Variable Refrigerant Flow (VRF) Systems

System Description, Application and Commissioning

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Variable Refrigerant Flow (VRF) Systems

System Description and Overview

Introduction:

This document is meant to give a general understanding of Variable Refrigerant Flow systems to Building Operators, DFCM Project Managers, End-Users, and Commissioning agencies. It is not meant to be an in-depth discussion of VRF or a technical application guide. The intent is to give guidance for the purposes of system selection and general commissioning procedures.

General VRF Description:

Overview Description

Variable refrigerant flow systems are a type of refrigerant system which utilizes a centralized condensing unit and multiple fan coils to provide heating and cooling to building spaces. VRF systems are available which are capable of simultaneously heating and cooling spaces on the same central heat pump by recovering heat between building zones.

The zone fan coils typically have many configurations available ranging from wall or ceiling mounted cassettes to recessed ceiling mounted cassettes to fully concealed ducted units. The condensing unit may be located outdoors, such as with air source VRF systems, or in mechanical spaces within the building as is seen with water source VRF.

In general VRF comes in two varieties, two-pipe and three-pipe systems. Both of these are described in more detail in the following sections.

Types of VRF Systems:

Two Pipe VRF

Description: Two pipe VRF systems utilize a branch circuit (BC) controller on the refrigerant lines to enable heat recovery between building zones and to select zone operation in either heating or cooling mode. Without the BC controller the two pipe VRF configuration would not be capable of simultaneous heating and cooling operation or heat recovery. There is currently one manufacturer which makes the two-pipe heat recovery type VRF system.

Three Pipe VRF

Description: Three pipe VRF systems utilize a hot gas line in addition to the liquid and suction lines seen in the 2 pipe system. This type of system connects the central heat pump to zone control valves via three refrigerant lines. The zone control valves typically utilize a solenoid valve to switch zone operation between heating and cooling. Three pipe systems are capable of simultaneous heating and cooling by recovering and transferring heat between spaces via the refrigerant circuit.

Air Source VRF

Description: Air source VRF utilizes heat pumps designed to absorb or reject heat from the building refrigerant circuit to the ambient outdoor air. Climate plays a more significant role in the operation of air source systems, as extreme temperatures will have an impact on both the system capacity and system efficiency. These parameters need to be addressed in the project mechanical system design.

Water Source VRF

Description: Water source VRF utilizes heat pumps designed to absorb or reject heat from the building refrigerant circuit to a central hydronic loop. This loop is typically connected to a fluid cooler/cooling tower for heat rejection and a boiler for heat absorption. These systems may also be connected to a ground heat exchanger or ground water heat exchanger to reject or absorb heat in lieu of the fluid cooler / boiler approach.

The water source VRF system is not greatly affected by ambient outdoor conditions and does not suffer a capacity or efficiency deration due to extreme outdoor temperatures.

VRF in combination with other HVAC systems

General: As with many HVAC systems VRF may be used in conjunction with other HVAC system types to meet specific building use requirements.

Dedicated Outside Air System (DOAS): VRF systems are often paired with DOAS systems when building ventilation air requirements exceed the capacity of the individual zone VRF fan coils. DOAS systems are sized to condition and move the ventilation air required by the building zones. This results in the fans and ductwork being significantly smaller than central air handling systems.

With Supplemental Zone Heating/Cooling: When designing VRF systems, there are some cases where supplemental zone capacity may be required. This may be in the form of local radiant units or ductless split system units used as a second stage or alternate stage of heating cooling.

As Supplemental Zone Heating/Cooling: In some cases VRF systems may be used as stand-alone systems serving critical/special use areas that operate significantly different than the other building areas, such as data rooms or 24hour occupied areas. VRF may also be employed as a backup source of heating/cooling to a central air system.

Application of VRF Systems

When to use VRF:

General: As with any HVAC system VRF is not a one-system-fits-all solution. Several factors must be taken into account to determine if VRF is the right HVAC system for a project. In all cases, life-cycle cost analysis should be used to determine the overall cost-effectiveness of using VRF systems. The following paragraphs describe some specific criteria that can be used in preliminary discussions before LCC analysis can be completed.

The following project parameters tend to favor VRF application:

1. Building turnover: VRF systems have a higher than average flexibility in redesigning to new space requirements.
2. Building Expansion: VRF systems have a lower than average complexity for adding additional zone/plant capacity to meet additional loads from building expansion.
3. Building Heating/Cooling Diversity: Where building load diversity indicates a significant simultaneous heating/cooling demand, VRF with heat recovery can be a good fit. This is due to increased efficiency seen during heat recovery operation.
4. Buildings where space restrictions limit the ability to route ductwork, hydronic piping or place equipment – particularly retrofits – may benefit from VRF because of the small size of the refrigerant piping and relative low space impact of the equipment.

