Multi-Zone Test Facility for Variable Capacity Multi-Split Heat Pump Systems

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ABSTRACT

The latest advances in HVAC technologies focus on delivering the exact cooling or heating required to each individual zone by modulating the system capacity. New technologies like variable speed compressors and inexpensive controls have allowed manufacturers to introduce a new family of direct expansion systems with multiple indoor conditioning coils. The HVAC design and modeling community is interested in analyzing reliable and accurate laboratory data on such systems to further understand the actual benefits. In a typical dual room psychrometric chamber used to test unitary systems, one chamber houses the outdoor unit and the other houses the indoor unit. The multi-split systems provide a unique testing challenge. With multiple indoor coils, a single indoor chamber is unable to simulate individual return air conditions to each indoor coil. This problem is further exacerbated in case of systems which can provide simultaneous heating and cooling. This paper details the design, construction, and commissioning of a novel multi-zone test facility (test stand) for multi-split heat pump systems. A four zone, 10-Ton (35.2kW) ducted test stand is constructed for testing multi-split systems. Each zone has individual temperature, humidity and air flow control which allows indoor coils to be tested at different conditions irrespective of the other coils. The temperature control is achieved by using resistance heaters and cooling coils while the humidity control is achieved by an air /water atomizing system. An axial fan upstream of the indoor units is used to deliver air flow with required static pressure. All three control systems – temperature, humidity and air flow - are controlled through a dedicated data acquisition system. The same system is used to collect data from various sensors. The paper elaborates on the design challenges, construction details and various instrumentation aspects of the test stand.

INTRODUCTION

Single speed split systems with ducted indoor units are ubiquitous in the US residential air conditioning market. The light commercial market, like strip malls and small offices, has relied on roof top units (RTU's) to provide heating and cooling to the conditioned space. Small unitary systems typically rely on simple ON-OFF thermostatic control and distribute conditioned air to different rooms through ductwork. With increasing emphasis on energy efficient operation of end use devices, efficient air conditioning systems has become a priority for regulators, utilities, manufacturers and building owners. There is an impression in parts of the energy efficiency industry that multi-zone variable-capacity heat pumps offer an avenue for energy savings over more traditional single-speed equipment. In the United States, multi-zone direct

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expansion air conditioning / heat pump systems using variable refrigerant flow (VRF) are advancing in the market and there is a need to more fully understand their energy performance potential. VRF systems are essentially integrated, multi-zone direct expansion systems, permitting multiple, separately operable indoor units to be connected to the outdoor unit and incorporating features such as simultaneous cooling and heating (SCH). VRF manufacturers claim high energy efficiency, ease of installation and operation and superior zone control as some of the advantages of their systems. The combination of fuzzy logic, variable speed compressors and fans, and electronic expansion valves allows the system to deliver modulated cooling or heating needed for individual zones. VRF systems have high market penetration in Japan and other parts of Asia and market acceptance of VRF in the US is growing. One of the barriers for VRF systems in the US market is the relatively slow incorporation of VRF models in certified performance simulation tools that can be used for compliance calculations to satisfy energy codes, capture energy credits or to qualify for rebates. Various commercially available building energy modeling software's are incorporating VRF simulation capabilities but the underlying models use manufacturer published data. ANSI / AHRI Standard 1230 specifies important test conditions for performance rating for VRF systems. In addition to these test conditions, this project will provide a comprehensive performance map based on independent lab testing which would otherwise be unavailable. Valid simulation tools require reliable and accurate laboratory data with sufficient resolution to predict the performance of a VRF system in real world conditions. A multi-zone test setup is constructed for performance mapping of various VRF systems and to build a robust data set to model VRF systems. It must be noted that ANSI / AHRI Standard 1230 and other relevant standards are used as a guiding standards for various test conditions, methods and procedures but the aim of constructing this multi-zone test setup is not be a equipment rating facility.

