Advanced Heating Technology:

Applying VRF in Cold Climates

White Paper
May 2016

MITSUBISHI ELECTRIC
COOLING & HEATING

Every year the seasons come and go. Predictability can be helpful, but seasonal challenges themselves can be plentiful and tedious. Winter arrives with its cold temperatures and disruptive precipitation. When it comes to heating our spaces – from office buildings to schools to health and wellness facilities – the challenge is to not just get the heating we need, but to do it effectively and efficiently.

Historically, heating in cold climates has put industry professionals to the test. Many heating systems don't perform as the temperature drops, causing end users to rely on auxiliary heat, and often on fossil fuels. These are both things an energy- and money-conscious market is looking to move away from.

Heating in cold climates has also required clever product design and development. Heat pumps, for example, have historically been troublesome in extreme cold climates. Below 17 degrees Fahrenheit, an auxiliary heat system, such as a gas-fired boiler, was needed. In many places throughout the country electricity was a much more accessible, affordable fuel than gas. The result was a technological gap – the need for heat pumps that could operate in even the coldest weather.

Today, those heat pumps exist. Advanced heating technology was developed to address these very issues, and heat pumps can now offer impressive performance in even the coldest climates – with no need for auxiliary heat. Heat pumps with advanced heating technology save end users energy and money. This is excellent news for the building professionals who get called in winter after icy winter to solve cold-climate heating challenges.

VRF – A Brief Overview

The U.S. Energy Information Administration claims that as much as 40 percent of a building's operating costs are tied to HVAC and other mechanical systems. It's important to minimize operating costs while achieving other goals like reliable performance, a modern appearance and personalized comfort. Variable Refrigerant Flow (VRF) is an HVAC technology that minimizes operating costs. It makes the most of square footage and budget while offering energy-efficient technology that provides superior occupant comfort.

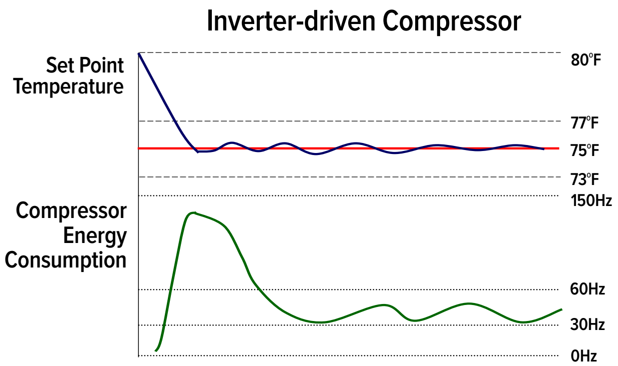
VRF achieves such success by dividing a building's interior into zones, each of which can be operated separately. This is possible because of the outdoor units' inverter-driven compressor that varies its motor rotation speed, allowing it to precisely meet each zone's conditioning requirement while reducing overall power consumption. For VRF with heat recovery, one room can even be cooled while another is simultaneously heated. In this case the system's total capacity is distributed to each indoor unit via a branch circuit controller. The result is personal comfort control for occupants.

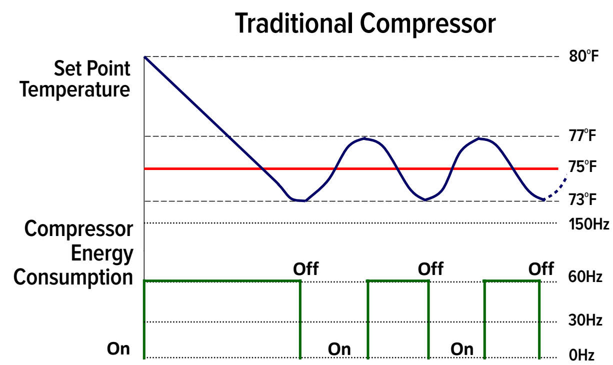
This is not a new technology. VRF has been used throughout the world since the 1980s. In many countries, it is the most-used HVAC technology: for example in Japan VRF represents approximately 90 percent of installed systems within commercial buildings, Europe 81 percent and China 86 percent. VRF for commercial applications was introduced to the U.S. market in 2003. Since then, there have been major improvements in the performance of the inverter-driven compressor, including improved energy efficiencies and reduced operational noise. There have also been major improvements in heating capabilities.

The result for today's end user includes:

1 Precise temperature control.

Fixed-speed compressors in conventional HVAC systems are either running at full power or are off. In the U.S., a zone exhibits partial-load conditions more than 90 percent of the time. Conventional systems cannot handle these partial load requirements, resulting in energy fluctuations and poor set point satisfaction. VRF offers full-range variable capacity to deliver only the amount of conditioning to match a zone's cooling or heating demand. Working in tandem with integrated controls and sensors that measure loads for each zone, the compressor seamlessly adjusts speeds to maintain the desired zone temperature. This function, along with a low-profile ducted or ductless design, typically increases energy efficiency about 25 percent over conventional ducted systems, partly due to the energy lost by forcing air through ductwork.

