Variable Refrigerant Flow:

A Versatile HVAC Solution for K-12 Educational Facilities

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COOLING & HEATING

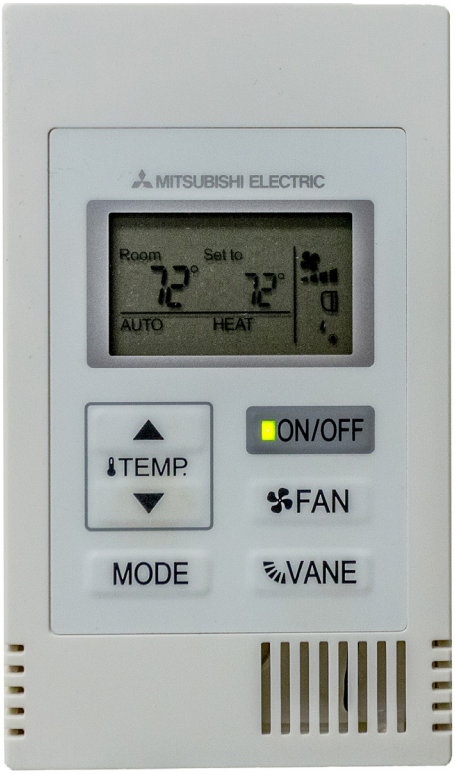
K-12 educational facilities face a long list of HVAC challenges. These often occur in the way of occupant comfort or a high level of control. Other specific challenges to K-12 educational facilities, though, include: stringent air quality requirements (especially pertaining to ventilation), the need for low noise levels, a variety of comfort needs to meet a variety of spaces and occupants, and a preference for simple maintenance. A school's challenges also change depending on its location throughout the country; for example, a school in Florida might face humidity issues, a school in Vermont might not, but might face cold-climate heating issues.

Variable Refrigerant Flow (VRF), an HVAC technology, is a great solution for almost any K-12 educational facility. It responds to each of this application's specific challenges, offering industry-leading efficiencies, integration with ventilation systems, advanced filtration systems, whisper-quiet operation and more. VRF is also a smart choice for any location in the country, including the coldest climates.

While VRF is regarded as a cutting-edge technology, it has a long, proven history in K-12 applications — both for new construction and retrofits. Many building professionals are now looking to VRF as the K-12 world changes. For example, regions that previously did not require cooling systems — such as the Northeast — are now requesting cooling due to an extended or shifted operational year and hotter temperatures. And as VRF continues to innovate and improve, it evolves from being a good solution for K-12 educational facilities to *the* solution.

VRF – A Brief Overview

The U.S. Energy Information Administration states 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, personalized comfort and a modern appearance. VRF makes the most of budget and space while offering energy-efficient technology that provides superior occupant comfort. VRF can also use either air or water as the heat exchange medium.



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, some spaces can even be cooled while others are simultaneously heated. In this case, the system's capacity is distributed to each indoor unit via a branch circuit controller. The result is personal comfort control for occupants.

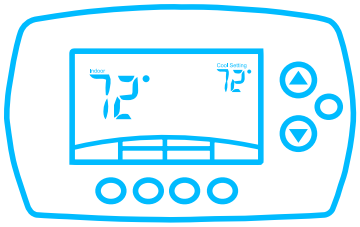
This isn't a new technology. VRF has been used throughout the world since the 1980s. In many countries, it's the most-used HVAC technology: for example in Japan VRF represents approximately 90 percent of installed systems within commercial buildings, Europe 81 percent and China 86 percent. VRF for commercial 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.

Over the years, projects using VRF have also discovered the benefits of its reduced and simple maintenance requirements.

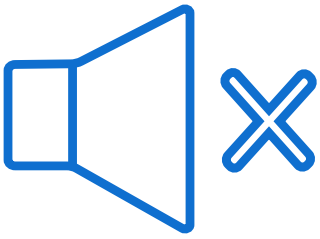
If you've heard that VRF requires a lot of maintenance — and that this maintenance requires advanced training — you've heard wrong. While VRF manufacturers do offer training programs for system designers and installers, the system is ultimately simple to operate and maintain. As a state-of-the-art system, it also offers powerful self-diagnostics and aids in troubleshooting.