LABORATORY TESTING OF VRF SYSTEM

Laboratory testing of VRF system requires psychrometric chambers to simulate indoor as well as outdoor conditions in which the system is going to operate. A dual room psychrometric chamber is generally used for testing single split systems, with one chamber simulating outdoor conditions and the other simulating indoor conditions. The multi-split systems need more than one indoor chamber to simulate different indoor conditions. A single indoor chamber with multiple indoor units can be used for simplified testing, but all the indoor units will run at same return air condition making some test points like SCH impossible to test.

The indoor unit under test does not change its operation based on whether it is housed in a separate indoor chamber or together with other units in a single chamber. The indoor unit operation is based on the return air temperature, relative humidity and the air flow rate across the heat exchanger. Knowing that the operation of indoor unit is dependent on return air conditions and air flow rate, a laboratory test setup which supplies conditioned return air (temperature, relative humidity and flow rate) to an indoor unit can be used to test instead of a chamber. Taking this concept further, if multiple streams of conditioned return air are provided to multiple indoor units tied to a single outdoor unit, then each indoor unit can be operated at different return air conditions. In this scenario only one chamber is used to house the outdoor unit and the indoor units need a setup to deliver return air at specified condition.

To create a performance map of the VRF system under test, the system needs to be operated at various indoor and outdoor conditions and also with indoor units in various modes (heating, cooling, fan only). To cover a range of conditions for both indoor and outdoor unit of the system, the following items are required

1. Test setup will include an environmental chamber which has external means to control temperature between ~ 10°F (-12ºC) to ~105°F (40ºC) and relative humidity roughly between 10% and 70% inside the chamber. The outdoor unit of the VRF-HR (heat recovery) system will be placed in this environmental chamber.
2. Test setup will include four separately controlled ducted air stands with external means to control air temperature, relative humidity, air flow rate and static pressure.
3. Test setup will include instrumentation to measure air flow, system pressures and temperatures, power, refrigerant

mass flow and relative humidity at different locations in the test system, and have flexibility for the addition of other measurement points as needed during testing.

TEST SETUP DESIGN

The test setup is divided into two separate zones, an outdoor section that is used to simulate outdoor conditions for outdoor unit and an indoor section for simulating indoor unit conditions.

Outdoor Section

The outdoor section of the dual-room climate chamber shown in Figure 1 is used to house the outdoor unit of the VRF-HR units. The nominal capacity of the outdoor climate chamber is 10 tons (35.2kW). The VRF-HR units to be tested have a nominal capacity of 6 tons (21.1kW). This chamber has electric resistance heaters, steam generator and a dehumidifier to control the temperature and humidity conditions for the outdoor unit. Precise air temperature ± 0.5° F (± 0.28ºC) and relative humidity ± 1% will be controlled by integrated programmable controllers. The climate chamber will be maintained nominally in the range from 10°F (-12ºC) to 60°F (15.5ºC) for heating mode testing. In cooling mode, the chamber will simulate conditions up to 105°F (40ºC). In heating mode approximately 10°F (-12ºC) is currently the lower limit on the chamber with upgrades to the cooling circuit planned in near future.

