Variable-refrigerant flow (VRF) systems are a type of direct-expansion heat-pump system in which multiple indoor units can be connected to a common condensing unit, either air- or water-source, via a refrigerant piping network. These indoor units, which can be ducted or ductless, are sized for the peak cooling or heating load of the zones they condition, while the condenser system is sized for the highest block (simultaneous) cooling or heating load.

VRF systems also have the ability to connect a total indoor unit capacity that exceeds 100% of the condenser system rating, known as the “connection ratio.” This can be accomplished because indoor loads in comfort-cooling applications will shift throughout a building or space throughout the day. This shift is affected by changes in occupancy, orientation of the building, equipment use, location of zones, etc. This is what is referred to as the “block load,” which by definition is the “largest sum of all simultaneously occurring zone loads.”

VRF systems are available in heat-pump and heat-recovery applications. In the heat-pump application, the total system will operate in a common mode of operation that is determined by a “master” indoor unit or remote controller. Each individual indoor unit can have individual setpoints and can be controlled to operate independently of one another based on their setpoint and measured room/return for their zone or room.

For buildings that require cooling and heating simultaneously, the VRF heat-recovery application is also available. What typically required a secondary heat source (electric/hydraulic reheat or perimeter heating), can be accomplished by VRF heat recovery, as it transfers heat absorbed from areas of the system operating as cooling, to areas of the system operating in heating through the use of a heat-recovery unit.

VRF systems offer highly efficient, scalable systems that provide varying levels of end-user controllability and flexibility.

VRF system operation overview

VRF systems utilize inverter-driven compressors, which vary compressor(s) speed and refrigerant mass flow. Ultimately, compressor speed is based on total system operating conditions. This allows the compressor to operate at reduced speed/capacity during times when the actual load is less than the peak compressor capacity, which helps improve efficiencies compared to conventional systems and reduces energy consumption during part load conditions. The speed of the compressor is determined by the high- and low-side saturation temperature and pressure, as well as how far they are from the predetermined target values determined by the units control-board logic. In the cooling mode, the
target evaporation saturation temperature is about 43°F, and in heating mode the target condensing temperature is about 115°F. The deviation of these values from target, combined with mode of operation and several other operating parameters is what generally determines compressor speed.

Capacity is controlled at the indoor units as well. The indoor coils utilize electronic expansion valves that can modulate in steps between fully open and fully closed to reach the desired opening percentage. These expansion valves modulate the amount of refrigerant through the indoor unit’s coil based on the room setpoint, actual return- or room-air temperature (measured through either a return-air sensor in the unit or at the remote controller, if available), superheat at the coil (if in cooling mode) or subcooling at the coil (if in heating mode).

When the indoor units are under high-load conditions, they can modulate the expansion valves near the full open position to increase refrigerant flow and bring the room back to the temperature setpoint with only a minor pull-down/warm-up period. The compressor(s) would ramp up their speed to make sure that enough refrigerant was flowing for the indoor units to use. Conversely, as the indoor units bring their rooms closer to setpoint, the expansion valves will throttle closed, reducing the indoor unit’s capacity. This avoids the short cycling, temperature swings and poor dehumidification associated conventional equipment during lower load conditions. In general, most VRF systems can maintain a room or return-air temperature of ±1°F deviation from setpoint if sized, installed and configured correctly.

Defrost control
While operating in the heating mode, all air-source heat pumps will start to accumulate frost buildup. The rate this accumulation varies based on outside dry-bulb and wet-bulb temperature. To combat this, all air-source heat pumps must initiate some type of defrost cycle. The defrost cycle, which
The first step to applying VRF systems for heating applications is to determine whether the cooling load or heating load is dominant, and what the outdoor design conditions are for the building’s location.

Some air-source VRF systems do not require the entire condenser section to switch to defrost mode simultaneously, but instead may opt to defrost sections of the condenser coil at a time. While this may not allow the system to maintain full heating capacity, it does prevent low-temperature refrigerant from circulating to the indoor units. Defrost operation is not required for water-source VRF systems.

VRF for heating applications: performance/efficiencies

VRF systems possess and are able to maintain higher heating capacities and coefficients of performance (COP) at rated outdoor conditions when compared to conventional heat pumps.