Additional end-user benefits, which are further described throughout this paper, include:

Reduced utility bills



Personalized comfort control



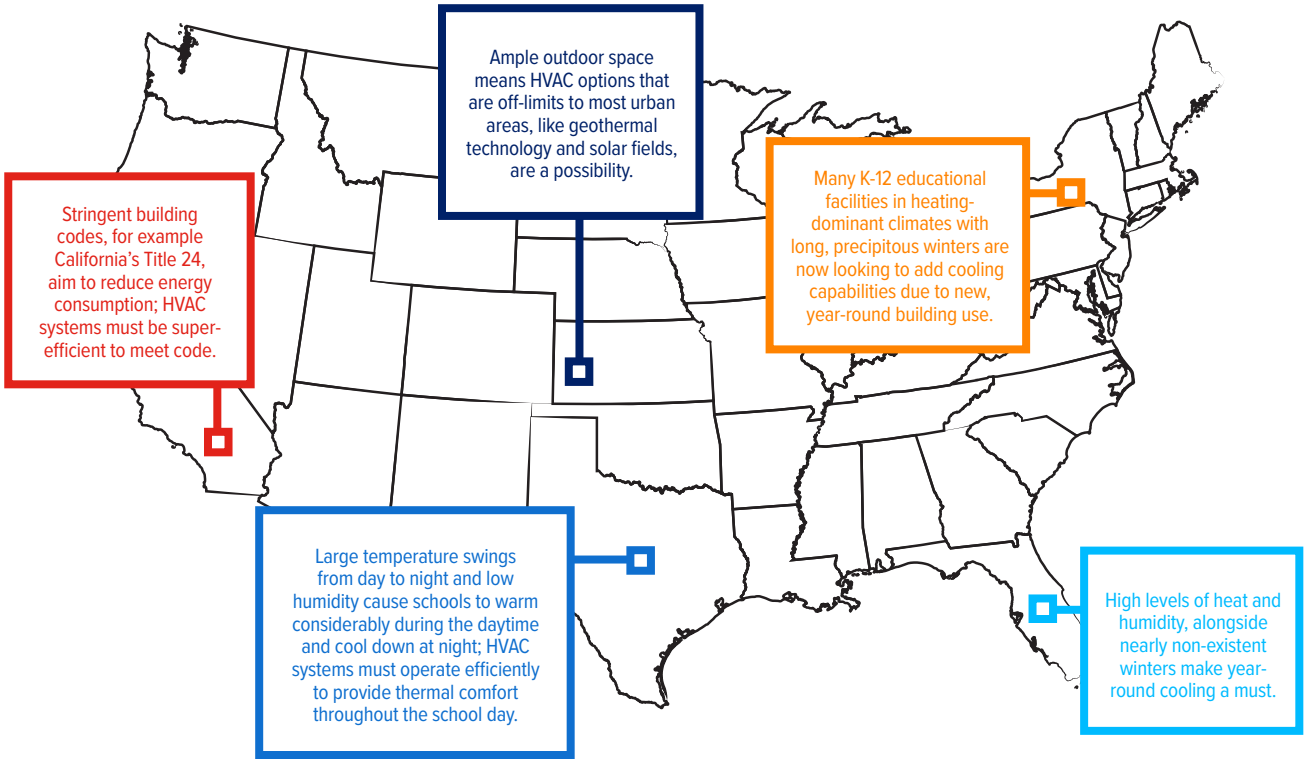
Whisper-quiet operation

High Indoor Air Quality (IAQ)

With so much to offer, it's no surprise that much of the world has taken to VRF, including many K-12 educational facilities across the country. Now let's explore the challenges specific to these facilities, and see how VRF responds to each.

The Unique Challenges of K-12 Educational Facilities

Schools' HVAC requirements range greatly depending on factors like their size or age groups served. Perhaps the most significant factor determining a school's HVAC needs is location. Different regions have different climates, population dynamics (how dense the area is, and if its population is increasing, stagnant or decreasing), level of interest in sustainability and building or energy codes.



Despite these differences, VRF acts as a unifying technology — offering schools in every region a smart solution to their biggest HVAC challenges. The next section addresses those challenges, and how VRF responds to them.

