385m	P
6	VOLTAGE	11.912 V	11.912 V	-100.13µV	± 16.456mV	P
	CURRENT	875.00mA	875.00mA	-9.0003µA	± 1.5375mA	P
	POWER	9.0267 W	9.0250 W	-1.7519mW	± 32.599mW	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (30°)	866.02m	865.90m	-125.40µ	± 2.0692m	P
7	VOLTAGE	24.974 V	24.970 V	-4.0016mV	± 37.985mV	P
	CURRENT	2.4811 A	2.4800 A	-1.1379mA	± 3.8400mA	P
	POWER	30.981 W	31.020 W	38.030mW	± 119.95mW	P
	FREQUENCY	400.00Hz	400.00Hz	0.0000Hz	± 400.0mHz	P
	PF (60°)	500.00m	500.70m	700.02µ	± 2.8000m	P
8	VOLTAGE	54.829 V	54.810 V	-16.998mV	± 77.905mV	P
	CURRENT	5.4398 A	5.4470 A	7.1358mA	± 7.8235mA	P
	POWER	149.13 W	149.37 W	238.84mW	± 546.17mW	P
	FREQUENCY	120.00Hz	119.98Hz	-19.99mHz	± 119.9mHz	P
	PF (60°)	500.00m	500.40m	400.03µ	± 2.2400m	P
9	VOLTAGE	109.46 V	109.48 V	22.003mV	± 155.24mV	P
	CURRENT	8.8787 A	8.8780 A	-777.24µA	± 14.539mA	P
	POWER	485.93 W	485.90 W	-39.916mW	± 1.8737 W	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (60°)	500.00m	500.00m	2.9802µ	± 2.1200m	P
10	VOLTAGE	239.99 V	239.90 V	-89.996mV	± 370.45mV	P
	CURRENT	9.8635 A	9.8620 A	-1.5525mA	± 30.031mA	P
	POWER	612.66 W	612.20 W	-464.59mW	± 3.7564 W	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (75°)	258.81m	258.70m	-119.06µ	± 3.5454m	P
11	VOLTAGE	547.28 V	547.20 V	-59.997mV	± 774.10mV	P
	CURRENT	10.352 A	10.347 A	-5.8412mA	± 55.273mA	P
	POWER	1.4664KW	1.4596KW	-6.8438 W	± 12.157 W	P
	FREQUENCY	120.00Hz	119.95Hz	-50.00mHz	± 119.9mHz	P
	PF (75°)	258.81m	258.00m	-819.08µ	± 2.4636m	P
12	VOLTAGE	797.46 V	797.40 V	-59.997mV	± 1.3992 V	P
	CURRENT	10.866 A	10.832 A	-34.428mA	± 105.51mA	P
	POWER	2.2428KW	2.2490KW	6.1923 W	± 29.175 W	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (75°)	258.81m	259.80m	980.91µ	± 2.2318m	P



