Variable Refrigerant Flow Systems

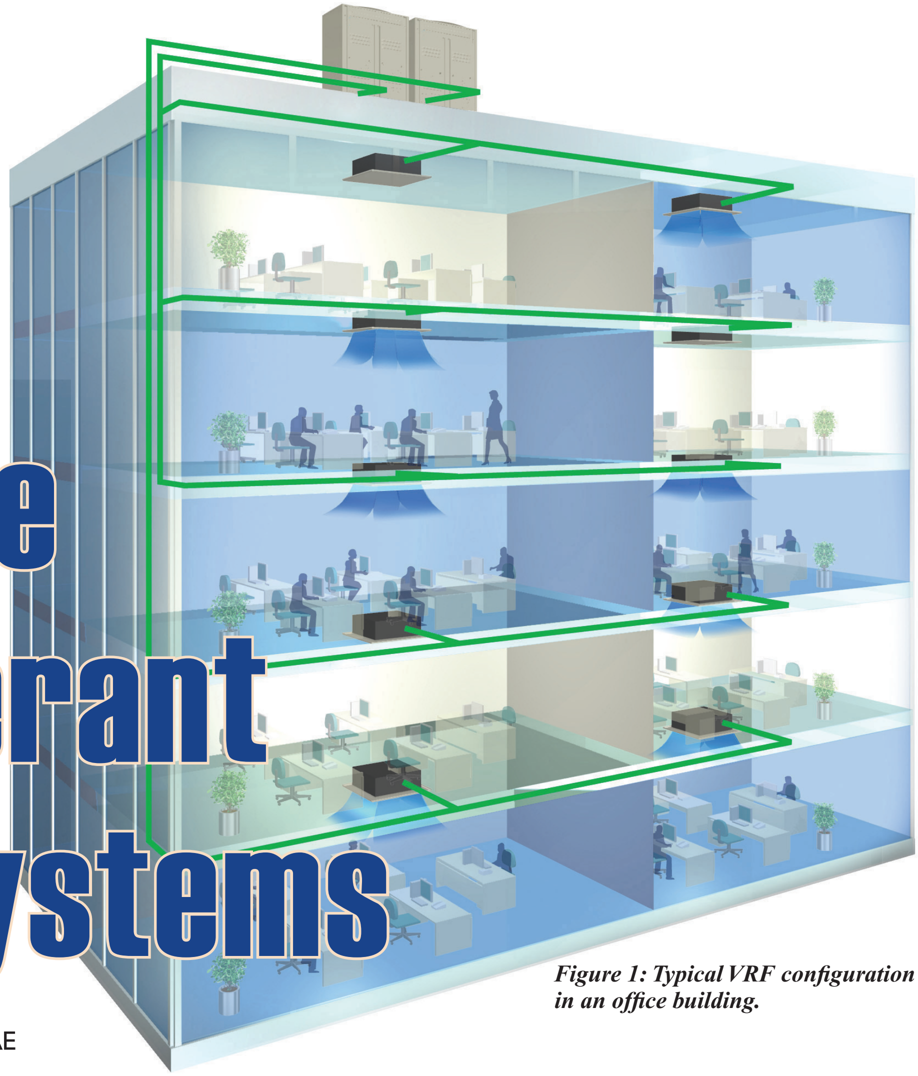

Figure 1: Typical VRF configuration in an office building.

By William Goetzler, Member ASHRAE

Variable refrigerant flow (VRF) systems, which were introduced in Japan more than 20 years ago, have become popular in many countries, yet they are relatively unknown in the United States. The technology has gradually expanded its market presence, reaching European markets in 1987, and steadily gaining market share throughout the world. In Japan, VRF systems are used in approximately 50% of medium-sized commercial buildings (up to 70,000 ft^2 [6500 m^2]) and one-third of large commercial buildings (more than 70,000 ft^2 [6500 m^2]).[1]

Although vigorous marketing of VRF systems in the U.S. began only two to three years ago, several thousand systems likely will be sold in the U.S. this year, amounting to tens of thousands of tons of capacity. Of course, the market is still very small compared to the chiller market, but VRF systems are marketed in the U.S. by at least five manufacturers.