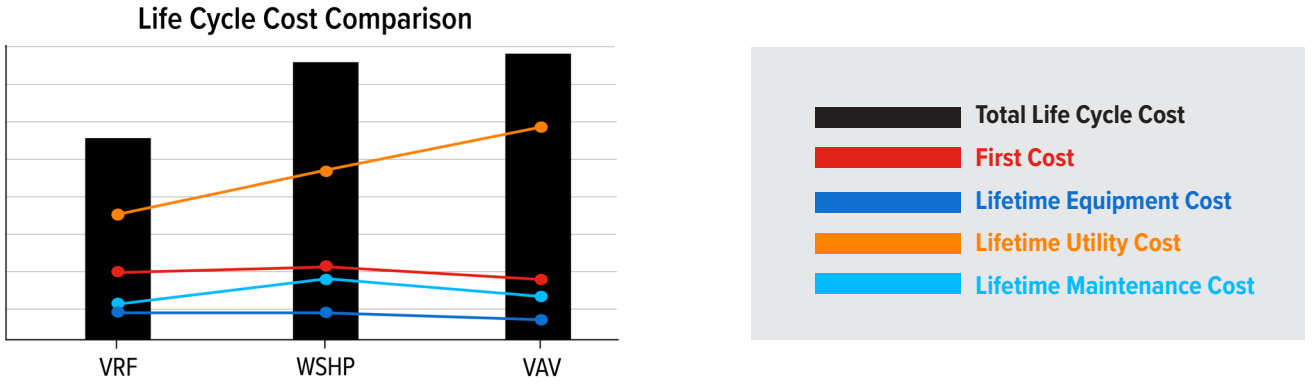
Challenge: Tight budgets

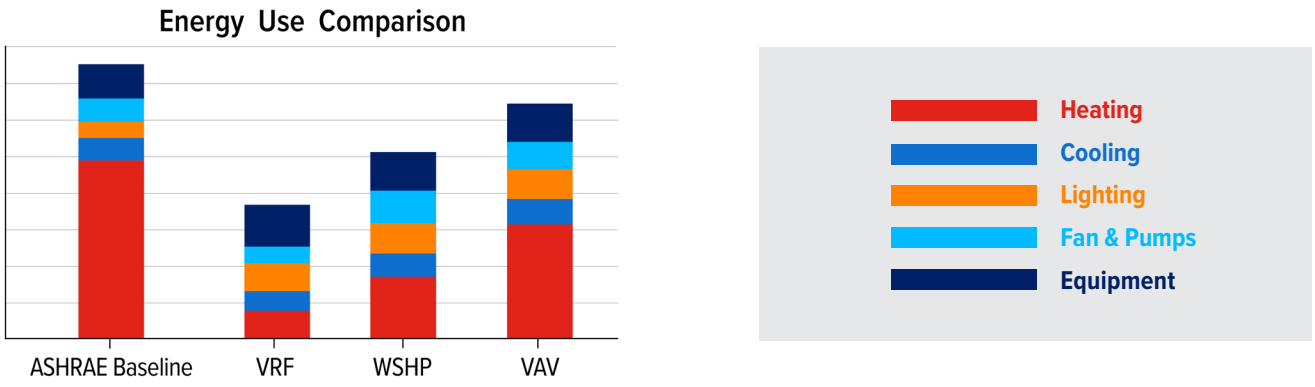
Anyone involved with operating a school knows that energy management is an ongoing challenge. At the heart of that challenge are two opposing forces pulling at facility managers: keeping costs down and keeping occupants comfortable. Energy costs throughout the country vary, but even when they're cheap compared to neighboring regions, energy costs are still a huge consideration for schools that must keep hundreds of occupants comfortable day in and day out. At the same time, the cost of energy is going to continue to increase. Teachers and students aren't focused on this fact, however. They just want to be comfortable in their spaces, and they'll do what they have to do to achieve that comfort — adjust the thermostats they can access, open or close windows and open or close doors.

VRF offers a solution to this ever-present challenge by providing superior lifecycle costs. While VRF's initial equipment cost can be higher than that of some traditional systems, VRF's installation and operational costs are often lower. Compared to integrating a controls systems into a building management system, VRF saves money during installation with its standard controls system. Further cost efficiency can be achieved by selecting an advanced controls system provided by the VRF manufacturer, as this eliminates the need for multiple controls integrators. Installation costs can further be reduced because VRF offers a simpler installation than conventional systems, saving on materials and labor.

When it comes to saving money during operation, VRF offers industry-leading efficiencies. 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.

Over a product's life cycle, these benefits add up — ultimately making the case that VRF is a superior financial choice compared to other options currently available. Some manufacturers have developed tools that quantitatively demonstrate these advantages of VRF, simulating the life cycle cost and other calculations for old and new buildings. Below you'll see sample, simplified outputs from two actual simulations. The first compares the life cycle cost of VRF to water source heat pump (WSHP) and variable air volume (VAV) systems. The second compares the Energy Use Intensity of VRF to WSHP, VAV and the ASHRAE basline (PTAC-DX/gas). In an actual simulation, both outputs would quantify the figures only visually displayed here — for example estimating the Lifetime Equipment cost of VRF, WSHP and VAV to the nearest dollar. These quantified estimates are based on specific input criteria like location, square footage and whether a building is being renovated or newly constructed.