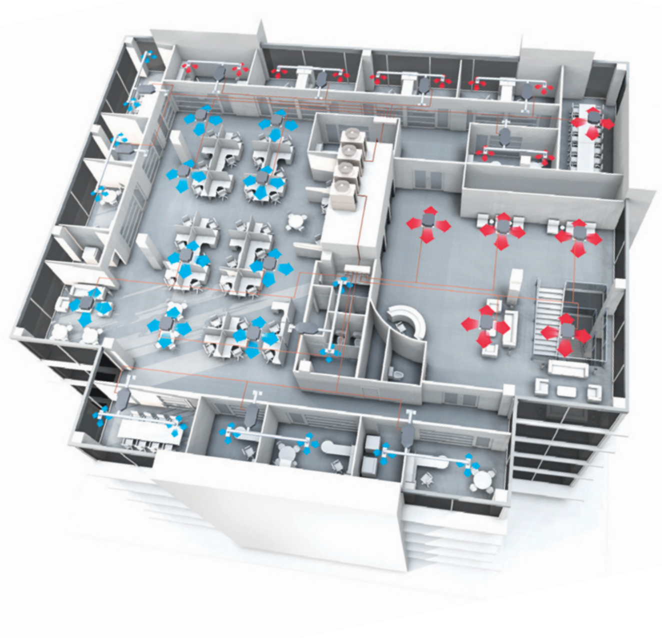




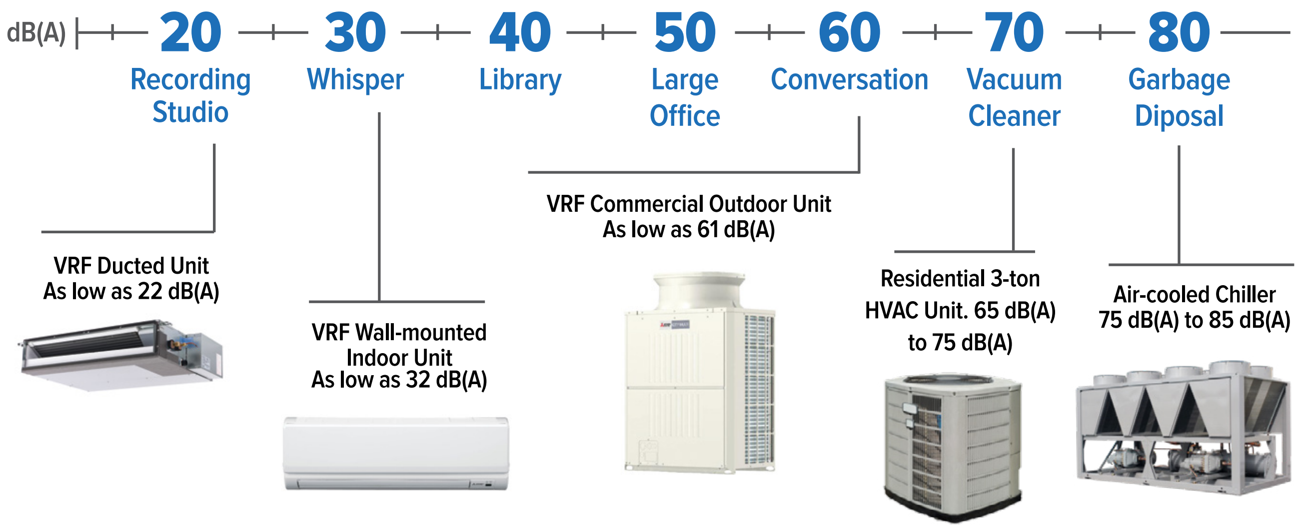
As a result, VRF can help facilities meet Green Globes and Leadership in Energy & Environmental Design (LEED®) requirements, and achieve the highest Integrated Energy Efficiency Ratio (IEER) ratings.

2 Elimination of hot and cold spots.

Just because a building is located in a cold climate doesn't mean that every occupant requires the same temperature for their space. Maybe one side of an office building gets ample sunlight and actually needs cooling during the winter. Perhaps a health clinic or school with areas for both active and inactive occupants needs a mix of temperatures. In these situations, VRF's ability to treat hot and cold spots via zoning capabilities and simultaneous cooling and heating ensures everyone's comfort.



3 **Quiet operation.** VRF operates at whisper–quiet levels. This is no exaggeration: Whispers come in at 35 decibels; VRF indoor units have a lower decibel rating – for some brands, between 19 and 34 decibels.



With so much to offer, it's no surprise that much of the world has taken to VRF. Now that advanced heating technology makes VRF an appealing choice in even the coldest climates, let's explore the application possibilities.

Advanced Heating Technology: What Is It and How Does It Work?

There is currently no industry–wide definition of advanced heating technology since it is relatively new and only some VRF manufacturers offer it. Among those who do, a general definition of the technology is the ability to provide full rated heating capacity at zero degrees Fahrenheit (or below depending on the manufacturer) and offering substantial heating capacity at minus 13 degrees Fahrenheit.

How is that possible? As the outdoor temperature drops below freezing, heat pumps traditionally faced decreased performance as the rate of the refrigerant flow circulating through the system dropped, reducing the amount of heat generated. Advanced heating technology solves that problem via a 'flash injection circuit,' or by injecting a portion of the refrigerant into the compressor at a lower temperature than normal[1], reducing the temperature inside the compression chamber. With the compressor running at higher speeds than normal, the system can maintain a high heating capacity despite colder outdoor temperatures. This process is typically used in units over 24,000 Btu/h of capacity, and kicks in automatically when the ambient temperature drops below 25 degrees Fahrenheit.

[1] The refrigerant temperature is decreased when it bypasses the outdoor coil and recollects heat energy in a heat exchanger.