The success of the VRF in other countries, and its historically limited market presence in the U.S., has several sources, including:

- Differences in construction practices;
- The long history and large installed base of ducted direct exchange (DX) systems and chillers in the U.S. compared, for example, to Europe, where many buildings did not have air conditioning until recent decades;
- Differences in regulatory environment (e.g., regulations that discourage electric chiller installations in Japan); and
- VRF technology has been developed and promoted by Asian companies, which had limited market presence in the U.S. until recently. Also, building owners are wary of HVAC suppliers whose parts availability, service and technical support infrastructure is uncertain.

What is VRF?

Many HVAC professionals are familiar with ductless minisplit products. A varia-

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tion of this product, often referred to as a multisplit, includes multiple indoor evaporators connected to a single condensing unit. Ductless products are fundamentally different from ducted systems in that heat is transferred to or from the space directly by circulating refrigerant to evaporators located near or within the conditioned space. In contrast, conventional systems transfer heat from the space to the refrigerant by circulating air (in ducted systems) or water (in chillers) throughout the building.

VRF systems are larger capacity, more complex versions of the ductless multisplit systems, with the additional capability of connecting ducted style fan coil units. They are inherently more sophisticated than multisplits, with multiple compressors, many evaporators, and complex oil and refrigerant management and control systems. They do not provide ventilation, so a separate ventilation system is necessary.

The term variable refrigerant flow refers to the ability of the system to control the amount of refrigerant flowing to each of the evaporators, enabling the use of many evaporators of differing capacities and configurations, individualized comfort control, simultaneous heating and cooling in different zones, and heat recovery from one zone to another. This refrigerant flow control lies at the heart of VRF systems and is the major technical challenge as well as the source of many of the system's advantages. *Figure 1* illustrates a standard VRF configuration, while *Figure 2* shows a heat recovery unit providing simultaneous heating and cooling.

VRF Benefits

VRF systems have several key benefits, including:

- **Installation Advantages.** Chillers often require cranes for installation, but VRF systems are lightweight and modular. Each module can be transported easily and fits into a standard elevator. Multiples of these modules can be used to achieve cooling capacities of hundreds of tons. Each module (or set of two) is an independent refrigerant loop, but they are controlled by a common control system. The modularity also enables staged, floor-by-floor installations, for example, if a building is only partly occupied, which is similar to currently available self-contained VAV systems. The relatively light weight of the system also may reduce requirements for structural reinforcement of roofs. Because ductwork is required only for the ventilation system, it can be smaller than the ducting in standard ducted systems, reducing building height and costs.

  In cases where operable windows are present and meet code requirements for ventilation, VRF systems are also particularly suitable for retrofitting historical buildings without disturbing the structure or for older buildings with no air conditioning. Finally, because the condensing units are normally placed outdoors, no need exists for a machine room.
- **Design Flexibility.** A single condensing unit can be connected to many indoor units of varying capacity (e.g., 0.5 to 4 tons [1.75 to 14 kW]) and configurations (e.g., ceiling recessed, wall-mounted, floor console). Current products enable up to 20 indoor units to be supplied by a single condensing unit. Modularity also makes it easy to adapt the HVAC system to expansion or reconfiguration of the space, which may require additional capacity or different terminal units.
- **Maintenance and Commissioning.** VRF systems with their standardized configurations and sophisticated electronic controls are aiming toward near plug-and-play commissioning. Because they are DX systems, maintenance costs for a VRF should be lower than for water-cooled chillers, so water treatment issues are avoided. Normal maintenance for a VRF, similar to that of any DX system, consists mainly of changing filters and cleaning coils. However, chillers, which often operate for 20 to 30 years, normally would be anticipated to have a longer life expectancy than a DX system such as a VRF.[2] The large number of compressors in a VRF may create a higher probability of compressor failure, although the redundancy also leads, in many cases, to a greater ability to continue to occupy the space while repairs are made.
- **Comfort.** Many zones are possible, each with individual setpoint control. Because VRF systems use variable speed compressors with wide capacity modulation capabilities, they can maintain precise temperature control, generally within ±1°F (±0.6°C), according to manufacturers' literature.
- **Energy Efficiency.** The energy efficiency of VRF systems derives from several factors. The VRF essentially eliminates duct losses, which are often estimated to be between 10% to 20% of total airflow in a ducted system.[3] VRF systems typically include two to three compressors, one of which is variable speed, in each condensing unit, enabling wide capacity modulation. This approach yields high part-load efficiency, which translates into high seasonal energy efficiency, because HVAC systems typically spend most of their operating hours in the range of 40% to 80% of maximum capacity.