Indoor Section

The design of the indoor testing facility is a unique challenge. Since the systems to be tested have 4 indoor units, there needs to be 4 separately controlled air streams to simulate different conditions for different zones. This is needed in order to run mixed mode tests where two indoor units might be running in heating mode and the other two in cooling mode. To overcome the difficulties associated with testing 4 indoor units simultaneously, a duct based test setup is proposed. Instead of creating and conditioning four separate climate chambers, a four-zone ducted test stand is designed where the air supplied to each ducted zone is independently controllable. Each ducted zone supplies specific amount of conditioned air to the return-air intake of the indoor unit. To condition the return air, a common supply duct with a variable speed fan and a cooling coil will pre-cool and dehumidify the air supplied to each ducted zone. Each duct will have heater, air / water atomizing humidifier for humidity control and a damper system for flow regulation. This entire setup will provide independent control over conditions at the inlet of each indoor unit. Figure 2 shows the plan view of the test setup. The principle of operation is as follows: Ambient air is drawn into a common intake and through a pre-cooling coil which cools the air stream and reduces the absolute humidity. Beyond the cooling coil, the air stream splits into four separate 12” x 12” (0.3m x 0.3m) ducts with individual dampers to control volume flow through each circuit. Each of the four ducts has a resistance duct heater and a spray mist humidifier to bring the conditioned air up to prescribed conditions. The heaters and humidifiers in each duct are independently controlled to maintain temperature and relative humidity at the prescribed set point. The variable speed fan will provide the required air pressure to overcome the resistance of the test stand ducts, resistance heater, blenders and instrumentation equipment. The fan speed will not be varied during an individual test.

Figure 3 shows the as-built test setup. The common air intake, labeled as Return Air is visible on the right side whereas the four supply air ducts can be seen on the left side labeled as Zone 1 thru Zone 4. A control station for the indoor test setup is visible in the bottom left corner.

Figure 1 Dual Room Climate Chamber (The right side chamber will house the VRF outdoor unit under test.)

INSTRUMENTATION

The data acquisition and control of the test stand is accomplished through a dedicated PXI system. Programming is done using commercially available data acquisition software. Various subsystems in the test setup are controlled either manually or through the computer program. Table 1 gives a list of controlled parameters and the method of control.

Air enthalpy method is used for each indoor unit to measure the cooling or heating capacity. No capacity measurements are done on the outdoor unit. As a validity check two indoor units have mass flow meters installed to calculate the refrigerant side capacity. For calculating capacity based on air enthalpy method the supply and return air temperature and relative humidity, air flow rate are critical parameters. Five revenue grade power meters (one for outdoor unit power and four for indoor units) are installed for determining the power consumed and the efficiency of the system. Additional instrumentation such as thermocouples, refrigerant pressure measurements at various points in the system and a chilled mirror hygrometer are diagnostic in nature to understand the operation sequence in various modes and for troubleshooting.