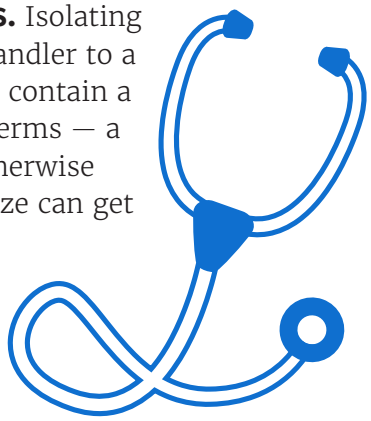
Challenge: Strict indoor air requirements

In K-12 educational facilities, indoor air quality is important. Viruses, bacteria, allergens, dust, gases and other contaminants circulate inside, creating breathing hazards and bad odors. Illness spreads quickly as kids touch surfaces. As a result, schools face a host of mandates relating to indoor air. VRF answers this challenge in five ways:

1 **Offering advanced filters.** VRF's indoor units have filters that capture and remove contaminants that can trigger allergy and asthma symptoms, spread illness and impact air quality. Some manufacturers offer platinum deodorizing filters, which use nanotechnology to absorb odors to neutralize the worst smells. VRF's filters are easily accessible and washable, and last up to 10 years — simplifying and improving the effectiveness of routine maintenance.

2 **Continuously providing comfortable temperatures.** With traditional, non-inverter technology, the units tend to cycle a lot — turning on and off repeatedly. The frequent cycling causes major temperature swings and, potentially, health issues. VRF meets the load of a space and maintains that load.

3 **Offering zoning abilities.** Isolating an air handler to a classroom helps contain a sick student's germs — a boon to IAQ. Otherwise one child's sneeze can get passed along to many people.



4 **Integrating with ventilation systems.** Ventilation air is often viewed as a challenge in utilizing VRF in school applications. This is due to the high outside air requirement typically found in this application. However, there are numerous ways to address these concerns while still maintaining, and even adding to, the energy efficiency of a VRF system. The approach considered will vary based on the project's climate, but there are a few common ways to address this issue.

In warm and dry climates, outside air can often be brought into the VRF indoor units via inline fans, with little to no preconditioning of the outside air. The VRF indoor unit will then mix this air with the return air from the space, fully condition it and introduce it into the space being served. Note that this method works only for climates where the design outdoor temperatures and humidity levels — as well as the required amount of outside air — do not result in mixed air temperatures to the coil exceeding manufacturer-recommended limits. If this isn't the case, further conditioning of the outside air is required.

In some regions of the country — excluding those with high relative humidity — and depending on the amount of outside air required, this conditioning can be achieved with an Energy Recovery Ventilator (ERV). Often, ERVs can be used with an unbalanced airflow (to allow positive or negative pressure in the space), and will allow for energy recovery to/from the exhaust air stream prior to discharging. Not only does this provide additional efficiency by recapturing the energy from the exhaust airstream, but it will often allow the VRF outdoor unit to be reduced in size, partially or totally offsetting the initial cost of the ERV. It should be noted that ERVs do not typically fully condition the supply air to room-neutral conditions, so further conditioning is highly recommended before introducing the air into the space being served. For this reason, ERVs are often used as preconditioning devices, with the supply air stream being delivered to the VRF indoor units for further conditioning before being delivered to the space.

Energy Recovery Ventilator

For those instances where a relatively large amount of outdoor air is required, a Dedicated Outside Air System (DOAS) is recommended. DOAS units are typically designed to fully condition outside air to room-neutral conditions, allowing it to be introduced directly into the space, independent of the VRF system. This is known as a decoupled system, and provides the additional benefit of allowing the two systems to operate completely independently if desired. In some climates, the DOAS system may alternatively be used to temper the air, delivering it to the VRF indoor units for final conditioning. One benefit of this approach is that the DOAS system will be smaller in size, leading to a lower initial cost, although the VRF system will have to be upsized to accommodate the additional outside air load. However, it must be noted that the resultant entering air conditions to the VRF indoor unit must be examined to ensure that those conditions are within manufacturer-recommended limits.