  At the present time, no ARI-certified rating system exists for measuring the efficiency of a VRF system, so simple EER comparisons to other systems can not be quoted here. A careful review of all engineering data must be performed to make accurate, quantitative comparisons.

For buildings requiring simultaneous heating and cooling, heat recovery VRF systems can be used. These systems circulate refrigerant between zones, transferring heat from the indoor units of zones being cooled to those of zones being heated. Each manufacturer has its own proprietary design, but most use a three-pipe system (liquid, suction and discharge) and special valving arrangements. Typically, extra heat exchangers in distribution boxes are used to transfer some reject heat from the superheated refrigerant exiting the zone being cooled to the refrigerant that is going to the zone to be heated.

The modularity of the VRF also enables relatively simple submetering of electricity (i.e., placing an electric meter on one or a few condensing units is relatively simple, accurate and inexpensive, whereas metering chilled water or refrigerant is more complex). Though difficult to quantify, submetered VRF systems may encourage energy-saving behavior in multitenant buildings if energy costs are charged explicitly to each tenant rather than being hidden in overall leasing costs.

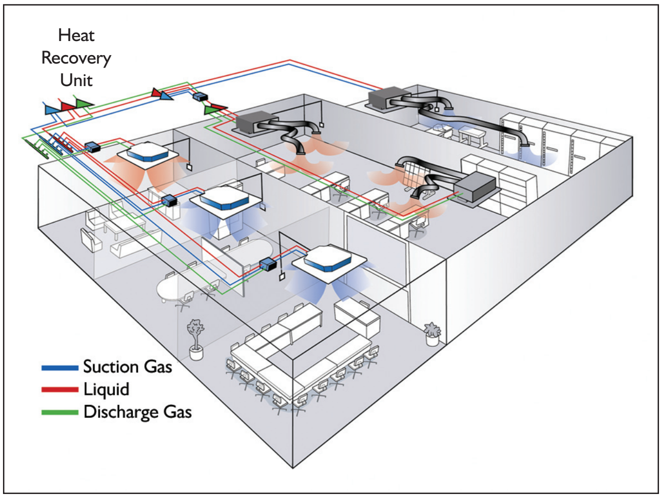

Figure 2: Heat recovery VRF system.

First Costs

As with chilled water systems, installed costs for VRF systems are highly variable, project dependent, and difficult to pin down. Total installed costs for VRF systems are estimated by some sources to be 5% to 20% higher than for chilled water systems providing equivalent capacity,[2] but actual costs are highly project dependent. The same reference describes a 100,000 ft^2 (9300 m^2) office building project in Brazil where the VRF system was approximately 15% to 22% more expensive than a comparable chilled water system, but notes that the cost was skewed by the high import tariff on the VRF. Also cited is a 43,000 ft^2 (4000 m^2) German hotel where the VRF was approximately equivalent in price to an air-cooled screw chiller system. Equipment costs in the U.S. would probably be similar to those in Europe. However, at the present time, American contractors would likely bid a higher installation cost than their European counterparts because they are less familiar with the product and need to build in a larger contingency. As their experience and comfort level with the product increases, installation costs should converge. A comparison done by a VRF manufacturer of a 200 ton (700 kW) VRF to both air- and water-cooled chillers in a U.S. application also showed an installed cost premium of approximately 5% to 20% for the VRF, but this was based on expected, rather than actual, costs.[1]

All these estimates apply to new construction. Replacing a chiller and air-handling unit with another chiller and air handler normally will be much less expensive than replacing it with a VRF and ventilation system. The major cost issue is that a VRF would need new refrigerant piping while the chiller already would have its water piping installed.