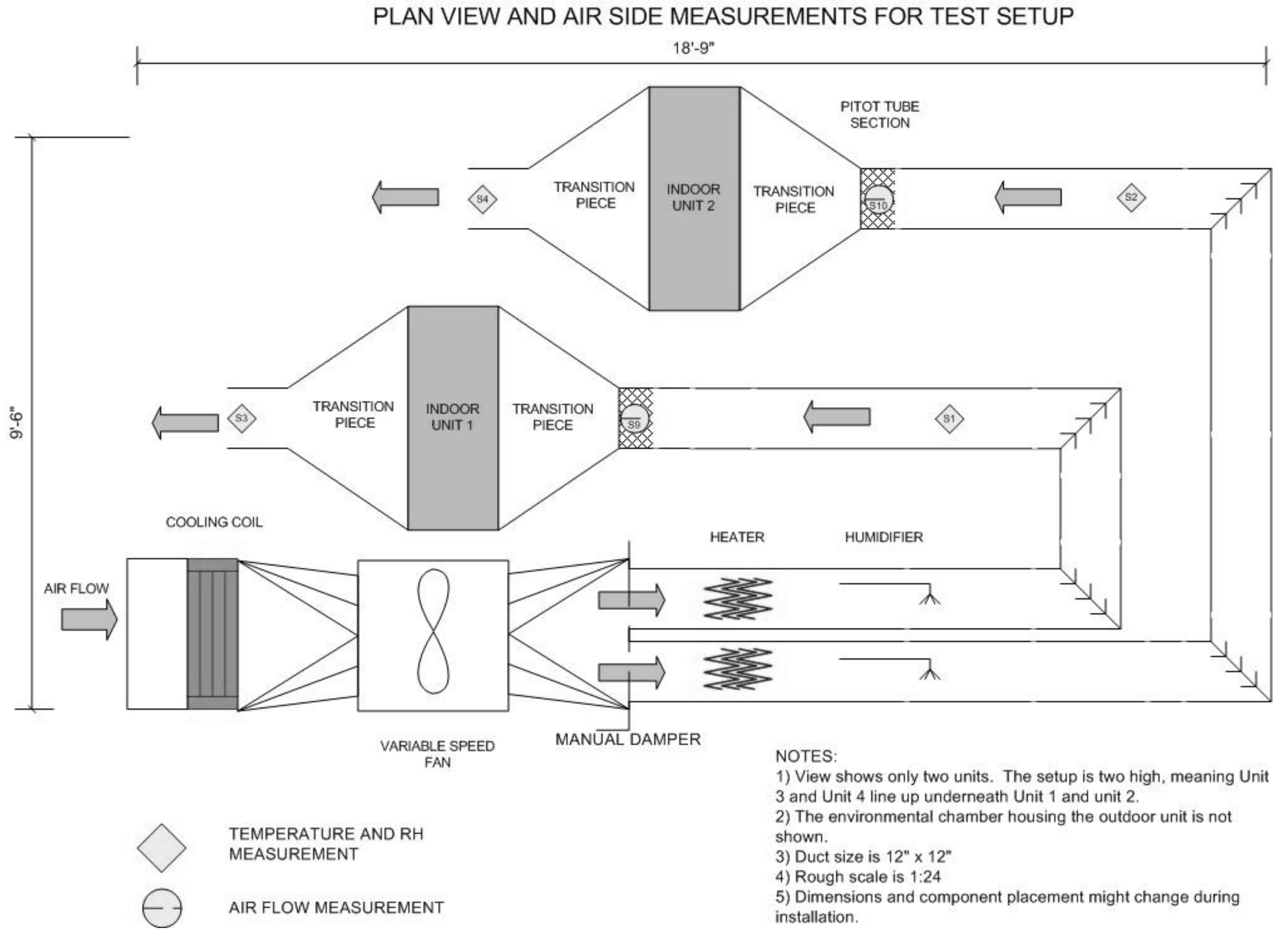

Figure 2 Plan View for Test Setup

TEST PROCEDURE

The system under test can be VRF – HR unit or just a VRF heat pump which doesn't have the advanced SCH operation. In cooling mode, all digital controllers for the indoor units are set to cooling mode and the temperature is set to the lowest allowable for e.g. 64°F (17.8ºC). Since the return air temperature and relative humidity are controlled by the test setup, the test systems controller is never satisfied and the unit runs continuously. The outdoor and the return air conditions are controlled to a set of predetermined conditions. Similar to cooling mode, in heating mode the digital controllers are set to the highest allowable temperature for e.g. 84°F (28.9ºC). In mixed mode, corresponding digital controllers are set to either minimum or maximum temperature depending on mode of operation. The unit adjusts the compressor speed, fan speeds (on outdoor unit) and expansion device position based on its internal control logic. No control over the internal operation of the test unit, fan speeds etc., is exercised. The system is said to be operating in a steady state if the imposed conditions on the system (return air dry bulb temperature and relative humidity, outdoor dry bulb temperature and relative humidity and indoor unit air flow) and the supply air dry bulb temperature are within the tolerance zone for at least 10 minutes. The test operating tolerance zone for return air dry bulb temperature and outdoor dry bulb temperature is ± 2°F (1.1ºC), for outdoor wet bulb temperature is ± 1°F (0.5ºC), for indoor unit air flow is ±2% of rated air flow and for supply air temperature is ± 1°F (0.5ºC) (as per AHRI 1230).