The first step to applying VRF systems for heating applications is to determine whether the cooling load or heating load is dominant, and what the outdoor design conditions are for the building’s location. This will be used in determining the nominal capacity of the condensing unit for the system.

Figure 3 compares the heating capacities of a 20-ton VRF system to a package rooftop heat-pump system. Not only does the VRF system begin with a higher heating capacity, it also maintains that higher capacity at lower outdoor temperatures,
with published capacity ratings for many VRF systems measured as low as -13°F wb.

VRF systems are more than capable of successfully handling the heating load of a building during very low outdoor temperatures when the system is sized and designed properly. However, designing a VRF system around heating in an area with very low design outdoor temperatures can lead to a system that is oversized in cooling. The larger refrigerant charge may cause challenges for the designer who has to ensure the design is code compliant in regard to Refrigerant Concentration Limits.

One way to minimize the impact of outdoor temperature on system capacity is to install an air-cooled VRF system inside, or the designer can select a water-source VRF system and use a boiler loop to add heat to the VRF system for use in a geothermal application. Regardless of installation location, provisions must be provided for snow levels or condensate disposal with air-source equipment.

**Integrating with additional heat sources**

Depending on the particular project that the VRF system is being applied to, it may be necessary to integrate with an additional heat source, such as electric heaters, steam or hydronic heating systems, and terminal units. VRF manufacturers provide the ability to do this via adapter boards that are installed at the indoor units to control additional heat sources (see the example in Figure 4). There is also the option to lock out the heating operation of a VRF system at...
the condensing-unit section using a dry contact that can be part of an ambient thermostat or summer/winter switch, or through the unit’s outdoor-temperature thermistor.

A commercial building in a cold climate where building management may not provide primary heat until mid-October is one example where this would be seen. The VRF system can be relied on for heating prior to the primary heating start-up date. Once the heating plant is operational, the heat pump operation can be locked out. The VRF indoor-unit controls could still control the external heat sources even during the heat-pump lockout, reducing the need for secondary thermostats and controls.

Another example would be an application where the VRF system is used for heating down to a certain outdoor temperature, say 35°F. At this specified temperature, the VRF system can lock out the heating mode and allow for the use of an additional heat source. This can allow the designer to reduce the size of the VRF system and, depending on energy costs for the area, can allow the building to operate based on its most economical fuel source.

Project examples
Owners of the KEL Building in Edmonton, CA decided to install an air-sourced VRF heat-recovery system with nine zones and 25 indoor units. The system had to meet all the heating/cooling requirements of the office building portion as well as attic server room. The outdoor design temperature for Edmonton for heating is -27°F.
The VRF condensing unit (two modules) is located in a small mechanical room that is equipped with dampers to effectively manage the condition in which the air-cooled units are operating. When the outdoor temperature is above 32°F, the dampers to the outside open; when the temperature is below 32°F, the outside air dampers close and dampers to an inside warehouse open. The warehouse is equipped with unit heaters to maintain a space temperature of 50°F (see Figure 5).

Another example resides at the Sorrentino’s Compassion House in Edmonton, CA. Here, a water-source VRF heat-recovery system was selected for use in a 6,000-sq-ft addition that required very tight and individual temperature control for each room, stringent sound level requirements, and a minimal footprint.

The Sorrentino’s Compassion House addition is served with two 7-ton water-source VRF heat-recovery systems and 14 ducted indoor units. A wall-hung condensing boiler and small, outside fluid cooler make up the auxiliary system to support the VRF system (i.e. heat augmentation for the winter and heat rejection for the summer).

Conclusion
This article has reviewed the basic operation and application of VRF systems for use in heating applications, where they may be the sole heat source or be integrated to operate in conjunction with an additional heat source. For more information, refer to the manufacturers websites and training classes.

Bill Artis Leed AP BD+C, is a Project Engineer at Daikin Applied, and can be contacted at william.artis@daikinapplied.com. For more information, visit www.daikinapplied.com.

Michael Beblo holds the Red Seal as Refrigeration & Air Conditioning Journeyman Mechanic as well as an HVAC Diploma. He has taught HVAC for 28 years at the Northern Alberta Institute of Technology and is currently a Technical Consultant to an engineering design company as well as VRF equipment rep firm.

See the heat™ and see why at www.flir.com/hvacr