In summary, it is likely that, at present, in the U.S., a VRF system would involve a cost premium over a chiller in applications where the VRF is competitive. In some cases, where chiller installations are particularly problematic (e.g., if access for installing a new chiller requires major expense or demolition, if water piping is deteriorating and difficult to access for repair) the VRF may have the lowest installed cost. In many others, the VRF will not be suitable at all.

Energy Efficiency

As with installed costs, the energy efficiency of VRF systems is application dependent. Both field tests and simulations can be skewed by factors such as climate or the choice of baseline systems for comparison.

For example, one article cited an installation in a government building where much of the space is unoccupied during much of the day when workers are out in the field.[4] A rooftop VAV was used on one side of the building and a VRF on the other. The energy consumption of the VRF was approximately 38% lower than for the VAV. However, other project details, including the baseline system efficiency, were not published.

The general applicability of simulations also can be questionable, due to the many different scenarios encountered in the real world, and the limitations of current simulation tools.

A full year, hourly simulation, using standard spreadsheet software, of a 538 ton (1892 kW) VRF compared to both screw and centrifugal chillers yielded high energy savings for the VRF relative to the other options.[5] The cooling energy savings of about 30% may be explained by the relatively temperate Brazilian climate. Another recent simulation compared a state-of-the-art 200 ton (700 kW) VRF system to both an air-cooled screw chiller and a water-cooled chiller.[1] The highest efficiency, newest R-410a VRF system achieved energy savings of 30% to 40% compared to the chillers, but an older R-22 VRF system showed little or no savings compared to the chillers. The VRF system savings are due to their high part-load efficiency. The improved efficiency of the newest VRF systems compared to older generations is due to component changes such as variable speed fan motors and compressors that use ECM motors. The chiller efficiency is higher than that of the VRF only at >90% load, but 80% of the chiller operating hours occurred at 45% to 80% load. Variable speed compressors in chillers are now common, but other components such as pumps are often single speed.

Applications

VRF systems are generally best suited to buildings with diverse, multiple zones requiring individual control, such as office buildings, hospitals, or hotels. A VRF system does not compete well with rooftop systems in a large low-rise building such as a big box retail store. Although VRF heat pumps operate at ambient temperatures as low as 0°F (–18°C), as in all heat pumps, their efficiency drops off considerably at low temperatures, so they are less cost effective compared to gas heating in very cold climates.

Market Acceptance Issues*

Previous studies,[2] recent experience in marketing the VRF, as well as focus groups conducted with engineers, contractors, and facility managers, have revealed several important concerns regarding the application of VRF systems in the U.S. As manufacturers have intensified their education and training efforts to address these concerns, and have explained some of the technical features of the VRF that address these issues, many of these concerns have been alleviated.

Lack of Awareness of Energy Efficiency Advantages. Most industry professionals refer only to EER or kW/ton ratings when considering efficiency. The more subtle energy efficiency advantages of VRF systems, such as the reduction in duct losses, the ease of electrical submetering, and even the higher part load efficiency, frequently are overlooked. Engineers rarely have the time and inclination to undertake complex building energy simulations, and current non-proprietary tools such as Energy Plus cannot address VRF systems. Furthermore, ARI has not yet established a certification program for VRF system performance, although it is expected by 2008.

First Cost. In many cases, the initial cost of a VRF system is higher than that of a chilled water system, water source heat pump, or rooftop DX system. Building owners often have no incentive to accept higher first costs even if the payback period is short, and they can be skeptical of energy savings predictions. While a VRF may be cost competitive for new construction, in a chiller replacement situation with existing water piping, replacing the chiller would normally be less expensive than installing a VRF.