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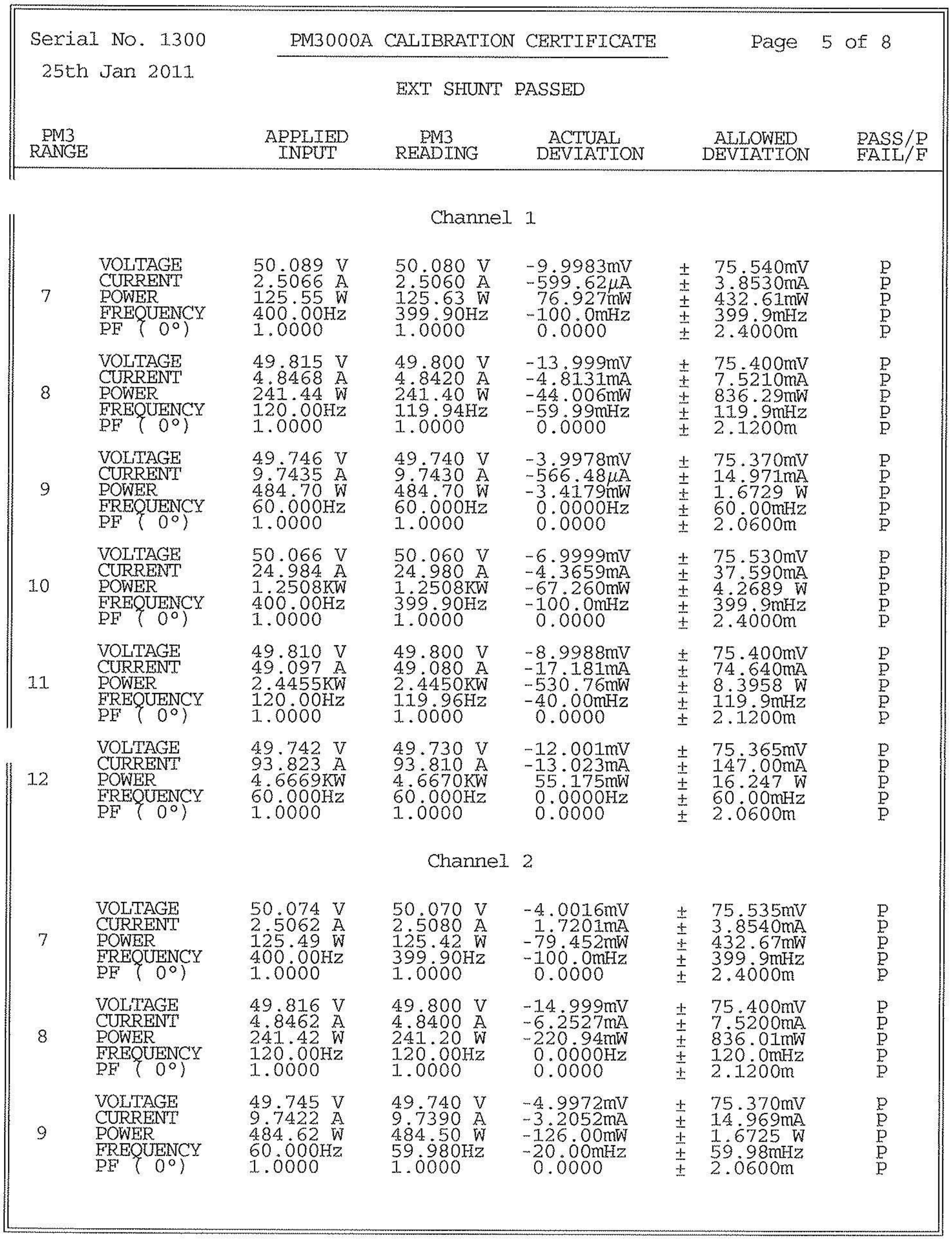
CHANNEL 3 PASSED

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION	ALLOWED DEVIATION	PASS/P FAIL/F
1	VOLTAGE	239.53mV	239.50mV	-29.996µV	± 869.75µV	P
	CURRENT	21.366mA	21.440mA	73.477µA	± 135.72µA	P
	POWER	5.1179mW	5.1250mW	7.0771µW	± 153.20µW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.4000m	P
2	VOLTAGE	499.52mV	499.60mV	90.003µV	± 1.2498mV	P
	CURRENT	48.527mA	48.550mA	22.646µA	± 174.27µA	P
	POWER	24.240mW	24.240mW	-0.3837µW	± 257.44µW	P
	FREQUENCY	120.00Hz	119.97Hz	-29.99mHz	± 119.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.1200m	P
3	VOLTAGE	896.70mV	896.80mV	109.97µV	± 1.9484mV	P
	CURRENT	87.678mA	87.690mA	11.034µA	± 243.84µA	P
	POWER	78.621mW	78.630mW	8.2701µW	± 520.98µW	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.0600m	P
4	VOLTAGE	3.0052 V	3.0050 V	-199.79µV	± 4.5025mV	P
	CURRENT	241.76mA	241.70mA	-66.429µA	± 470.85µA	P
	POWER	629.21mW	630.70mW	1.4836mW	± 2.5591mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (30°)	866.02m	867.70m	1.6745m	± 2.4618m	P
5	VOLTAGE	5.9942 V	5.9940 V	-200.27µV	± 8.4970mV	P
	CURRENT	483.63mA	483.50mA	-132.88µA	± 841.75µA	P
	POWER	2.5106 W	2.5100 W	-601.05µW	± 9.1866mW	P
	FREQUENCY	120.00Hz	119.97Hz	-29.99mHz	± 119.9mHz	P
	PF (30°)	866.02m	866.20m	174.58µ	± 2.1385m	P
6	VOLTAGE	11.913 V	11.916 V	2.5005mV	± 16.458mV	P
	CURRENT	874.76mA	874.70mA	-68.843µA	± 1.5373mA	P
	POWER	9.0254 W	9.0250 W	-411.03µW	± 32.600mW	P
	FREQUENCY	60.000Hz	60.000Hz	0.0000Hz	± 60.00mHz	P
	PF (30°)	866.02m	865.80m	-225.36µ	± 2.0692m	P
7	VOLTAGE	24.975 V	24.970 V	-5.0010mV	± 37.985mV	P
	CURRENT	2.4805 A	2.4800 A	-537.87µA	± 3.8400mA	P
	POWER	30.975 W	31.020 W	44.284mW	± 119.95mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (60°)	500.00m	500.80m	800.04µ	± 2.8000m	P
8	VOLTAGE	54.836 V	54.820 V	-15.998mV	± 77.910mV	P
	CURRENT	5.4469 A	5.4470 A	36.716µA	± 7.8235mA	P
	POWER	149.34 W	149.48 W	135.16mW	± 546.31mW	P
	FREQUENCY	120.00Hz	119.97Hz	-29.99mHz	± 119.9mHz	P
	PF (60°)	500.00m	500.40m	400.03µ	± 2.2400m	P
9	VOLTAGE	109.47 V	109.48 V	10.002mV	± 155.24mV	P
	CURRENT	8.8803 A	8.8810 A	621.79µA	± 14.540mA	P
	POWER	486.07 W	486.30 W	223.66mW	± 1.8744 W	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (60°)	500.00m	500.10m	100.04µ	± 2.1200m	P
10	VOLTAGE	239.98 V	239.90 V	-80.001mV	± 370.45mV	P
	CURRENT	9.8776 A	9.8770 A	-653.26µA	± 30.038mA	P
	POWER	613.51 W	613.10 W	-414.85mW	± 3.7597 W	P
	FREQUENCY	400.00Hz	400.00Hz	0.0000Hz	± 400.0mHz	P
	PF (75°)	258.81m	258.60m	-219.07µ	± 3.5454m	P
11	VOLTAGE	547.26 V	547.20 V	-39.978mV	± 774.10mV	P
	CURRENT	10.352 A	10.354 A	1.6593mA	± 55.277mA	P
	POWER	1.4663KW	1.4614KW	-4.9191 W	± 12.161 W	P
	FREQUENCY	120.00Hz	119.94Hz	-59.99mHz	± 119.9mHz	P
	PF (75°)	258.81m	258.10m	-719.07µ	± 2.4636m	P
12	VOLTAGE	797.46 V	797.40 V	-59.997mV	± 1.3992 V	P
	CURRENT	10.866 A	10.828 A	-38.328mA	± 105.51mA	P
	POWER	2.2427KW	2.2500KW	7.2131 W	± 29.174 W	P
	FREQUENCY	60.000Hz	59.990Hz	-9.998mHz	± 59.99mHz	P
	PF (75°)	258.81m	260.10m	1.2809m	± 2.2318m	P