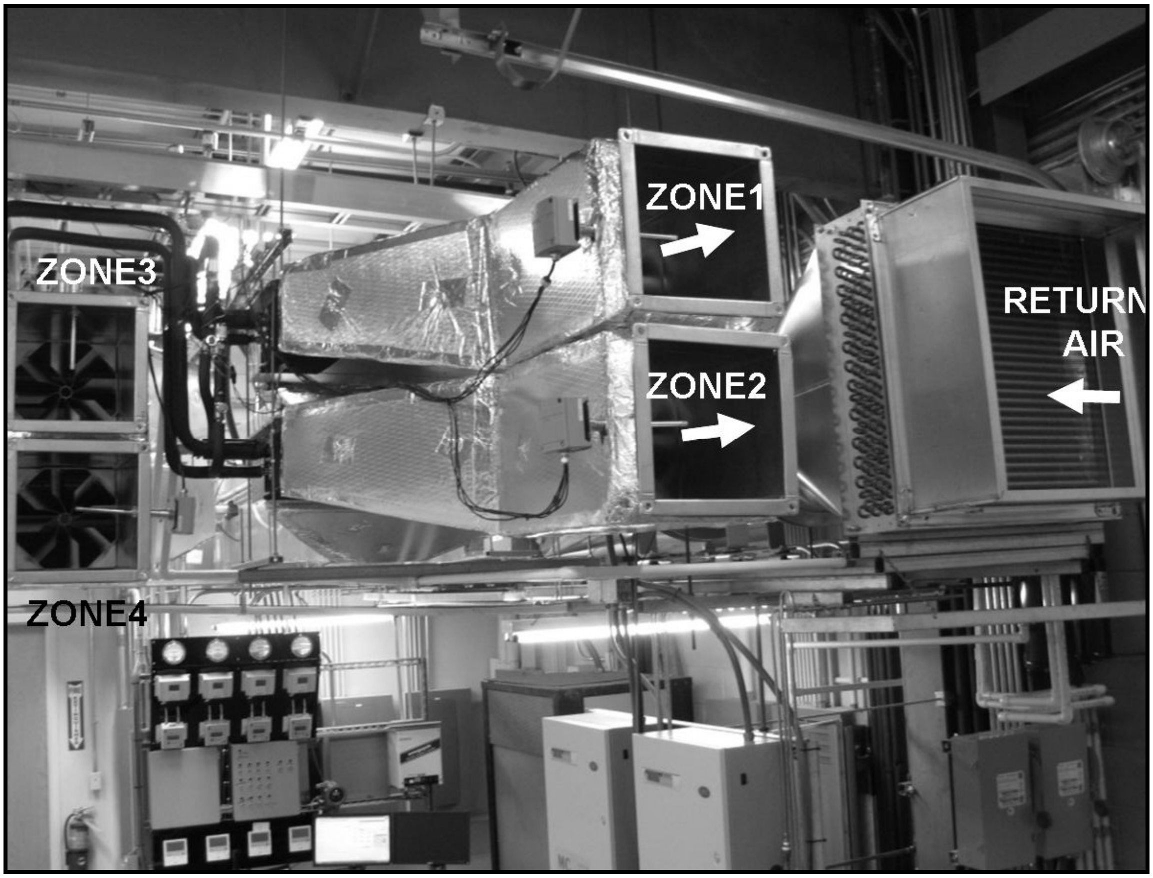

Figure 3 Completed Test Setup (Indoor Section)

TEST SETUP COMMISSIONING

Difficult-to-achieve test conditions for indoor and outdoor setup were chosen to ensure that the test setup can reach those conditions. Two different conditions were chosen, one for cooling mode and one for heating mode. A third condition, a standard rating test condition is also chosen to compare data collected to the manufacturer data.

Cooling Mode

In cooling mode an indoor condition of 85°F (29.4ºC) dry bulb and 70°F (21.1ºC) wet bulb temperature and outdoor chamber condition of 65°F (18.3ºC) dry bulb temperature was chosen. These conditions yield the highest cooling capacity of the unit within the operating envelope. At 65°F (18.3ºC) DBT the outdoor unit is rejecting maximum heat in the outdoor chamber. This will increase the temperature of the outdoor chamber.

