

Designing VRF Systems

By Ramez Afify, Member ASHRAE

The main advantage of a variable refrigerant flow (VRF) system is its ability to respond to fluctuations in space load conditions. By comparison, conventional direct expansion (DX) systems offer limited or no modulation in response to changes in the space load conditions. The problem worsens when conventional DX units are oversized or during part-load operation (because the compressors cycle frequently). A simple VRF system, comprised of an outdoor condensing unit and several indoor evaporators, which are interconnected by refrigerant pipes and sophisticated oil and refrigerant management controls, allows each individual thermostat to modulate its corresponding electronic expansion valve to maintain its space temperature setpoint.

VRF systems have been used in Asia and Europe for almost twenty-five years. With a higher efficiency and increased controllability, the VRF system can help achieve a sustainable design. Unfortunately, the design of VRF systems is more complicated and requires additional work

compared to designing a conventional DX system.

This article provides guidelines for determining the feasibility of a VRF system and discusses the factors that should be considered from initial planning through completion of a project. Although some

manufacturers now offer water-cooled VRF systems, this article focuses on air-cooled, split-type VRF systems.

Choosing VRF

In deciding if a VRF system is feasible for a particular project, the designer should consider building characteristics; cooling and heating load requirements; peak occurrence; simultaneous heating and cooling requirements; fresh air needs; accessibility requirements; minimum and maximum outdoor temperatures; sustainability; and acoustic characteristics.

Building Characteristics

Although manufacturers routinely increase the maximum allowable refrigerant pipe run, the longer the lengths of refrigerant pipes, the more expensive the initial and operating costs. For most VRF units, the maximum allowable vertical distance between an outdoor unit and its farthest indoor unit is approximately 150 ft (46 m); the

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maximum permissible vertical distance between two individual indoor units is approximately 45 ft (14 m); and the maximum actual refrigerant piping lengths allowable between outdoor and farthest indoor units is up to 490 ft (149 m).

Building geometry must be studied carefully. The system should not be considered if the expected pipe lengths or height difference exceed those listed in the manufacturer's catalog. In buildings where several outdoor locations are available for the installation of the outdoor units, such as roof, setback, and ground floor, each condensing section should be placed as close as possible to the indoor units it serves. The physical size of the outdoor section of a typical VRF is somewhat larger than that of a conventional DX condensing section, with a height up to 6 ft (1.8 m) excluding supports.

Indoor units are available in multiple configurations such as wall-mounted, ceiling-mounted cassette suspended, and concealed ducted types. It is possible to combine multiple types of indoor sections with a single outdoor section.

Building Load Profile

The combined cooling capacity of the indoor sections can match, exceed, or be lower than the capacity of the outdoor section connected to them. An engineer can specify an outdoor unit with a capacity that constitutes anywhere between 70% and 130% of the combined indoor units capacities. The design engineer must review the load profile for the building so that each outdoor section is sized based on the peak load of all the indoor sections at any given time. Adding up the peak load for each indoor unit and using that total number to size the outdoor unit likely will result in an unnecessarily oversized outdoor section. Although an oversized outdoor unit in a VRF system is capable of operating at lower capacity, avoid oversizing unless it is required for a particular project due to an anticipated future expansion or other criteria (Example 1).

Sustainability

One attractive feature of the system is its higher efficiency in comparison to conventional heat pump units. Less power is consumed by the VRF system at part load compared to conventional systems, which is due to the variable speed driven compressors and fans at outdoor sections. The designer should consider other factors to increase the system efficiency and sustainability. For example, sizing should be carefully evaluated and oversizing should be avoided. Environment-friendly refrigerants such as R-410a should be specified. Relying on the heat pump cycle for heating, in lieu of electric resistance heat, should be considered, depending on outdoor air conditions and building heating loads. This is because significant heating

capacities are available at low ambient temperatures. (e.g., the heating capacity available at 5°F [-15°C] can be up to 70% of the heating capacity available at 60°F [16°C], depending on the particular design of the VRF system).

Fresh Air Requirements

One of the most challenging aspects of designing VRF systems is the need to provide a separate outside air supply to each unit to comply with ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, and building codes. Most manufacturers offer an outside air kit, for connecting to outside air ductwork. A separate outside air fan and control system is generally required for larger buildings. In humid climates, providing preconditioned outside air to each indoor unit ensures good indoor air quality.

Simultaneous Heating and Cooling

Some manufacturers offer a VRF system capable of providing simultaneous heating and cooling. In those systems, although several indoor sections are connected to one outdoor section, some indoor sections can provide heating, while others provide cooling. The prices for those units and their installation are

higher than that of cooling- or heating-only units. More economical design can sometimes be achieved by combining zones with similar heating or cooling requirements together. When zones with different cooling/heating requirements are connected to the same outdoor section, consider units that are capable of providing simultaneous heating and cooling. Examples of zones that may require simultaneous heating and cooling when combined are interior and exterior zones;

exterior zones with different exposures; and zones requiring comfort cooling with rooms requiring close environmental control.

Units capable of providing simultaneous heating and cooling are not available in smaller sizes (e.g., capacities below 6 tons [21 kW]).