A further breakdown

1 Outdoor unit in heating mode sends superheated gas to indoor unit.

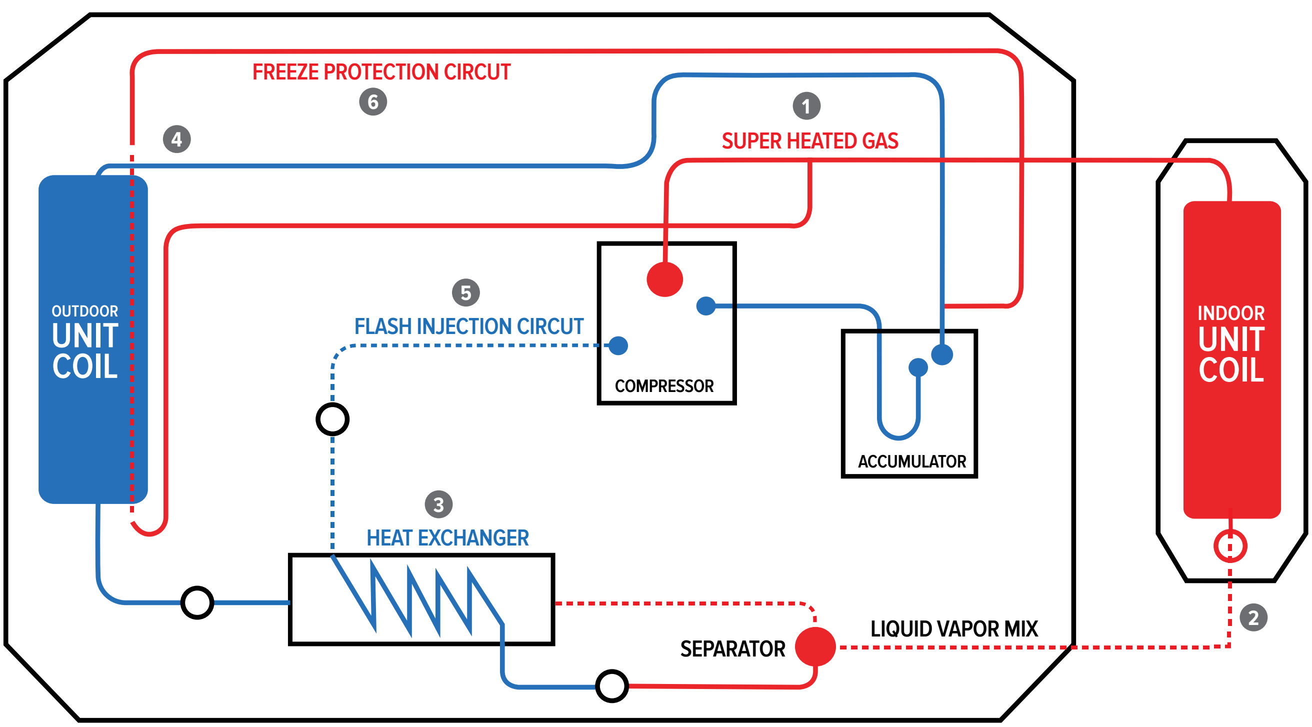
2 Gas becomes liquid/vapor mix inside indoor unit and migrates to the separator.

3 Heat exchanger pulls remaining heat from liquid/vapor mix; mix becomes subcooled liquid.

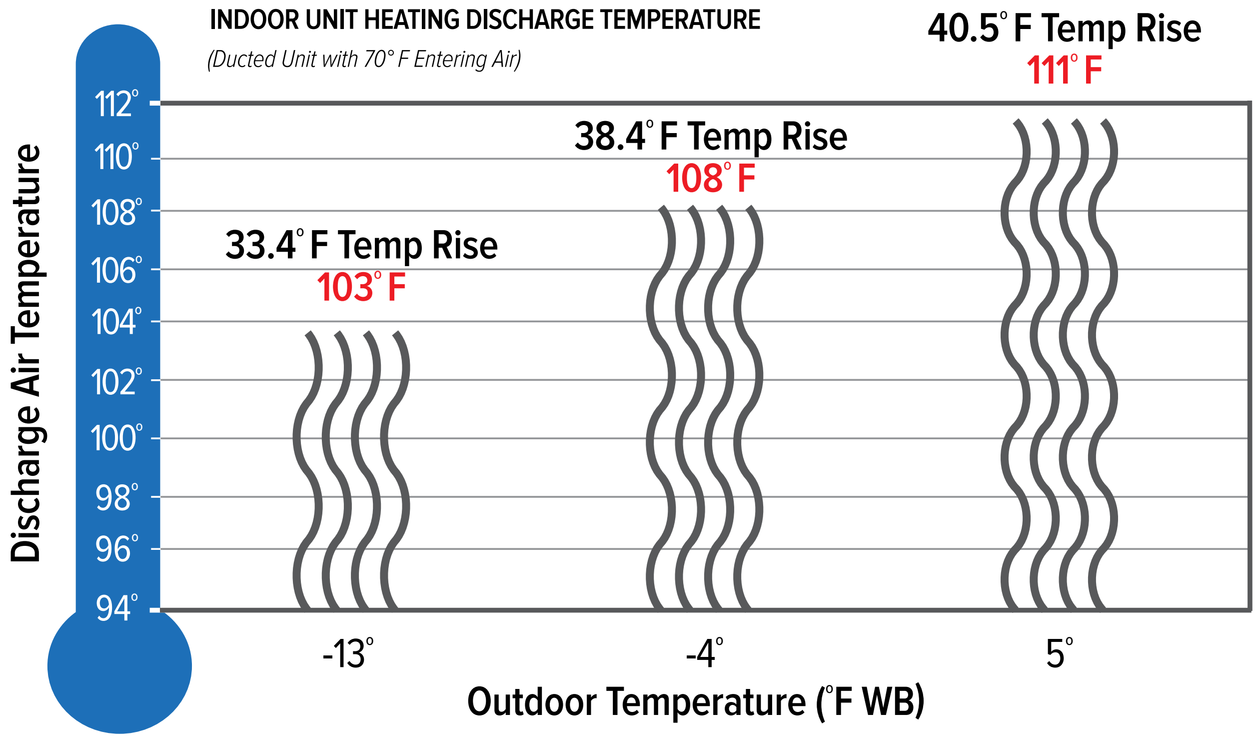
4 Outdoor unit pulls heat from outside air to get liquid into gaseous form. In order for this to happen, the refrigerant must be colder than the air outside, making a freeze protection circuit necessary. For example, if the temperature outside is minus 10 degrees Fahrenheit, the refrigerant must be colder.