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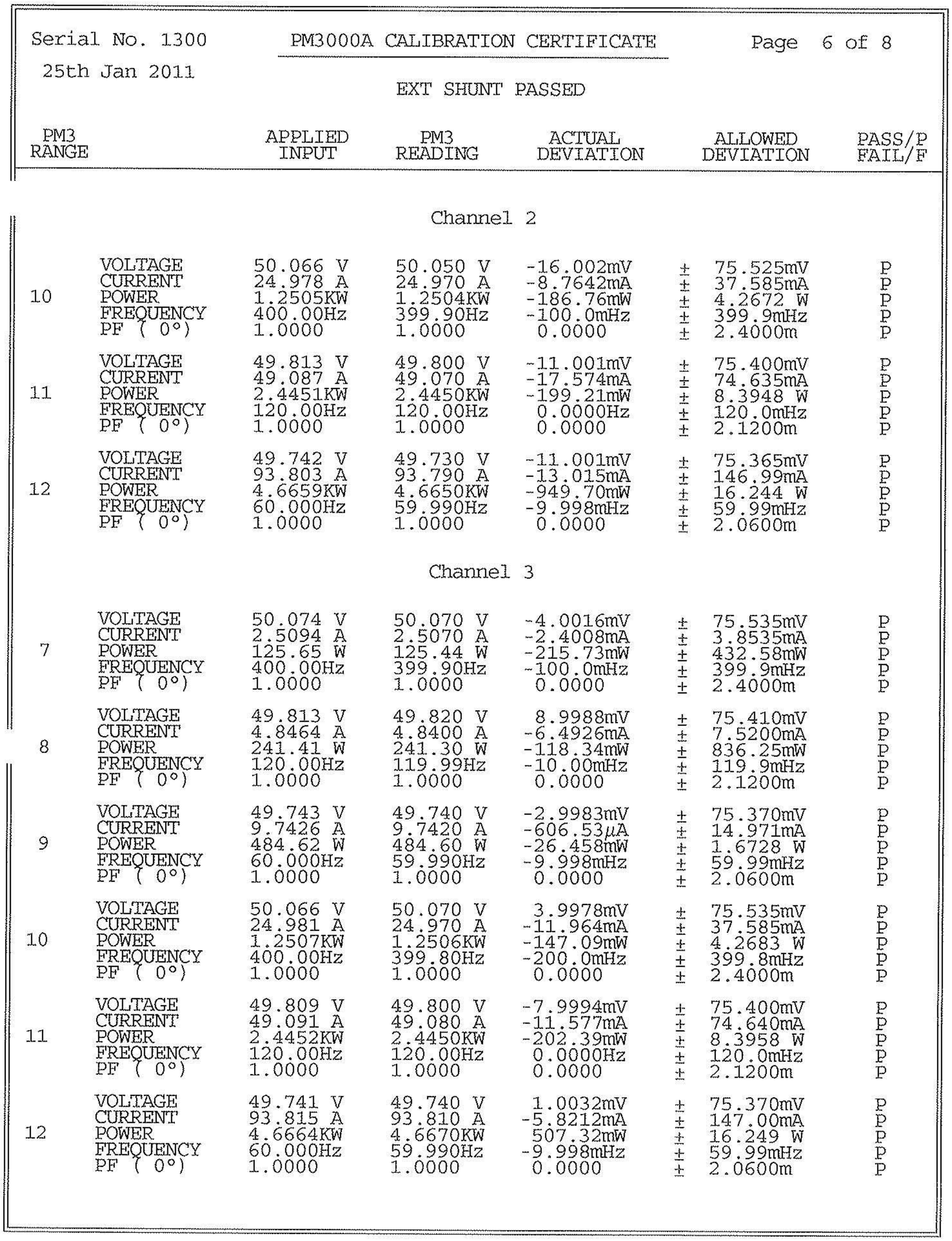
EXT SHUNT PASSED