Gas Heating for Cold Climates. Currently available VRF systems have no integrated gas heating option. This factor hampers their acceptance in cold climates for buildings with substantial heating loads. Integration of the VRF with hydronic heating works well and is sometimes done when such systems already exist. However, using gas or oil heating with a VRF requires a separate furnace or boiler, which is more expensive than a gas-fired rooftop system or a chiller/boiler system.

Refrigerant Piping. Contractors are concerned about long refrigerant piping runs for several reasons. They believe that compliance with ANSI/ASHRAE Standard 15-2001, *Safety Standard for Refrigeration Systems,* is difficult. Long refrigerant lines also raise the specter of refrigerant leaks, which can be difficult to find and repair, particularly in inaccessible spaces. These are legitimate concerns, but they can be overcome.

*Some of the information in this section is derived from Reference 2.

Compliance with Standard 15-2001 is accomplished in the same manner as with any DX system. The total refrigerant charge in the refrigerant loop must be within the limits prescribed by Standard 15-2001 for the smallest zone served by the system to ensure the safety of occupants if the entire charge is released. In practice, the charge in a single system's refrigerant loop (condensing unit and multiple fan coil units) is usually not problematic, except when serving relatively small spaces. In those cases, one solution is to use a single fan coil unit for multiple rooms, with ducting to each room. In that case, the space to be considered in the safety calculation is the total space of the multiple rooms served by the fan coil unit. Other suitable design approaches also exist. Compliance with Standard 15-2001 can be achieved through careful system design.

Minimization of leaks is also critical. VRF manufacturers have developed products and protocols to address this concern. Typically, all joints are brazed joints with no flared fittings. Headers and splitters are specifically designed for the product and do not require flaring or changing wall thicknesses. Contractor training includes protocols that require pressure testing of each refrigerant circuit during commissioning.

Long refrigerant piping loops also raise concerns about oil return, and VRF products are designed to ensure proper oil return. Typically, each compressor has its own oil separator, which is optimized for the VRF system. Periodically, the VRF goes into oil retrieval mode, during which time the thermostatic expansion valve opens, and the compressor cycles at high pressure to flush oil out of any locations where it has accumulated.

Manufacturer Support. VRF systems were introduced by Japanese companies with limited presence in the U.S., particularly in the large commercial HVAC market. In the past, they have had limited sales and support for these products in the U.S. Today, however, at least five manufacturers offer VRF systems in the U.S., and several acquisitions involving U.S. and Japanese manufacturers in recent years also should reduce this concern.

Code Compliance Issues Specific to the U.S. Europe and Japan, where VRF systems are widespread, have code requirements analogous to Standard 15-2001 and ANSI/ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality,* and VRF installations are engineered to meet those requirements.

Future Directions

VRF manufacturers will target several additional challenges over the next few years.

- **ARI Rating Standard.** Currently, no approved ARI standard exists for a performance rating of VRF systems. Consequently, manufacturers need to apply for waivers from the Department of Energy to market their products in the U.S. Although these waivers have been granted, new applications need to be submitted for new product groups. Furthermore, an ARI standard will enable stakeholders to compare different manufacturers' products more accurately and will provide them with a greater comfort level with the products. A draft provisional standard is under review with final publication expected in 2008.

- **Energy Modeling Tools.** Current, non-proprietary building energy simulation tools like Energy Plus and DOE-2 cannot model VRF systems. Manufacturers are working to resolve this issue. In the meantime, only proprietary tools are available, which some stakeholders view with skepticism.
- **Integration of Outside Air.** 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 and economizing, while optimizing overall performance.
- **Broaden Installer Base.** The shortage of skilled installers is problematic for the HVAC industry as a whole, but expanding the number of installers who are comfortable with extensive refrigerant piping work is particularly critical for the VRF market.

Conclusions

VRF systems are not suitable for all commercial building applications. However, they are an excellent option for certain projects, and one more tool for engineers to consider. As more VRF units are installed and we gain further operating experience in the U.S., many of the concerns expressed by industry professionals are likely to diminish.

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Acknowledgments

Figures 1 and *2* are from Daikin Industries, Ltd.

Advertisement formerly in this space.