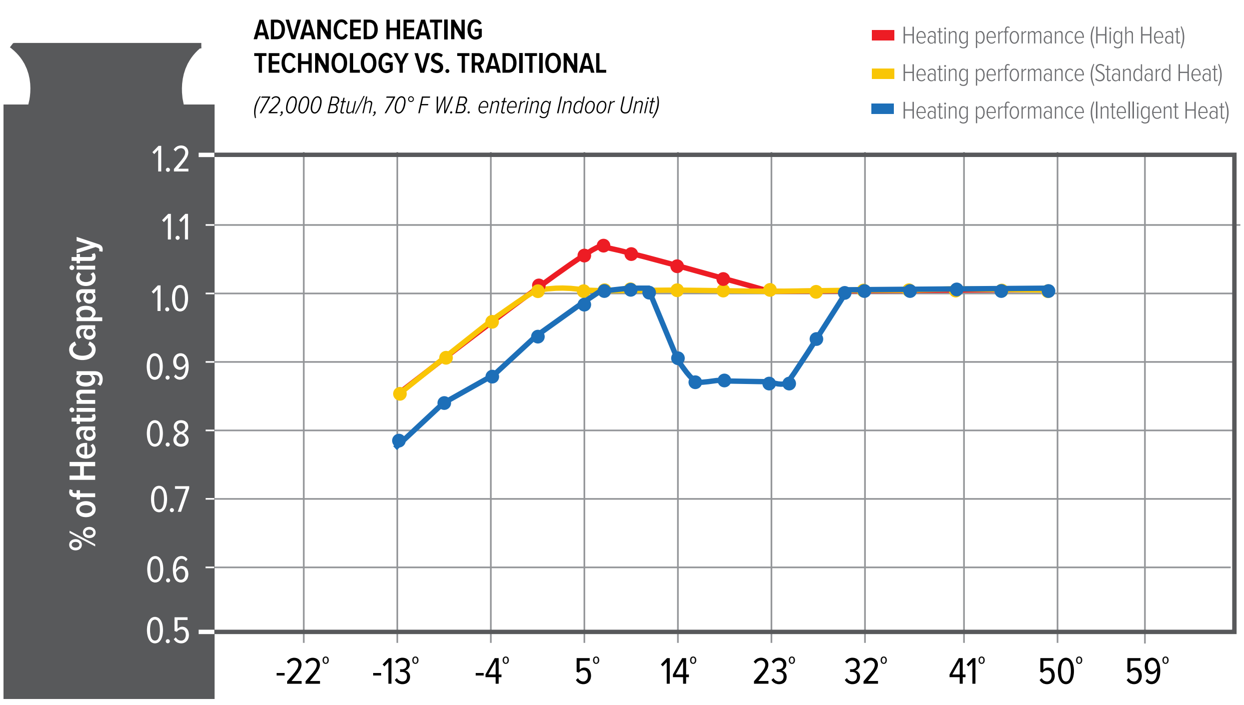
5 Flash injection circuit cools down compressor.

6 In the freeze protection circuit, a hot gas loop eliminates ice buildup.



The result of this technology is impressive capacity – 100 percent at 0 degrees Fahrenheit and 85 percent at minus 13 degrees Fahrenheit, for example. Again, while the technology is too new to have an industry–wide definition available, the following system capacity chart and indoor unit heating discharge temperature chart show actual examples of VRF with advanced heating technology's performance.





In the case of VRF with heat recovery and advanced heating technology, simultaneous cooling and heating operation is generally available down to minus 4 degrees Fahrenheit (instead of the 14 degrees Fahrenheit associated with most manufacturers' standard version of VRF). Having the ability to cool and heat simultaneously during negative ambient temperatures is necessary in applications such as office buildings that need to serve both workers sitting all day (requiring heating) and occupants using gym facilities (requiring cooling) even as the temperature drops.

Between minus 4 degrees Fahrenheit and minus 25 degrees Fahrenheit, a VRF system with heat recovery and advanced heating technology will operate in heating mode only.