Where any of the following listed parameters are encountered, careful consideration must be given to VRF application:

1. Low Ambient Operation: Where outdoor air conditions during occupied hours are at or near 0°F in the heating season, air source VRF experiences capacity limitations on standard equipment. Normally, air source VRF will lose 15-30% of design heating capacity at 0°F. For these reasons, if project conditions – such as unavailability of natural gas at the site – favor VRF, LCCA should be used to justify application of the system.
    a. NOTE: Using water source VRF, adding supplemental zone capacity such as radiant elements, oversizing VRF equipment or utilizing specialized equipment which increases system capacity at the expense of efficiency can be done to counter this.
2. Outside Air Demand: If space occupancy or building use requires >30% outside air/supply air VRF may not be a good fit. DOAS systems with pretreatment can offset the outside air load, but air change requirements may still be difficult to meet with a VRF system.

3. Low building load diversity: If building loads do not show a significant simultaneous heating/cooling load, or show an overwhelming tendency towards a constant condition – such as a data center, VRF may not be a good fit.

4. High air filtration requirements: VRF cassette type fan coils have limited filtration capacity. For projects requiring MERV 13 or higher filtration, ducted fan coil VRF may be required, or supplemental systems capable of higher filtration capacity will need to be used.

Design guidelines:

1. General: The following is a list of design and construction considerations compiled from past VRF projects. These items should be reviewed and included in project construction documents as best practice guidelines.
   a. Provide shut-off valves on refrigerant lines to facilitate component removal/repair
   b. Require Installers to be certified by manufacturer and have 3-5 previous projects completed
   c. Require system control components, wiring, component addressing and start-up to be performed by factory certified personnel with DDC control system installation experience.
   d. VRF manufacturer will provide interface and points list to allow BMS to monitor system and set schedule and space set point temperatures
   e. Conduct post-bid meeting including design engineer, VRF controls, BMS controls, and project commissioning authority to coordinate controls to ensure compliance with specifications and Owner's Project Requirements.
   f. Watch system requirements for proprietary equipment used for system repair or maintenance
   g. All system pipe fittings to be brazed – no flared fittings
      a. Brazing to be performed with nitrogen flowing in piping at all times
   h. All piping should be required to be continuously pressure and vacuum tested during installation
      a. Open ends of piping will be hermetically sealed (pinched and brazed) when not in work, no taping of open ends
      b. Piping will be left under pressure, filled with nitrogen
   i. Specify ACR refrigerant piping pre-charged with nitrogen
   j. Use soft copper tubing between controller/control valve and fan coil to reduce number of fittings
   k. Do not specify filter dryers or sight glasses on refrigerant pipes
   l. Size VRF fan coil connected load at 60-70% of total system capacity. This may be modified by manufacturer recommendations.

m. Consider system redundancy, especially regarding compressors, to ensure that component failure will not result in the system being compromised until repair is completed.

n. Ensure provisions are included in the contract documents covering the training of maintenance personnel in the operation, maintenance and troubleshooting of the installed VRF system.

2. Other design considerations:

   a. Energy Code (IECC 2012): Current energy code (IECC 2012) only allows 300,000 Btu/h (25 tons) of building cooling capacity to be without air or water economizer. In addition, code requires any individual fan cooling system greater than 33,000 Btu/h (≥3 tons) to be provided with either air or water side economizer. The energy code does not specifically address VRF systems, but has a separate requirement that requires a bypass to disable heat recovery during economizer conditions.

   b. Energy Code (ASHRAE 90.1-2010): If the project opts to follow AHSRAE 90.1 in lieu of IECC 2012 (as allowed by IECC 2012, chapter 4, C402.1), air or water economizers are required on fan cooling systems with capacities greater than 54,000 Btu/h (>4.5 tons). Note that ASHRAE does not have a building capacity limit on systems without economizer.

   c. ASHRAE Standard 15-2010, *Safety Standard for Refrigeration Systems*: VRF equipment manufacturers recognize this standard as the main guide for personal safety involving refrigeration systems. Limits are established on minimum room area that can be served by a direct refrigerant system based on refrigerant type and total charge (in lbs. of refrigerant). This is to ensure that a maximum safe concentration of refrigerant is not exceeded should a leak in the system occur. Mechanical system designs should take into account the recommendations of this standard to ensure occupant safety.

   d. System Changeover/Optimum Start: Refrigerant based HVAC systems such as heat pumps, ductless split a/c, and VRF are prone to slower changeover and recovery times. This will impact the time required to recover from unoccupied set-point temperatures, and temporary off-hours occupancy.

   e. A leak in a VRF system – will likely result in most of the refrigerant charge being lost. Lack of refrigerant will mean the system will be completely off-line until the leak can be repaired and/or isolated and the system is recharged with refrigerant. This may mean the building being without HVAC for a significant period of time depending on maintenance response, complexity of repair and availability of refrigerant. System recovery time, as described above will also affect the time needed to bring the building back to full operation, potentially up to 24 hours after repairs are completed.

f. Critical Cooling Applications: Verify with the system manufacturer that overall system operation is not impacted by failure of power or power loss to a single terminal device.