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION	ALLOWED DEVIATION	PASS/P FAIL/F
			Channel 1			
7	VOLTAGE	50.089 V	50.080 V	-9.9983mV	± 75.540mV	P
	CURRENT	2.5066 A	2.5060 A	-599.62µA	± 3.8530mA	P
	POWER	125.55 W	125.63 W	76.927mW	± 432.61mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.4000m	P
8	VOLTAGE	49.815 V	49.800 V	-13.999mV	± 75.400mV	P
	CURRENT	4.8468 A	4.8420 A	-4.8131mA	± 7.5210mA	P
	POWER	241.44 W	241.40 W	-44.006mW	± 836.29mW	P
	FREQUENCY	120.00Hz	119.94Hz	-59.99mHz	± 119.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.1200m	P
9	VOLTAGE	49.746 V	49.740 V	-3.9978mV	± 75.370mV	P
	CURRENT	9.7435 A	9.7430 A	-566.48µA	± 14.971mA	P
	POWER	484.70 W	484.70 W	-3.4179mW	± 1.6729 W	P
	FREQUENCY	60.000Hz	60.000Hz	0.0000Hz	± 60.00mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.0600m	P
10	VOLTAGE	50.066 V	50.060 V	-6.9999mV	± 75.530mV	P
	CURRENT	24.984 A	24.980 A	-4.3659mA	± 37.590mA	P
	POWER	1.2508KW	1.2508KW	-67.260mW	± 4.2689 W	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.4000m	P
11	VOLTAGE	49.810 V	49.800 V	-8.9988mV	± 75.400mV	P
	CURRENT	49.097 A	49.080 A	-17.181mA	± 74.640mA	P
	POWER	2.4455KW	2.4450KW	-530.76mW	± 8.3958 W	P
	FREQUENCY	120.00Hz	119.96Hz	-40.00mHz	± 119.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.1200m	P
12	VOLTAGE	49.742 V	49.730 V	-12.001mV	± 75.365mV	P
	CURRENT	93.823 A	93.810 A	-13.023mA	± 147.00mA	P
	POWER	4.6669KW	4.6670KW	55.175mW	± 16.247 W	P
	FREQUENCY	60.000Hz	60.000Hz	0.0000Hz	± 60.00mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.0600m	P
			Channel 2			
7	VOLTAGE	50.074 V	50.070 V	-4.0016mV	± 75.535mV	P
	CURRENT	2.5062 A	2.5080 A	1.7201mA	± 3.8540mA	P
	POWER	125.49 W	125.42 W	-79.452mW	± 432.67mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	± 399.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.4000m	P
8	VOLTAGE	49.816 V	49.800 V	-14.999mV	± 75.400mV	P
	CURRENT	4.8462 A	4.8400 A	-6.2527mA	± 7.5200mA	P
	POWER	241.42 W	241.20 W	-220.94mW	± 836.01mW	P
	FREQUENCY	120.00Hz	120.00Hz	0.0000Hz	± 120.0mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.1200m	P
9	VOLTAGE	49.745 V	49.740 V	-4.9972mV	± 75.370mV	P
	CURRENT	9.7422 A	9.7390 A	-3.2052mA	± 14.969mA	P
	POWER	484.62 W	484.50 W	-126.00mW	± 1.6725 W	P
	FREQUENCY	60.000Hz	59.980Hz	-20.00mHz	± 59.98mHz	P
	PF (0°)	1.0000	1.0000	0.0000	± 2.0600m	P