None of this, of course, would be possible without a defrost cycle. For VRF with advanced heating technology, modern defrost cycles:

- de-energize the reversing valve;
- stop the indoor unit fan motor, preventing cold air from being distributed into the conditioned space;
- stop the outdoor unit fan, allowing the outdoor coil to increase in temperature to more efficiently eliminate ice build-up; and
- operate the compressor frequency at a high speed, increasing the discharge gas' temperature.

A VRF system with advanced heating technology looks at three variables to determine when a defrost cycle should be initiated: outdoor ambient air temperature, cumulative compressor operating time and outdoor pipe temperature. The cycle auto-terminates either when the maximum defrost time is reached or when the outdoor pipe temperature has reached or exceeded a pre-set level for a pre-set amount of time (e.g., 50 degrees Fahrenheit for two minutes). End users will find that defrost cycles occur more often when it's warmer out, for example 32 degrees Fahrenheit and snowing, than during periods of extreme cold given the lack of moisture in the air. Regardless of the temperature, end users likely won't notice the defrost cycle taking place at all. If their system stops heating during a defrost cycle, heat will only be absent for a few minutes.

Some manufacturers also offer a technology that creates heating capacity even during a defrost cycle. This happens by defrosting one section of the condenser coil at a time. The resultant operation shows a marked increase in heating capacity during defrost (from 0 percent to up to 60 percent depending on the outside temperature), as well as a small increase in overall heating capacity.

This technology takes different forms depending on the manufacturer. Some use hot gas defrost, others reverse defrost and others use a hybrid. With some manufacturers, a hybrid of hot gas and reverse defrost can take place in a single module, making the technology applicable to smaller projects.

While hot gas defrost does increase the frequency of defrost cycles and make "cold blow" possible, it is still widely sought after for its impressive increase to heating capacity.

Cold Weather Accessories

Manufacturers who offer heat pumps with advanced heating technology also offer add-ons designed with cold-climate performance in mind. These accessories increase performance, and in extreme, snowy conditions, are often necessary.

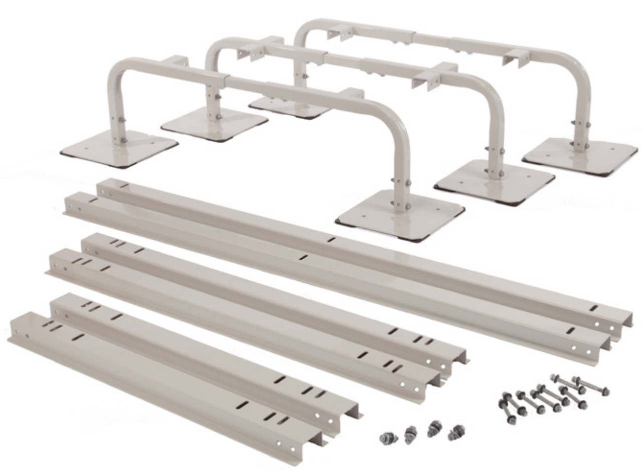
They include:

- Wind baffles and snow guards, which protect outdoor unit coil surfaces from hail damage and snow buildup, and improve defrost efficiency in windy conditions.
- Snow hoods, which protect the outdoor unit fan guard from hail damage and snow buildup.
- Equipment stands, or snow stands, which minimize ice accumulation from the unit base by enabling installation several feet off the ground, and thus several feet away from snow drifts and frozen drainage water – ultimately helping prevent frozen coils.
- Base pan heaters, which protect the bottom of the coil from ice buildup even during a defrost cycle, and which are already included in some manufacturers' outdoor units. Base pan heaters are ideal for low-temperature, high-humidity environments where the outdoor unit will be operating in heating mode for extended periods of time.