Building Automation

VRF controls vs. Building Management System

All VRF manufacturers utilize proprietary controls to operate their version of VRF systems. These controls coordinate the operation of the condensing unit, BC or zone control valves, and zone fan coils in response to space/building demand. Local control interface panels are available through which most information on system operating schedules, space set point and off-hours set point temperatures, system operating parameters and errors/faults can be viewed and adjusted. In general these controls do not allow full integration into a BMS. This is similar to packaged refrigeration equipment such as split system air conditioners and packaged rooftop units.

Proper system controls, including control installation and set-up, are critical for successful VRF system deployment. Controls sub-contractors should be utilized that have:

- Manufacturer training on VRF control installation and setup
- Demonstrable experience with installation, set-up and integration of VRF system controls with Building Management Systems.

Previous control installation experience must be with the VRF system being installed, and preferably with the BMS system the VRF controls are being integrated into.

The project construction documents should require the VRF controls to be provided with a gateway interface which will allow the BMS to remotely monitor and control the VRF system. The level of controllability available will be dependent on the VRF manufacturer. Points should include at a minimum:

1. Equipment status (on/off) – command/monitor
2. Mode (heating/cooling) – monitor
3. Fan speed/status – monitor
4. Space temperature – monitor
5. Space set point temperature – command/monitor
6. Filter status – monitor
7. Alarm signal – monitor
8. Error code – monitor
9. Building schedule – command/monitor
10. Remote control lockout – command/monitor

Commissioning Guidelines

VRF Commissioning Overview:

System commissioning is critical in that it ensures the installation of the VRF system has been constructed according to design and per the manufacturer's requirements. Maintaining solid quality assurance on VRF installation is a key factor in the successful deployment of this type of HVAC system.

VRF Commissioning Process:

Because of the high rate of variability in system layout and equipment characteristics between VRF manufacturer's, Commissioning (Cx) should include review of non-basis-of-design VRF manufacturer systems to ensure design intent is being met.

Commissioning authorities should consider attending Manufacturer provided training on VRF systems for insight as to good installation and operating practice for specific system types. Note that training should be undertaken for each specific VRF manufacturer to ensure differences between each system are understood.

Cx efforts should also focus on verification of specified installation processes such as:

- Installing contractor records lengths and sizes of all field piping to calculate necessary system charge
- Piping sizes and lengths conform to manufacturers installation guidelines
- Daily sealing and pressurizing of installed VRF piping using nitrogen
- Brazing done without flux using phosphor copper brazing rod and nitrogen flush
- Witnessing of required pressure testing and system evacuation / dehydration
- Thermistor type vacuum gauge is used during evacuation
- System charged with liquid phase refrigerant
- Piping insulated to manufacturers recommendations for thickness and temperature rating
- Installed equipment matches submittals, and
- Seasonal testing – as part of the functional test process – to verify system operation in a variety of outdoor conditions.
  - It is recommended that testing conditions include heating dominant, cooling dominant and mixed heating/cooling system operation.

EXAMPLE DOCUMENTATION

To assist with commissioning of VRF systems, example commissioning checklists, testing forms, and testing procedures have been provided in the appendix which may be modified to fit specific project criteria.

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System Functional Performance Test

1 Have all indoor units enter heating mode (90 degrees) - Record results
2 Isolate building from heat source/sink, circulate building loop - Record results
3 Remove isolation
4 Have all indoor units enter cooling mode (55 degrees) - Record results
5 Isolate building from heat source/sink, circulate building loop - Record results
6 Remove isolation
7 Set all thermostats to 72 degrees
8 Wait for building space temperatures to normalize (space temps between 68-76 degrees)
9 Isolate building from heat source/sink, circulate building loop - Record results