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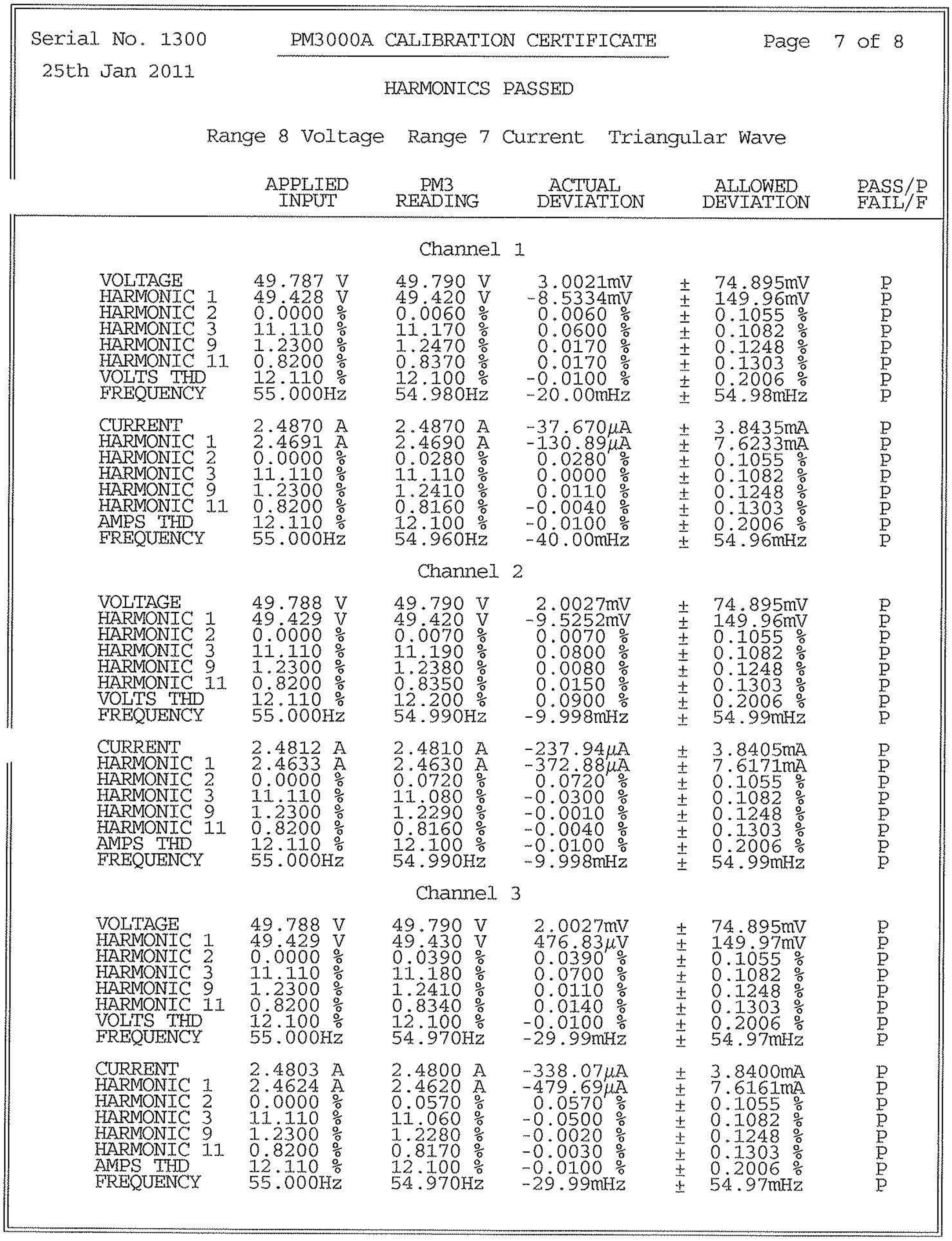
EXT SHUNT PASSED