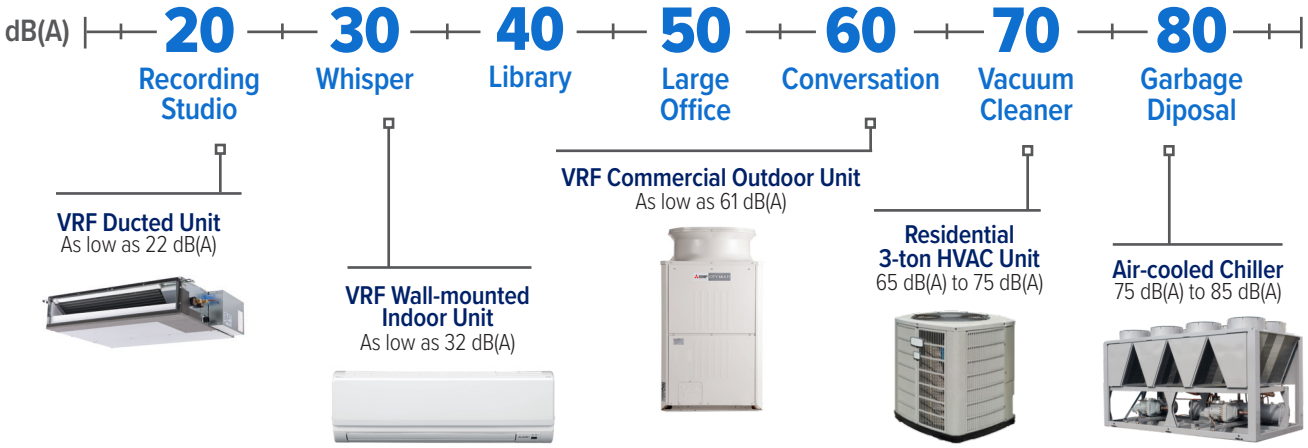
Dedicated Outside Air System

Some manufacturers of VRF also produce both ERV and DOAS units, allowing for a seamless integration of VRF and ventilation equipment. In such cases, schools will benefit from the additional energy savings offered by a DOAS unit utilizing inverter-driven compressor technology combined with energy recovery. Additional features such as enhanced humidity control (to allow room-neutral discharge air conditions), factory-mounted variable frequency drives (for supply air volume control) and onboard microprocessor systems (for precise temperature and humidity control) provide further benefits.

Challenge: Operational noise levels must be minimal

For a school to be effective, students must be able to hear their teachers and teachers must be able to speak for hours without straining their voices. As a result, both the indoor and outdoor units of an HVAC system must operate discreetly.

VRF keeps operational noise levels to a true minimum, running at whisper-quiet levels. This isn't an exaggeration: Whispers come in at 35 decibels; VRF indoor units have a lower decibel rating — for some brands, between 19 and 34 decibels. VRF's outdoor units are also much quieter than those of traditional systems, ensuring that their operation disturbs neither nearby indoor spaces nor outdoor spaces (e.g., recess area, sports area).



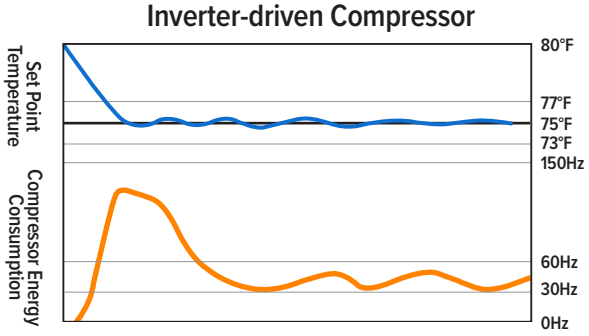
Challenge: Varying loads and comfort needs

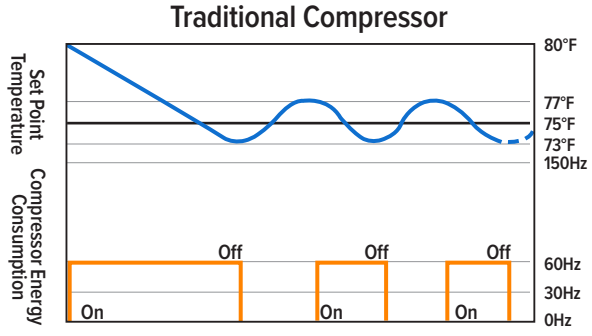
Over the course of a single day, an individual classroom's load can vary greatly. During one period, a classroom might have 30 active second graders completing lessons and doing activities. The very next period, the same classroom might empty out entirely except for the teacher during their prep period. Such extremes can make it difficult to keep a space comfortable for the occupants, whether they are few or many in number. Loads can also vary depending on the time of year; many school buildings are bustling throughout the fall and spring, but empty during the summer.

While loads vary, so do occupants' comfort needs. A K-12 educational facility might simultaneously house extremely active and inactive students — for example those who are running around as part of an activity and those who are taking naps. All schools will also have to account for both children's and adults' comfort needs. Finally, the actual spaces vary greatly in schools — from classrooms to offices to auditoriums.