Heating Test	Water In Temp		Water Out Temp	
Heating Test Isolation - 0 Minutes	Water In Temp		Water Out Temp	
Heating Test Isolation - 15 Minutes	Water In Temp		Water Out Temp	
Heating Test Isolation - 30 Minutes	Water In Temp		Water Out Temp	
Heating Test Isolation - 45 Minutes	Water In Temp		Water Out Temp	
Heating Test Isolation - 60 Minutes	Water In Temp		Water Out Temp	
Cooling Test	Water In Temp		Water Out Temp	
Cooling Test Isolation - 0 Minutes	Water In Temp		Water Out Temp	
Cooling Test Isolation - 15 Minutes	Water In Temp		Water Out Temp	
Cooling Test Isolation - 30 Minutes	Water In Temp		Water Out Temp	
Cooling Test Isolation - 45 Minutes	Water In Temp		Water Out Temp	
Cooling Test Isolation - 60 Minutes	Water In Temp		Water Out Temp	
Normal Op Test	Water In Temp		Water Out Temp	
Normal Op Test Isolation - 0 Minutes	Water In Temp		Water Out Temp	
Normal Op Test Isolation - 15 Minutes	Water In Temp		Water Out Temp	
Normal Op Test Isolation - 30 Minutes	Water In Temp		Water Out Temp	
Normal Op Test Isolation - 45 Minutes	Water In Temp		Water Out Temp	
Normal Op Test Isolation - 60 Minutes	Water In Temp		Water Out Temp	

NOTES

Pre-commissioning System and Installation Check List

To be filled out by mechanical contactor

SYSTEM AND INSTALLATION STATUS				Comments
1	Maintenance and Access to Remove Covers	Heatpump	☐ Good ☐ Fair ☐ Poor	
		BC Cntrl/Zone Cntrl Valve	☐ Good ☐ Fair ☐ Poor	
		Indoor Units	☐ Good ☐ Fair ☐ Poor	
2	Piping Variations from Construction Drawings			
3	Connection of mains power source	Heatpump	☐ Good ☐ Fair ☐ Poor	
4	Connection of Control System	Heatpump - BC	☐ Good ☐ Fair ☐ Poor	
		BC -BC (if used)	☐ Good ☐ Fair ☐ Poor	
		BC - Indoor	☐ Good ☐ Fair ☐ Poor	
		Indoor - Indoor	☐ Good ☐ Fair ☐ Poor	
		Indoor - RC	☐ Good ☐ Fair ☐ Poor	
		Electric Cable	Type: Size:	
		Comms Cable	Type: Size:	
5	Control Method which type	MITSUBISHI: ☐ EB-50GU ☐ GB50 ☐ TG2000 ☐ AG150A ☐ TC-24 ☐ AE200A ☐ GB-24	LG: ☐ PQC SZ250 ☐ PAC S4B ☐ PQC SZ421 ☐ AG150A	DAIKIN: ☐ DCS601 ☐ DCS302 ☐ DCM601
6	BacNET Interface to BMS			
8	Water Source VRF Safety Interlocks Connected	☐ Water Flow Switch ☐ Pump Interlock		
9	Connection of Options	☐ Good ☐ Fair ☐ Poor		
10	Water Flow Rate (if applicable)		GPM	
11	Water Temp. (if applicable)	Inlet (°F)	Outlet (°F)	

Notes and Comments

Pre-commissioning Condenser Water Piping Checklist Check List

To be filled out by mechanical contactor

SYSTEM AND INSTALLATION STATUS	Yes/No			Comments
1. Does each heatpump have adequate flow?		GPM:		
2. Are there any leaks?				
3. Is the water pressure acceptable?		PSI:		
4. Does each heatpump have the proper isolation valves to be isolated and bypassed?				
5. Does the main condenser water flow to the building meet design requirements?		GPM:		

PRESSURE TEST

Heatpump : Location:

3 Steps

Testing shall be inclusive of all equipment (all valves are open)

Testing shall be completed using nitrogen

Any leakage over 1% is considered excessive

1	**50 psig**	Minimum of 3 Minutes
2	**250 psig**	Minimum of 3 Minutes
3	**550 psig**	After step 2, raise pressure to 550 psig for the final air tight test. The pressure should be held for a minimum of 24 hours. Taking into account the ambient temperatures across the 24 hours. The pipe should be inspected for any deformations.