Hail/Snow Hoods

Hail/Snow Guards

Stands and Supports



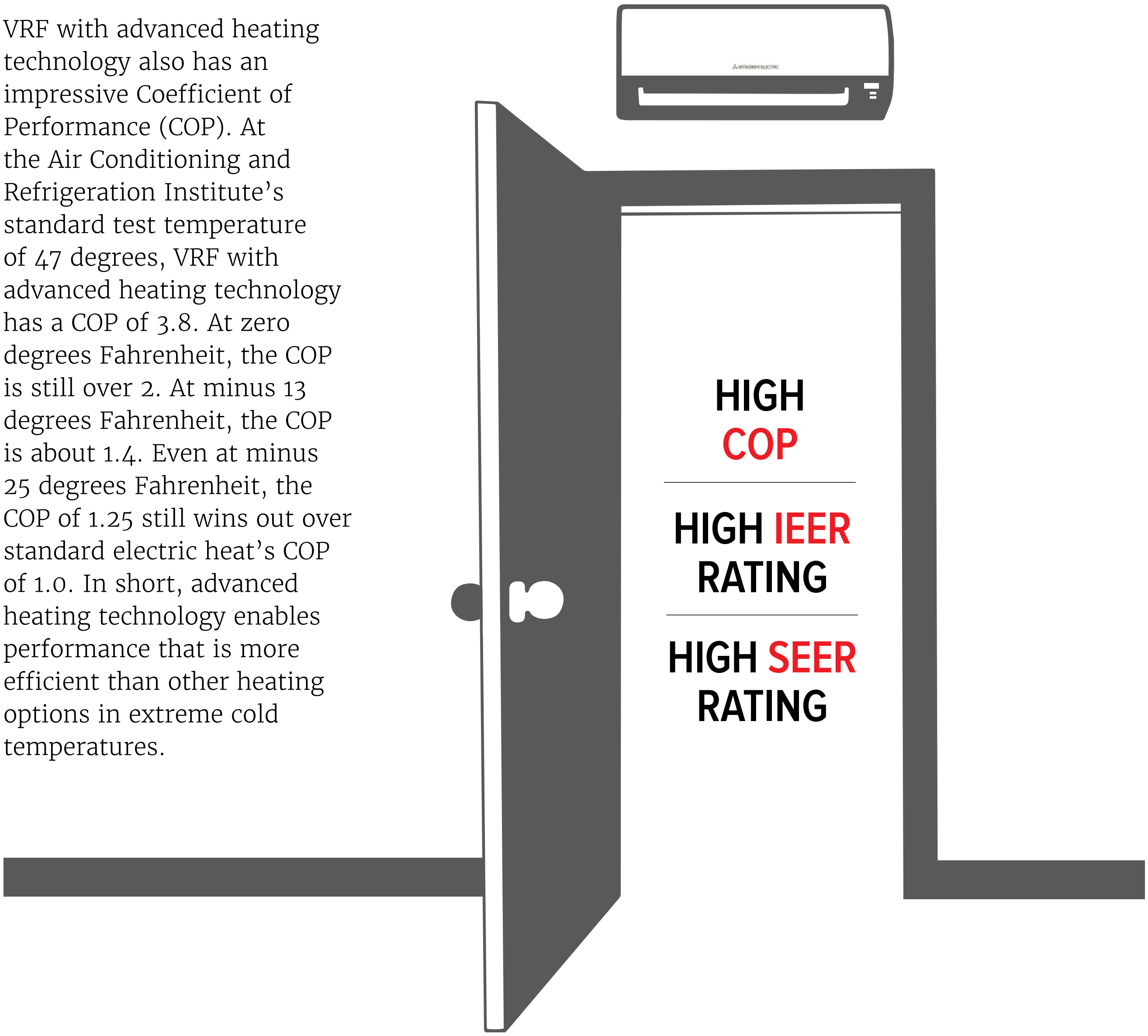
Features, Benefits

Heat pumps with advanced heating technology offer a wide range of benefits. There's truly something for everyone – engineers, architects, facility managers, building owners, energy raters, occupants, etc. Benefits include:

1 **Efficiency.** VRF with advanced heating technology earns impressive efficiency ratings. A typical VRF system with advanced heating technology will perform with an IEER rating of up to 16.8; VRF with heat recovery and advanced heating technology will see even higher IEER ratings – up to 18.4.

Advanced heating technology is also available in single-zone systems, also known as split-ductless or zoned comfort solutions. In these cases, the Seasonal Energy Efficiency Ratio (SEER) gets up to a rating of 30.5 with advanced heating technology, though most units are rated in the high teens or low to-mid 20s.

VRF with advanced heating technology also has an impressive Coefficient of Performance (COP). At the Air Conditioning and Refrigeration Institute's standard test temperature of 47 degrees, VRF with advanced heating technology has a COP of 3.8. At zero degrees Fahrenheit, the COP is still over 2. At minus 13 degrees Fahrenheit, the COP is about 1.4. Even at minus 25 degrees Fahrenheit, the COP of 1.25 still wins out over standard electric heat's COP of 1.0. In short, advanced heating technology enables performance that is more efficient than other heating options in extreme cold temperatures.

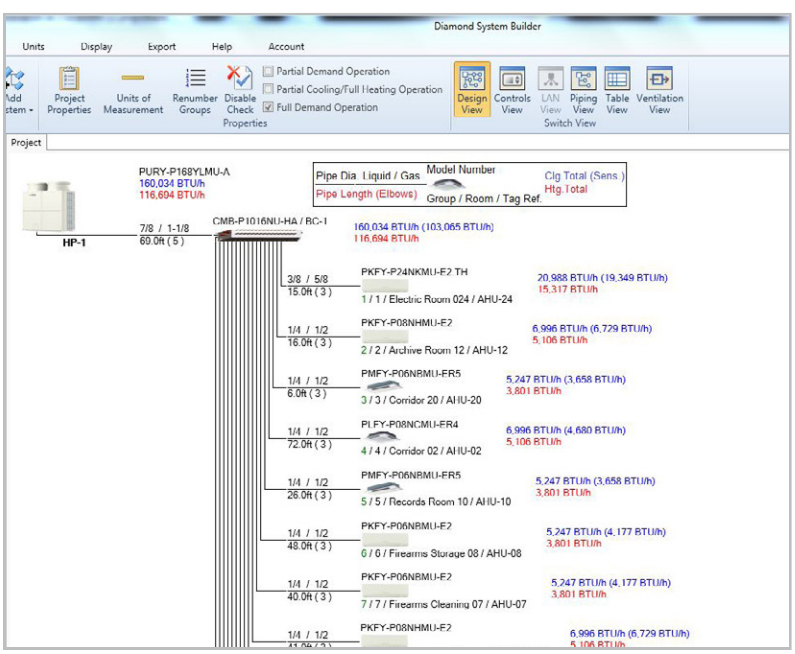


2 **Cost savings.** It is true that VRF's initial cost can be higher than traditional systems. In a cold climate application, the first cost can increase further due to factors like a higher electrical requirement or the need for cold-weather accessories. However VRF's installation cost is often lower than that of systems providing similar comfort and control, for example a four-pipe boiler/chiller setup with a building management system (BMS). This is because with VRF, a controls system comes standard and users can add advanced monitoring and control for a fraction of the cost of a BMS.