Channel 2

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION		ALLOWED DEVIATION	PASS/P FAIL/F
10	VOLTAGE	50.066 V	50.050 V	-16.002mV	±	75.525mV	P
	CURRENT	24.978 A	24.970 A	-8.7642mA	±	37.585mA	P
	POWER	1.2505KW	1.2504KW	-186.76mW	±	4.2672 W	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	±	399.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.4000m	P
11	VOLTAGE	49.813 V	49.800 V	-11.001mV	±	75.400mV	P
	CURRENT	49.087 A	49.070 A	-17.574mA	±	74.635mA	P
	POWER	2.4451KW	2.4450KW	-199.21mW	±	8.3948 W	P
	FREQUENCY	120.00Hz	120.00Hz	0.0000Hz	±	120.0mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.1200m	P
12	VOLTAGE	49.742 V	49.730 V	-11.001mV	±	75.365mV	P
	CURRENT	93.803 A	93.790 A	-13.015mA	±	146.99mA	P
	POWER	4.6659KW	4.6650KW	-949.70mW	±	16.244 W	P
	FREQUENCY	60.000Hz	59.990Hz	-9.998mHz	±	59.99mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.0600m	P

Channel 3

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION		ALLOWED DEVIATION	PASS/P FAIL/F
7	VOLTAGE	50.074 V	50.070 V	-4.0016mV	±	75.535mV	P
	CURRENT	2.5094 A	2.5070 A	-2.4008mA	±	3.8535mA	P
	POWER	125.65 W	125.44 W	-215.73mW	±	432.58mW	P
	FREQUENCY	400.00Hz	399.90Hz	-100.0mHz	±	399.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.4000m	P
8	VOLTAGE	49.813 V	49.820 V	8.9988mV	±	75.410mV	P
	CURRENT	4.8464 A	4.8400 A	-6.4926mA	±	7.5200mA	P
	POWER	241.41 W	241.30 W	-118.34mW	±	836.25mW	P
	FREQUENCY	120.00Hz	119.99Hz	-10.00mHz	±	119.9mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.1200m	P
9	VOLTAGE	49.743 V	49.740 V	-2.9983mV	±	75.370mV	P
	CURRENT	9.7426 A	9.7420 A	-606.53µA	±	14.971mA	P
	POWER	484.62 W	484.60 W	-26.458mW	±	1.6728 W	P
	FREQUENCY	60.000Hz	59.990Hz	-9.998mHz	±	59.99mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.0600m	P
10	VOLTAGE	50.066 V	50.070 V	3.9978mV	±	75.535mV	P
	CURRENT	24.981 A	24.970 A	-11.964mA	±	37.585mA	P
	POWER	1.2507KW	1.2506KW	-147.09mW	±	4.2683 W	P
	FREQUENCY	400.00Hz	399.80Hz	-200.0mHz	±	399.8mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.4000m	P
11	VOLTAGE	49.809 V	49.800 V	-7.9994mV	±	75.400mV	P
	CURRENT	49.091 A	49.080 A	-11.577mA	±	74.640mA	P
	POWER	2.4452KW	2.4450KW	-202.39mW	±	8.3958 W	P
	FREQUENCY	120.00Hz	120.00Hz	0.0000Hz	±	120.0mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.1200m	P
12	VOLTAGE	49.741 V	49.740 V	1.0032mV	±	75.370mV	P
	CURRENT	93.815 A	93.810 A	-5.8212mA	±	147.00mA	P
	POWER	4.6664KW	4.6670KW	507.32mW	±	16.249 W	P
	FREQUENCY	60.000Hz	59.990Hz	-9.998mHz	±	59.99mHz	P
	PF (0°)	1.0000	1.0000	0.0000	±	2.0600m	P