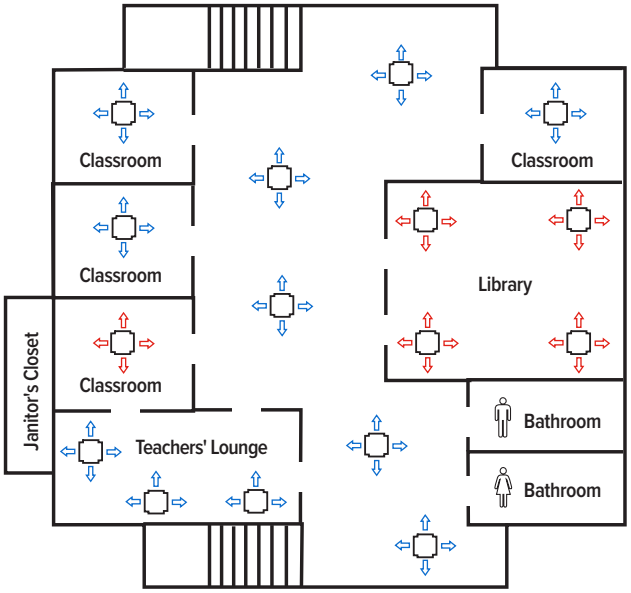
While load and comfort needs vary, the reality is that schools often need cooling regardless of the time of day or year, or who the occupants are. School buildings are filled with students, teachers and staff giving off heat throughout the day — including the hottest parts of the day — and house additional heat sources (e.g., computer labs, kitchens). Most schools still need heating systems, though. Whether heat is needed for just a few days or a few months, when it's needed, it has to be there.

VRF does an impressive job meeting spaces' and occupants' needs. 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 95 percent of the time. Conventional systems can't effectively 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 required to match a zone's cooling or heating demand. Working in tandem with integrated controls and sensors that measure conditions within each zone, the compressor seamlessly adjusts speeds to maintain the desired zone temperature.





VRF's ability to zone offers incredibly personalized comfort control. This control is furthered by VRF with heat recovery's ability to simultaneously cool and heat. Teachers will appreciate having control over their classroom. No longer will a corner classroom receiving direct sunlight have to be set to the same temperature as the chilly classroom next door. No longer will particularly active classrooms, for example with kindergarteners running around, have to be set to the same temperature as the lecture-style classroom around the corner. VRF's ability to treat hot and cold spots via zoning capabilities and simultaneous cooling and heating ensures everyone's comfort.



These functions, along with a low-profile ducted or ductless designed system, typically increase energy efficiency about 25 percent over conventional systems partly due to the energy lost by forcing air through ductwork. This helps schools reduce energy consumption, in turn reducing utility bills. It also helps schools meet Green Globes and Leadership in Energy & Environmental Design (LEED®) requirements, and achieve the highest Integrated Energy Efficiency Ratio ratings.

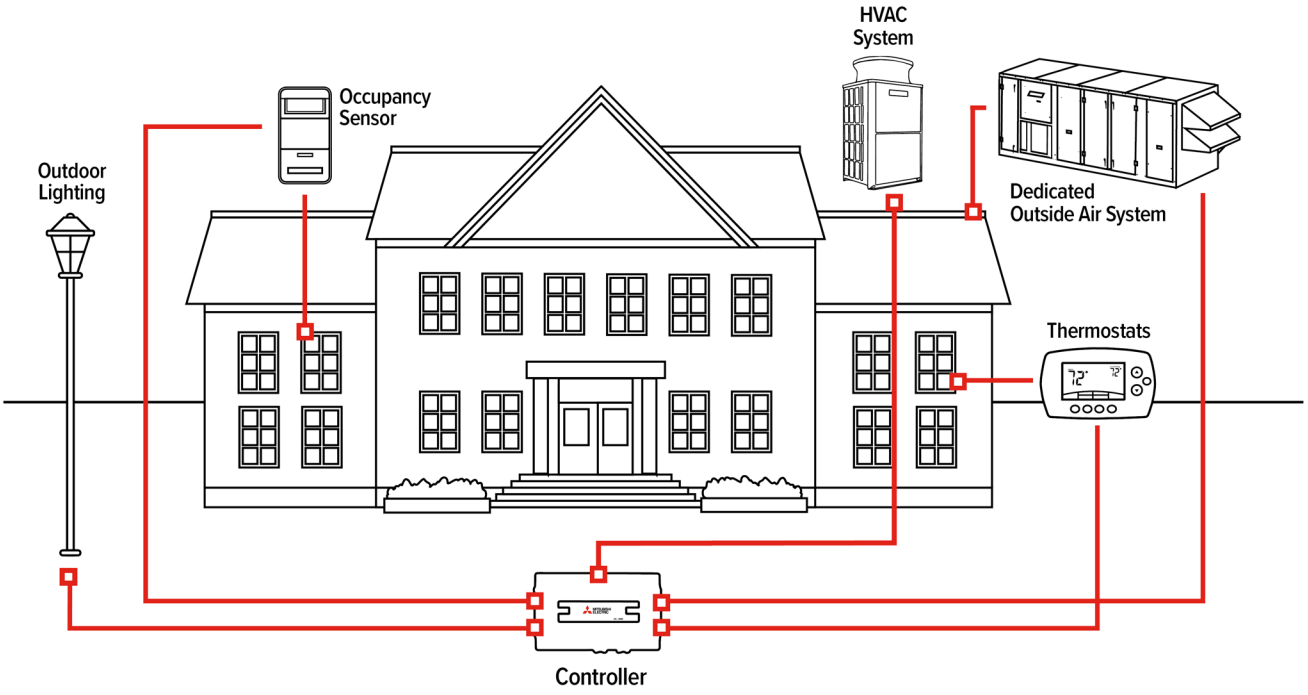
Finally, in response to schools needing year-round cooling, VRF is very effective at cooling. However, when heating is needed, the system already includes heating capabilities and no additional system is required.