Minimum Outdoor Air Temperature

Using VRF heat pump units for heating and cooling can increase building energy efficiency, especially when the heating obtained from the heat pump mode replaces an electric resistance heating coil. Most VRF units provide higher heating capacities than conventional DX heat pumps at low ambient temperatures. The designer must evaluate the heat output for the units at the outdoor design temperature. Manufacturers indicate the heating capacities at catalog minimum outside temperature, after which point, a low ambient kit is sometimes offered as an option. When the outdoor temperature drops below the temperature indicated in the catalog, the heating output from the heat pump cycle decreases. Supplemental heating should be

Sizing Example 1

Peak cooling load for Zone 1: 3 ton
Peak cooling load for Zone 2: 2.5 ton
Peak cooling load for Zone 3: 4 ton
Zones peak load = 3 + 2.5 + 4 = 9.5 ton
Building peak load: 7.0 ton
Available sizes for outdoor unit: 7.5 ton and 10 ton
Selection: Unless additional indoor units are planned for the future, select a 7.5 ton outdoor section.

Sizing Example 2

Consider a space comprised of three rooms with the cooling and heating loads as follows:

Room 1:

Required cooling load: 23,500 Btu/h

Required heating load: 26,000 Btu/h

Room 2:

Required cooling load: 24,000 Btu/h

Required heating load: 29,000 Btu/h

Room 3:

Required cooling load: 35,500 Btu/h

Required heating load: 29,000 Btu/h

Available Capacities for Indoor Units:

Unit 1: 24,000 Btu/h cooling, 27,000 Btu/h heating

Unit 2: 27,000 Btu/h cooling, 30,000 Btu/h heating

Unit 3: 36,000 Btu/h cooling, 40,000 Btu/h heating

Selection:

For Room 1, the cooling and heating requirements can be achieved by specifying Unit 1.

For Room 2, although cooling load can be met by using Unit 1, the heating load can only be achieved by using Unit 2. Based on this selection, the electronic expansion valve needs to modulate down, even during peak cooling.

For Room 3, the cooling requirement is dominant in this case and Unit 3 will be used.

considered when the heating capacity of the VRF units is below the heating capacity required by the application. Sequence of operation and commissioning must specify and prevent premature activation of supplemental heating.

Power and Accessibility

Power and accessibility are required for all system components, including evaporators, outdoor condenser, branch selector, and condensate drain pumps (where applicable).

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Unit Selection and System Layout

The complete specification of a VRF system requires careful planning. Each indoor section is selected based on the greater of the heating or cooling loads in the area it serves. In cold climates where the VRF system is used as the primary source for heating, some of the indoor sections will need to be sized based on heating requirements. Once all indoor sections are sized, the outdoor unit is selected based on the load profile of the facility (Example 2). When indoor sections are greatly oversized, the modulation function of the expansion valve is reduced or entirely lost. Most manufacturers offer selection software to help simplify the optimization process for the system's components.

Installation

The installer must be familiar with the system components and the installation requirements. Refrigerant pipes must remain clean, dry, and leak free. When stored prior to installation, the edges of refrigerant pipes need to be sealed. Nitrogen gas must be used during welding to prevent oxidation of the interiors of refrigerant pipes. A detailed installation manual must be followed. The installer should be familiar with the control options available for VRF systems. For example, each individual indoor unit can be controlled by a programmable thermostat or a multiple indoor units serving the same zone can be controlled by the same thermostat. Most VRF manufacturers offer a centralized control option, which enables the user to monitor and control the entire system from a single location or via the Internet.

Many manufacturers offer courses for installers regarding system installation. Unfortunately, differences in the installation requirements vary greatly between manufacturers, so installers must become familiar with each system.

Commissioning

Additional procedures must be added to the typical commissioning plan required for unitary air conditioning and heat pump systems. Examples of additional steps are:

- Verification of the proper operation of the electronic expansion valves;
- Ensuring thermostats capability of fully modulating their indoor units;

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- Capability of an outdoor section to provide adequate cooling and heating capacities at specified peak loads;
 - Capability of an outdoor section to provide cooling and heating capacities at extreme outdoor air temperatures; and
 - Self diagnostics features for the system should be checked at various conditions.

When a single VRF system is installed in phases, the entire system should be commissioned upon the completion of the installation.

Operation and Maintenance Manuals

The O&M manuals should include information for all units including wiring diagrams, troubleshooting and preventive maintenance procedures, spare parts, etc. As-built drawings should indicate locations of all system components.

VRF Limitations

VRF systems are not suitable for all applications. Some limitations include:

- There is a limitation on the indoor coil maximum and minimum entering dry- and wet-bulb temperatures, which makes the units unsuitable for 100% outside air applications especially in hot and humid climates.

- The cooling capacity available to an indoor section is reduced at lower outdoor temperatures. This limits the use of the system in cold climates to serve rooms that require year-round cooling, such as telecom rooms.
- The external static pressure available for ducted indoor sections is limited. For ducted indoor sections, the permissible ductwork lengths and fittings must be kept to a minimum. Ducted indoor sections should be placed near the zones they serve.

Conclusion

VRF systems offer controls that match the space heating/cooling loads to that of the indoor coil over a range of operation. Variable speed compressors and fans in the outdoor units modulate their speed, saving energy at part-load conditions. Outdoor sections should be sized to match building peak loads, not the sum of the peak load for each zone, reducing the capacity of outdoor units when compared to a conventional unitary system. The system offers designers and occupants the ability to choose multiple individualized zones, which improves system controllability. The system capabilities and limitations should be evaluated carefully to determine the suitability of the VRF for a project and to optimize its design.●

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