Table 1. Controlled Subsystems

Subsystem	Controller	Type	Comments
Heaters			
Return Air Duct	Data acquisition program	PWM	Multiple safety interlocks, manual override
Outdoor Chamber	Industrial controller	PWM	
Humidifiers			
Return Air Duct	OEM Supplied	PID	Manual override
Outdoor Chamber	Industrial controller	PWM	
Dehumidifiers			
Return Air Duct	Cooling coil (2 stage)	ON/OFF	Manually turn ON to reduce humidity
Outdoor Chamber	Commercial dehumidifier	ON/OFF	Manually turn ON to reduce humidity
Air Flow			
Return Air Duct	Damper	Manual	Manually adjust damper for each duct
Overall Air Flow	Variable speed drive	Manual	Control speed of main fan
Cooling			
Return Air Duct	Cooling coil (2 stage)	ON/OFF	Manually turn ON to reduce temperature
Outdoor Chamber	Cooling coil (2 stage)	ON/OFF	Manually turn ON to reduce temperature
VRF System			
Indoor Units	OEM Controller	Digital	Set temperature, fan speed and operating mode
Outdoor Unit			Reacts to the OEM controllers

Table 1: List of subsystems and corresponding controls

The cooling coil on the outdoor chamber needs to keep up with this heat load to maintain a steady temperature of 65°F (18.3ºC) DBT. This point is chosen specifically to test the outdoor chambers ability to maintain 65°F (18.3ºC) DBT. The lower the outdoor chamber temperature in cooling mode, harder it is to maintain. In the indoor setup, this test point confirms the operation of the heaters and the humidity control. The test setup could maintain conditions in both indoor and outdoor section for extended period of time confirming the cooling mode operation.

Heating Mode

In heating mode, a higher outdoor chamber temperature with lower indoor return air temperature is difficult to maintain. For this reason an indoor condition of 65°F (18.3ºC) DBT and outdoor condition of 60°F (15.5ºC) DBT were chosen. For this test point, the indoor test setup has to run both the cooling coil and the heaters to maintain 65°F (18.3ºC) DBT. The cooling coil first cools the air below 65°F (18.3ºC) and then the resistance heater in each duct brings the temperature up to the set point. This operation confirmed that the heaters could handle the load. In the outdoor chamber, the outdoor unit is trying to cool the chamber (absorb the heat into the refrigerant) and the chambers resistance heaters have to keep up with the load. The test setup was able to maintain these conditions without any difficulty.

Rating Test Point

AHRI rating test points from Standard 1230 for heating and cooling were also considered in the commissioning process. For cooling mode the AHRI rating point is indoor 80°F (26.6ºC) DBT and 67°F (19.4ºC) wet bulb temperature (WBT) and outdoor at 95°F (35ºC) DBT. For heating mode the condition is indoor at 70°F (21.1ºC) DBT and outdoor at

47°F (8.3ºC) DBT and 43F (6.1ºC) WBT. With the operation at the extremities of test matrix envelope already verified, the AHRI rating points were easily achieved.

CONCLUSIONS

A novel ducted multi-zone test setup for performance mapping of VRF systems is built and commissioned at EPRI's Thermal Environmental Laboratory in Knoxville, TN. The test setup is capable of testing VRF systems in full load cooling, full load heating, part load cooling, part load heating and heat recovery mode. The test setup was put through a commissioning process wherein difficult to achieve conditions were reached with a test unit. The test setup is fully operational and VRF systems from numerous manufacturers are being tested to obtain a comprehensive lab data set.

ACKNOWLEDGEMENTS

The test setup is part of a project for investigating VRF technology and is funded by Bonneville Power Administration, Florida Solar Energy Center and Southern California Edison.

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