Challenge: Controlling multiple spaces

Many schools are comprised of multiple buildings on one campus, and many school systems are comprised of multiple campuses across a district. In these cases, the school buildings are all different shapes and sizes. For the facility managers tasked with keeping these schools running — and running cost-effectively — the selected HVAC system must offer comprehensive controls.

VRF can integrate with the third-party software that K-12 educational facilities tend to use, for example, SchoolDude. Beyond that, VRF itself offers a wide variety of controls options, bolstering the aforementioned 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 VRF equipment and easily expanded on, this means more effective operation and further cost savings.

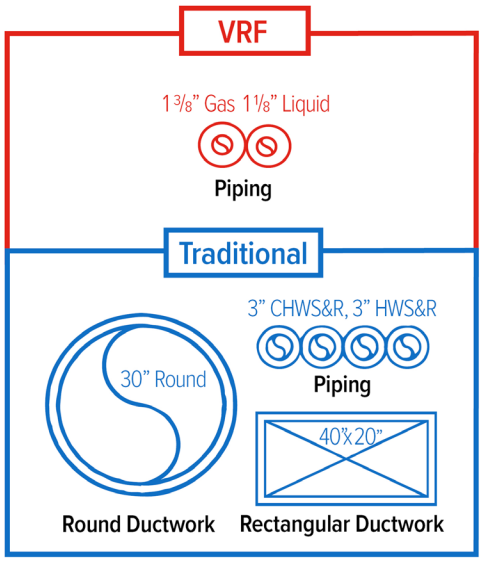
Some VRF manufacturers offer advanced controls, which let schools manage multiple spaces within the same building, multiple buildings on a site and multiple sites. In these cases, a school with several campuses spread across a state could use VRF's advanced controls to manage every campus. The controlled systems could come from any manufacturer; an HVAC system from one company could be managed alongside an outdoor lighting system from another company. By pairing VRF with an advanced controls system, a school will enjoy efficiency gains, lower integration costs — since having a built-in VRF portion cuts out the need for a third-party integrator — and ease of use. This setup also offers standardized controls, so teachers moving to different classrooms — or even schools within the district — are already familiar with the new space's system.



Challenge: Difficult installation

In terms of time and space, HVAC installations in K–12 educational facilities can be tricky. Schools most often try to schedule work during the summer to minimize the amount of disruption. They must also often work within a limited amount of space — an urban infill project, renovating an old school with "miles of ductwork," etc.

VRF offers an easy installation. Summer installation is achievable due to both a faster installation (in terms of labor) and the ability to phase the project. Retrofits are also a breeze due to VRF's minimal piping and small equipment footprint.



Challenge: Maintenance

One of the biggest concerns when it comes to a school's HVAC system is maintenance. Maintenance can be expensive, time-consuming and even hazardous. A school's custodial staff can also change frequently and vary in comfort level with advanced mechanical systems. As a result, a school's HVAC system needs to be as user-friendly and trouble-free as possible.

Cue VRF. VRF has fewer components than traditional systems, and that means many fewer to-dos for schools' maintenance teams. Simply, not much maintenance is required. What's required is easy and infrequent, and doesn't require a specialized service contractor. VRF units are also designed to have components easily accessible, yet also safely tucked away so only maintenance personnel (not students!) have access.

As an example, custodians working with VRF only need to clean the outdoor unit's coils annually, and clean filters once a month. Compare that to custodians working with a cooling tower / boiler combination, wherein the custodial staff must constantly maintain the water, or risk Legionella. That means chlorinating, cleaning and sterilizing. VRF simplifies all that. Among those who have experienced VRF, the words "easy maintenance" are mentioned frequently.