Operation represents another venue of cost savings with VRF. As efficiencies increase, operational costs decrease. Thanks to VRF's inverter-driven compressor, users can expect to see a savings of up to 25 percent on utility bills.

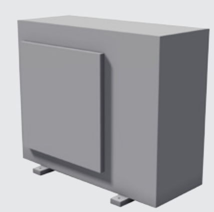
The end result is that while VRF's initial cost can be higher, the cost over a system's lifetime represents ample savings – and all while enjoying benefits like comfort and sustainability.

3 **Ease of design and specification.** VRF manufacturers offer professionals an arsenal of tools to make design and specification easy and successful. The example below shows the interface of a manufacturer-provided tool that helps users determine the cooling and heating output of selected equipment for project-specific locations. The program has error indicators and built-in safeguards against exceeding limitations; this assures that line lengths, maximum connected capacities, component selections and control schemes, among others, are within system requirements.

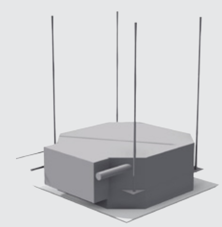


These tools generally produce AutoCAD® drawings (or similar format) and even import custom-built REVIT® models, such as these:

1



2



3

4 **Ease for the end user.** Since VRF with advanced heating technology can serve as a building's sole heating source throughout the year, end users can enjoy the simplicity of having just one cooling and heating system. Reducing the number of required systems has profound effects – saving end users upfront and installation costs, freeing up space where additional systems previously would have been required and reducing maintenance needs and complexities.

Along those lines, end users benefit from having properly sized equipment, which ultimately results in a longer operational life. Traditional equipment is often oversized to meet the heating needs during periods of extreme cold. This is problematic because oversizing degrades equipment by running the compressors at full speed for long periods of time, which results in a hot exterior temperature. VRF with advanced heating technology protects the compressors through an enhanced refrigerant circuit to avoid this degradation. **The importance of this benefit cannot be overstated; protecting the unit in extreme cold climates is a huge step forward, and will help ensure the equipment's long life and continuous operation.**

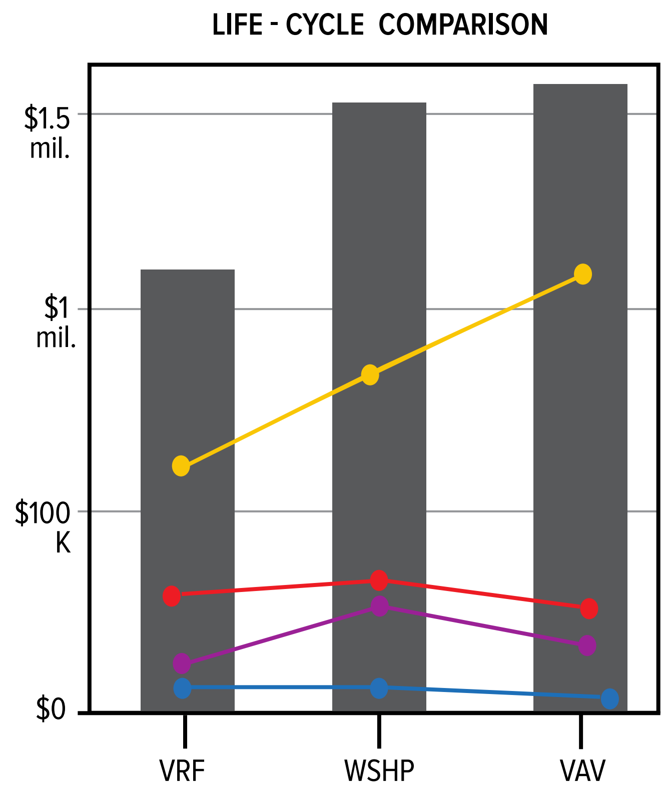
5 **Advanced Control.** VRF with advanced heating technology offers a variety of control options that bolster operational savings and personalized comfort. On a small scale, several types of controllers are available to provide personalized temperature control. On a large scale, centralized controllers can monitor, schedule and control multiple indoor units through a Web browser interface. Multiple central controllers can be networked together with integrated centralized control software and systems can even be tied to a building management system. With controls built into the equipment and easily expanded on, this means more effective operation and further cost savings.