Notes

Mechanical Contractor Signature and Date

Mechanical Engineer Signature and Date

Commissioning Agent or DFCM Project Manager Signature and Date

VACUUM TEST

Heatpump :   Location:

6 Steps

Testing shall be inclusive of all equipment (all valves are open)

1	Evacuate the system to 2500 microns from both service valves. System manifold gauges must not be used to measure vacuum. A micron gauge must be used at all times.
2	Break the vacuum with Nitrogen into "suction" service valve till atmospheric pressure has registered at the "discharge" valve.
3	Evacuate through both service valves to lowest pressure vacuum pump will achieve (Below 300 microns for 1 hour minimum). If 300 is achieved got to step 6.
4	Break the vacuum with nitrogen or refrigerant into "suction" service valve till atmospheric pressure has registered at the "discharge" valve.
5	Evacuate through both service valves to lowest pressure vacuum pump will achieve (Below 300 microns for 1 hour minimum)
6	Pressure Rise Test must then be carried out for a minimum of 30 minutes. If the pressure rises on the micron gauge repeat steps 2 and 5 till no rise is detected.
7	Charge refrigerant per manufacturer recommendations.
8	Amount of refrigerant put into system :

Notes

Mechanical Contractor Signature and Date

Mechanical Engineer Signature and Date

Commissioning Agent or DFCM Project Manager Signature and Date

VRF Heatpump - Checklist and Functional Performance Test

VRF Heatpump - Commissioning Checklist

	YES/NO
1. Does heatpump model match approved submittal?	
2. Does the heatpump have appropriate spacing for service and thaw cycle?	
3. Are all electrical connections and appropriate disconnects in place?	
4. Are refrigerant lines insulated and secured properly?	
5. Has the unit been through manufacturer startup?	
6. Have the refrigerant lines been properly charged?	
7. Does compressor and fan rotate correctly?	
8. Has thaw drainage been considered? Drain piping if necessary.	
9. Is equipment isolation in place if applicable?	
10. Has the heatpump and electrical been labeled appropriately?	

1	Outdoor Unit 1 Details	Model No:	0		Serial No:		
2	Compressor 1 details	Model No:	0		Serial No:		
3	Power Source (V)		L1 - N	L2 - N	L3 - N	E - N	
4	Address						
5	Control Voltage						
6 - Heating Test	Compressor %		Unit Amps		Water/Air In Temp		Water/Air Out Temp
7 - Cooling Test	Compressor %		Unit Amps		Water/Air In Temp		Water/Air Out Temp
8 - 50% Test	Compressor %		Unit Amps		Water/Air In Temp		Water/Air Out Temp

1 - Set all indoor units to heating mode (90 degrees) and record compressor heating test.
2 - Inspect all indoor units and compare to individual unit tests and record any significant anomolies.
3 - Set all indoor units to cooling mode (55 degrees) and record compressor cooling test.
4 - Inspect all indoor units and compare to individual unit tests and record any significant anomolies.
5 - Set 50% of indoor units to heating (90 degrees) and 50% to cooling (55 degrees) and records results
6 - Inspect all indoor units and compare to individual unit tests and record any significant anomolies.
7 - Return indoor units to 72 degrees.
8 - Inspect Unit

Was Checklist Complete? YES ☐ NO ☐

Comments

VRF Branch Circuit Controller / Zone Control Valve Commissioning Checklist

VRF Branch Controller / Zone Control Valve			
Model No.		Unit Address No.	
Serial No.			
Location			
Voltage	V	Control Voltage	

	YES / NO / N/A
1. Isolation vavles installed on branch circuits?	
2. Valves were installed straight?	
3. Drain piping connected?	
4. Power connected properly?	
5. Local power control installed?	
6. Condensate pump installed?	
7. Has the unit been labeled properly?	

Comments

VRF Indoor Unit Functional Performance Test

VRF Terminal Unit - Commissioning Checklist

	YES/NO
Is the T-stat able to control the temperature in both heating and cooling mode?	
Is the T-stat able to control discharge vanes (if applicable)?	
Have the filters been cleaned?	
Are the power connections clean and secured properly?	
Does the unit run without any unusual vibrations or noises?	
Is there adequate space for maintenance access?	

VRF INDOOR UNIT Wall or Ceiling Mount - Commissioning Checklist

Model No.				**Unit Address No.**		
Serial No.						
Location						
T-stat Address				**BC/Valve Port**		
Voltage			**V**	**Control Voltage**		**V**
Inlet	Cooling Temp		Heating Temp			
Outlet	Cooling Temp		Heating Temp			
Refrigerant Pipe and Valve Inspection						
Condensate Pipe Inspection						

Was Checklist Complete? YES ☐ NO ☐

1 - Verify that space temp is between 68-76 degrees.

2 - Set thermostat to 55 degrees; enter cooling temperatures

3 - Set thermostat to 90 degrees; enter heating temperatures

4 - Adjust vanes and fan speed. Verify unit responds accordingly.

5 - Set thermostat back to 72 degrees and complete rest of checklist.

Comments

CONTROLS Point-to-Point Checks

Item	Locations	Points Controlled	Notes	Passed?