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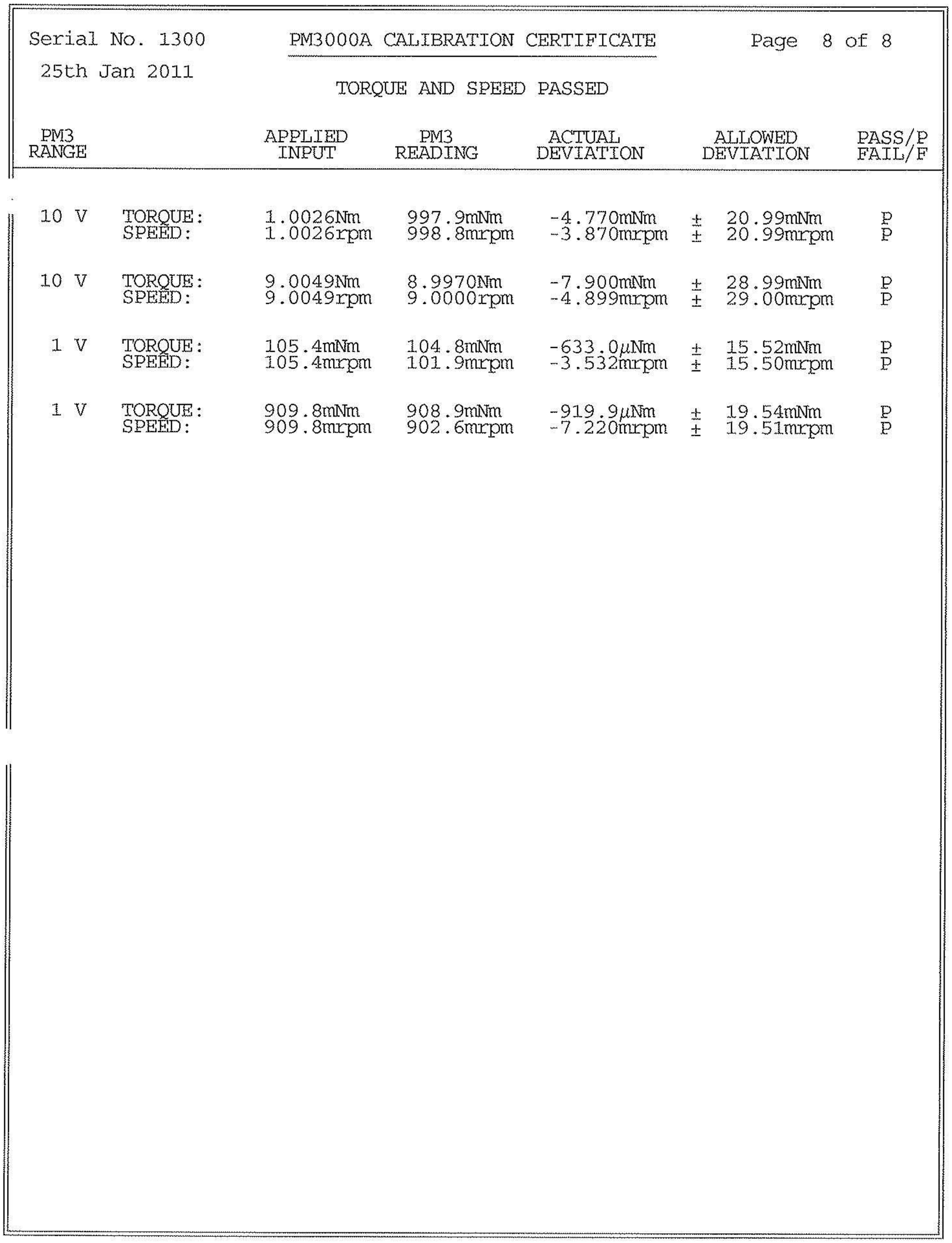
HARMONICS PASSED