How VRF With Advanced Heating Technology Compares

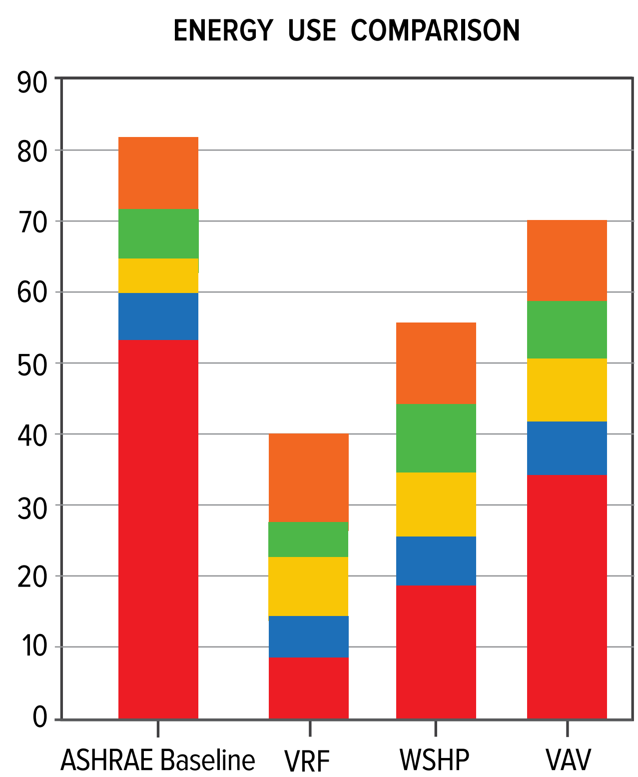
Even for geographical locations where gas is incredibly inexpensive, VRF with advanced heating technology is a worthwhile option because of VRF's personalized comfort control through zones, flexible design and installation, and the ability to right-size equipment (which results in more operational life out of a system). Further, as more projects incorporate solar panels and alternate energy generation methods, using an HVAC system fueled by electricity becomes a way to reduce the project's carbon footprint. Opting for a single cooling and heating system also means eliminating the need to purchase a central air-conditioning system in addition to a boiler, for example.

Over a product's life cycle, these benefits add up – ultimately making the case that VRF with advanced heating technology is a superior choice to other options currently available. Some manufacturers have developed efficiency evaluation tools that demonstrate the advantages, simulating the life cycle cost and other calculations for old and new buildings. On the next page you'll see the output from two actual simulations. The first compares the life-cycle cost of VRF with advanced heating technology to water source heat pump (WSHP) and variable air volume (VAV) systems. The second compares the Energy Use Intensity of VRF with advanced heating technology to WSHP, VAV and packaged terminal air conditioners.

	VRF	WSHP	VAV
TOTAL LIFE CYCLE COST	$1,100,863	$1,520,881	$1,555,679
FIRST COST	$303,002	$329,732	$270,742
LIFETIME EQUIPMENT COST	$63,050	$67,386	$43,594
LIFETIME UTILITY COST	$610,559	$861,191	$1,071,481
LIFETIME MAINTENANCE COST	$124,252	$262,572	$169,862



	PTAC-DX /GAS ASHRAE Baseline	VRF	WSHP	VAV
HEATING (KBtu/ft²)	53	8	19	35
COOLING (KBtu/ft²)	7	6	7	8
LIGHTING (KBtu/ft²)	9	9	9	9
FANS & PUMPS (KBtu/ft²)	7	6	10	8
EQUIPMENT (KBtu/ft²)	11	11	11	11



In both simulations, VRF with advanced heating technology far outperforms the other technologies.

Applications

Advanced heating technology is a critical component when a project calls for VRF and occupant comfort is essential. Professionals working on multifamily buildings must think about residents' year-round needs, just as those working in hospice care must consider patient comfort. From small to large buildings, from residences to commercial uses, the applications for VRF (and single-zone heat pumps) with advanced heating technology are numerous. Recent examples include:

HOLLIS MONTESSORI SCHOOL

Hollis, New Hampshire

Scope: The first independent **school** in the country to receive Passive House certification

Challenge, Results: An HVAC system for a new, 10,000-square-foot school had to meet Passive House standards and offer impressive indoor air quality. Heat pumps with advanced heating technology made this possible year-round, and offered an 85 percent energy savings compared to other similarly designed schools.

"We were hesitant about heat pumps at first – whether they would keep up with the northeast winter. But we were told these [units] could handle cold temperatures even on negative days and still produce the right amount of heat. I've absolutely found this to be true."

– Frank Grossman, president, board of directors, Hollis Montessori School

NORTH END APARTMENTS

Boston, Massachusetts

Scope: 7,000-square-foot **condo** building

Challenge, Results: An old, closed-off apartment building sought out upscale and energy-efficient mechanical systems to remain competitive in the Boston housing market. Heat pumps with advanced heating technology were selected for their high performance in even the coldest of winters, and for their small footprint and ability to zone.

"When you have continuous days of sub-zero weather, you have to have a system that can continue to work."

– Matt Donaghey, managing director and principal, Cricket Realty Holdings, LLC

DAVID WHITNEY BUILDING

Detroit, Michigan

Scope: 19-story **mixed-use** building with residences, a hotel, a restaurant and a bar

Challenge, Results: A $94.5 million renovation restored this century-old class A skyscraper to its previous grandeur. Key to that renovation was retrofitting the entire building with over 600 tons of VRF with advanced heating technology. The system was selected for its cost-savings, high level of control and ability to offer year-round comfort despite Michigan's icy winters.

"In January/February, the system was put to a test, and it provided the heat needed to make people happy and comfortable."

– Rick Mead, president, RW Mead & Sons

Conclusion

For decades now, VRF has enabled building professionals to push the envelope in many parts of the country. With advanced heating technology, VRF is now a solution, not a challenge, in extreme cold climates, making it an enticing option no matter the geographical location. End users across a variety of applications are already enjoying the benefits of VRF throughout the year – including zoning control and great efficiencies. From here, efficiencies will only improve.

MITSUBISHI ELECTRIC
COOLING & HEATING

1340 Satellite Blvd. NW
Suwanee, Georgia 30024
800-433-4822
mitsubishipro.com