Required Maintenance

Item	Traditional	VRF
Water treatment	X	
Cooling tower	X	
Pump seals	X	
10-year overhaul	X	
Boiler overhaul	X	
Chiller maintenance	X	
Tube brushing	X	
Belt changes	X	
Strainer cleaning	X	
Filter changes	X	X
Condenser cleaning	X	X

Applications

Schools across the country have turned to VRF. Some wanted to go green, others had IAQ issues and others needed better operational control. Here are some examples of recent installations.

Dodge City Schools

Dodge City, Kansas

Scope: Two elementary schools in older buildings with noisy, failing HVAC systems

Challenge, Results: By pairing water-source VRF with geothermal technology, the school district claimed $215,000 in grant and rebate money, and earned ENERGY STAR® certification. VRF's quiet operation and easy installation were particular draws for the 35,000-square-foot Central Elementary School and 19,600-square-foot Wilroads Elementary School.

> *VRF also offers an easy installation. The walls in Central — some are up to two feet thick, so getting ducts through the walls without damaging the structure would have been impossible.*
>
> – Chris Meyer, maintenance director, Dodge City Unified School District

St. Ignatius Loyola School

Cincinnati, Ohio

Scope: The largest private school in Ohio, serving kindergarten through eighth grade

Challenge, Results: The school's original three-story building, dating back to 1950, had no air conditioning and an expensive boiler. VRF offered the efficiency and clean look the school wanted, as well as reliable heating on even the coldest of winter days.

Photo: Scott Pease/Pease Photography, 2015

> *I control every classroom on my own computer. [The centralized controls have] saved us quite a bit of money — perhaps $11,000 a year. You figure, $300 a classroom for 37 classrooms.*
>
> – Tim Schweikert, physical plant manager, St. Ignatius Loyola School

Primrose School of South Tampa

Tampa, Florida

Scope: An urban school with LEED Silver certification for students from six weeks old to first grade

Challenge, Results: Up against the space constraints of an urban setting and the need for superior IAQ, this 22,000-square-foot school turned to VRF. The system met those needs and let the school maximize space for classrooms and playgrounds, keeping utility costs down and helping earn LEED points.

> *The indoor air quality at this school is excellent. In a split system, you have to condition to the maximum load. With this system you match the load to the capacity; it's a huge advantage for controlling humidity . . . I've been doing childcare architecture for 28 years now, and this is one of the best facilities I've seen.*
>
> – Mark Pavey, AIA, principal architect, Children's Design Group

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 IAQ. Heat pumps with advanced heating technology made this possible year-round and offered an 85 percent energy savings compared to other similarly designed schools.

> *The units work nicely to produce even heat. Pretty much anywhere you go in the building, it's the same temperature. This is especially nice for the teachers, who can just work. They don't have to think much about adjusting the temperature.*
>
> – Frank Grossman, president, board of directors, Hollis Montessori School

Willow School

Gladstone, New Jersey

Scope: A Living Building Challenge™ certified school serving preschool through eighth grade

Challenge, Results: VRF helped the school's new 20,000-square-foot building meet its energy goal of being 100 percent electric and net-positive. It also integrated seamlessly with ERVs.

> *We had to remain net-zero or net-positive. With solar panels and the [VRF] system we were able to achieve that. A conventional facility built to code uses between 100–150 kBtu per square foot . . . but this building uses only 21 kBtu per square foot — and that was including our commercial kitchen. If you remove the kitchen, it would only use 15 kBtu per square foot. When people look at this building, they're looking at one of the most energy-efficient buildings in the country.*
>
> – Mark Biedron, co-founder, The Willow School

Screven Elementary School

Sylvania, Georgia

Scope: A 143,000-square-foot school serving pre-K through fifth grade

Challenge, Results: Replacing a dated and inefficient HVAC system with VRF offered cost-saving centralized controls, a quick installation that didn't disrupt operations and a 25 percent average annual energy savings.

	Average Monthly Cost	Energy Use
Pre-renovation	$12,375	115,833 kWh
Post-renovation	$11,023	87,313 kWh

> *It was [VRF's] energy efficiency that grabbed our attention. We were also interested in the ability of the units to maintain the temperature within one or two degrees and the quiet operation. It almost sounded too good to be true.*
>
> – Chris Meyer, maintenance director, Dodge City Unified School District

Photo: Joe Loehle Photography

Average Energy Savings: 25% | Average Yearly Savings: $16,226

Conclusion

K–12 educational facilities face specific challenges like ventilation and budget. VRF, as demonstrated, is both a smart and *proven* answer. As time goes on, VRF systems will continually improve — offering higher efficiencies, a higher level of control, easier maintenance and more personalization of comfort.

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