Range 8 Voltage Range 7 Current Triangular Wave

	APPLIED INPUT	PM3 READING	ACTUAL DEVIATION	ALLOWED DEVIATION	PASS/P FAIL/F
Channel 1					
VOLTAGE	49.787 V	49.790 V	3.0021mV	± 74.895mV	P
HARMONIC 1	49.428 V	49.420 V	-8.5334mV	± 149.96mV	P
HARMONIC 2	0.0000 %	0.0060 %	0.0060 %	± 0.1055 %	P
HARMONIC 3	11.110 %	11.170 %	0.0600 %	± 0.1082 %	P
HARMONIC 9	1.2300 %	1.2470 %	0.0170 %	± 0.1248 %	P
HARMONIC 11	0.8200 %	0.8370 %	0.0170 %	± 0.1303 %	P
VOLTS THD	12.110 %	12.100 %	-0.0100 %	± 0.2006 %	P
FREQUENCY	55.000Hz	54.980Hz	-20.00mHz	± 54.98mHz	P
CURRENT	2.4870 A	2.4870 A	-37.670µA	± 3.8435mA	P
HARMONIC 1	2.4691 A	2.4690 A	-130.89µA	± 7.6233mA	P
HARMONIC 2	0.0000 %	0.0280 %	0.0280 %	± 0.1055 %	P
HARMONIC 3	11.110 %	11.110 %	0.0000 %	± 0.1082 %	P
HARMONIC 9	1.2300 %	1.2410 %	0.0110 %	± 0.1248 %	P
HARMONIC 11	0.8200 %	0.8160 %	-0.0040 %	± 0.1303 %	P
AMPS THD	12.110 %	12.100 %	-0.0100 %	± 0.2006 %	P
FREQUENCY	55.000Hz	54.960Hz	-40.00mHz	± 54.96mHz	P
Channel 2					
VOLTAGE	49.788 V	49.790 V	2.0027mV	± 74.895mV	P
HARMONIC 1	49.429 V	49.420 V	-9.5252mV	± 149.96mV	P
HARMONIC 2	0.0000 %	0.0070 %	0.0070 %	± 0.1055 %	P
HARMONIC 3	11.110 %	11.190 %	0.0800 %	± 0.1082 %	P
HARMONIC 9	1.2300 %	1.2380 %	0.0080 %	± 0.1248 %	P
HARMONIC 11	0.8200 %	0.8350 %	0.0150 %	± 0.1303 %	P
VOLTS THD	12.110 %	12.200 %	0.0900 %	± 0.2006 %	P
FREQUENCY	55.000Hz	54.990Hz	-9.998mHz	± 54.99mHz	P
CURRENT	2.4812 A	2.4810 A	-237.94µA	± 3.8405mA	P
HARMONIC 1	2.4633 A	2.4630 A	-372.88µA	± 7.6171mA	P
HARMONIC 2	0.0000 %	0.0720 %	0.0720 %	± 0.1055 %	P
HARMONIC 3	11.110 %	11.080 %	-0.0300 %	± 0.1082 %	P
HARMONIC 9	1.2300 %	1.2290 %	-0.0010 %	± 0.1248 %	P
HARMONIC 11	0.8200 %	0.8160 %	-0.0040 %	± 0.1303 %	P
AMPS THD	12.110 %	12.100 %	-0.0100 %	± 0.2006 %	P
FREQUENCY	55.000Hz	54.990Hz	-9.998mHz	± 54.99mHz	P
Channel 3					
VOLTAGE	49.788 V	49.790 V	2.0027mV	± 74.895mV	P
HARMONIC 1	49.429 V	49.430 V	476.83µV	± 149.97mV	P
HARMONIC 2	0.0000 %	0.0390 %	0.0390 %	± 0.1055 %	P
HARMONIC 3	11.110 %	11.180 %	0.0700 %	± 0.1082 %	P
HARMONIC 9	1.2300 %	1.2410 %	0.0110 %	± 0.1248 %	P
HARMONIC 11	0.8200 %	0.8340 %	0.0140 %	± 0.1303 %	P
VOLTS THD	12.100 %	12.100 %	-0.0100 %	± 0.2006 %	P
FREQUENCY	55.000Hz	54.970Hz	-29.99mHz	± 54.97mHz	P
CURRENT	2.4803 A	2.4800 A	-338.07µA	± 3.8400mA	P
HARMONIC 1	2.4624 A	2.4620 A	-479.69µA	± 7.6161mA	P
HARMONIC 2	0.0000 %	0.0570 %	0.0570 %	± 0.1055 %	P
HARMONIC 3	11.110 %	11.060 %	-0.0500 %	± 0.1082 %	P
HARMONIC 9	1.2300 %	1.2280 %	-0.0020 %	± 0.1248 %	P
HARMONIC 11	0.8200 %	0.8170 %	-0.0030 %	± 0.1303 %	P
AMPS THD	12.110 %	12.100 %	-0.0100 %	± 0.2006 %	P
FREQUENCY	55.000Hz	54.970Hz	-29.99mHz	± 54.97mHz	P



Serial No. 1300

25th Jan 2011

PM3000A CALIBRATION CERTIFICATE

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TORQUE AND SPEED PASSED

PM3 RANGE		APPLIED INPUT	PM3 READING	ACTUAL DEVIATION	ALLOWED DEVIATION	PASS/P FAIL/F
10 V	TORQUE:	1.0026Nm	997.9mNm	-4.770mNm	± 20.99mNm	P
	SPEED:	1.0026rpm	998.8mrpm	-3.870mrpm	± 20.99mrpm	P
10 V	TORQUE:	9.0049Nm	8.9970Nm	-7.900mNm	± 28.99mNm	P
	SPEED:	9.0049rpm	9.0000rpm	-4.899mrpm	± 29.00mrpm	P
1 V	TORQUE:	105.4mNm	104.8mNm	-633.0μNm	± 15.52mNm	P
	SPEED:	105.4mrpm	101.9mrpm	-3.532mrpm	± 15.50mrpm	P
1 V	TORQUE:	909.8mNm	908.9mNm	-919.9μNm	± 19.54mNm	P
	SPEED:	909.8mrpm	902.6mrpm	-7.220mrpm	± 19.51mrpm	P

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Task I.A Rev 02: Design and Construct Test Stand at EPRI’s Knoxville Thermal Environmental Laboratory, interim report to Southern California Edison.

Task I.B Rev 02: Test Stand Qualification for 2 and 3 Pipe Variable Refrigerant Flow – Heat Recovery Systems.