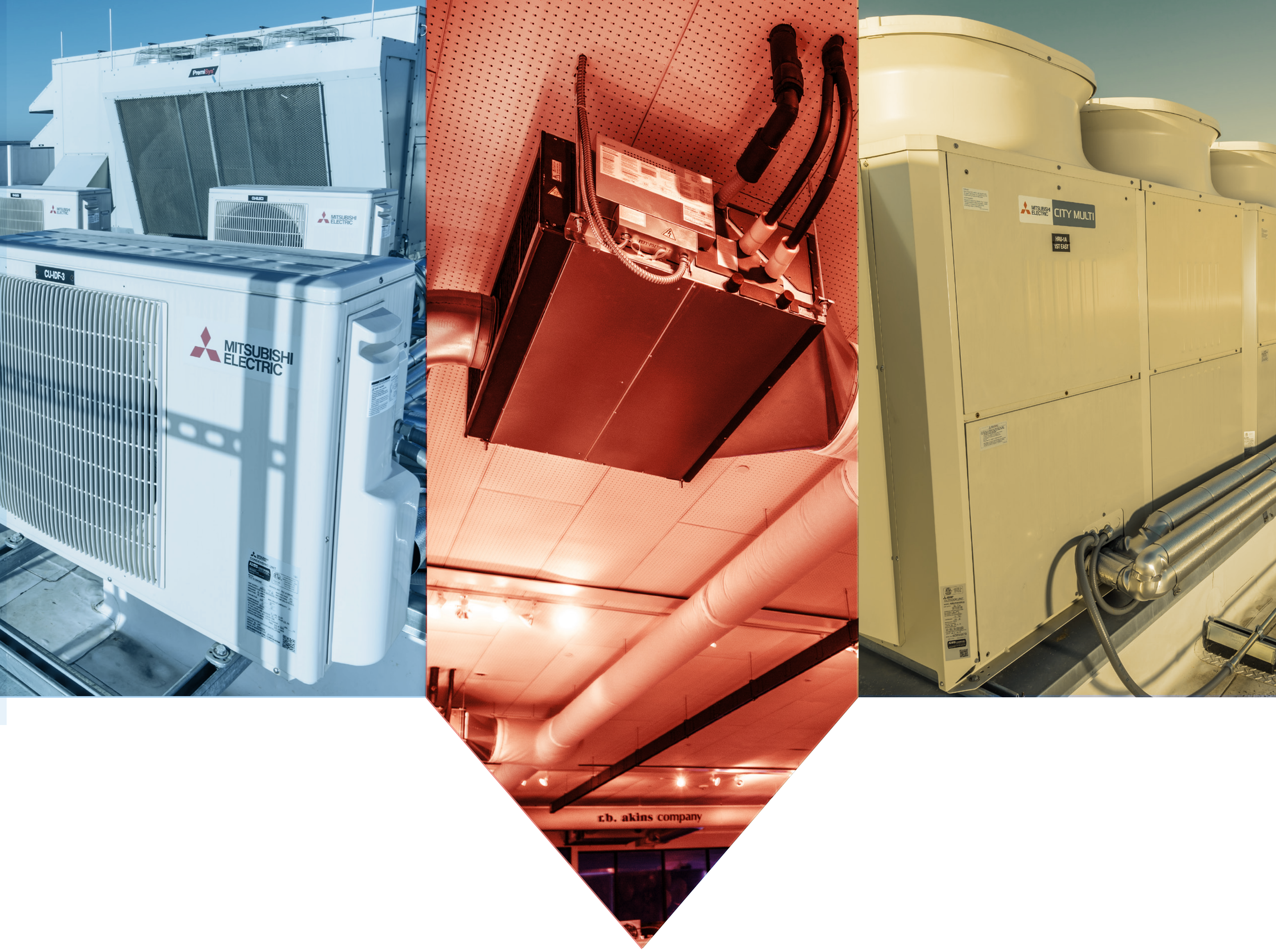

DOAS and VRF:

Applying Systems for High-Performance Buildings

White Paper
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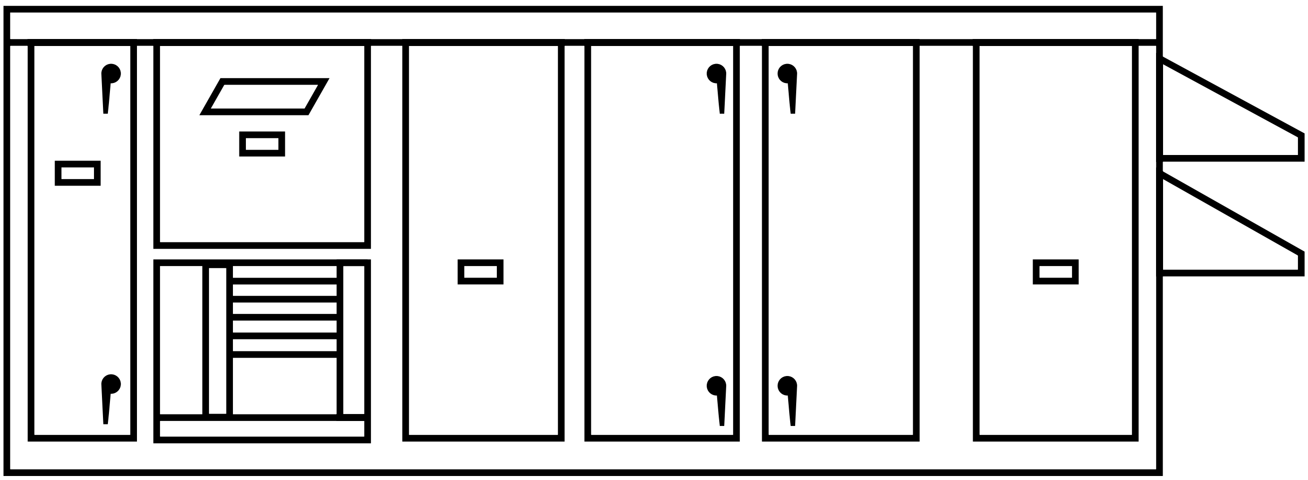
Introduction

Mechanical ventilation systems are a core part of commercial HVAC systems and are growing in sophistication and importance. This white paper discusses trends driving the need for more sophisticated approaches to ventilation and examines modern ventilation systems designed to meet today's needs.

At its most basic, mechanical ventilation introduces fresh, outside air into a space. While cooling and heating systems are regulated by energy codes concerned with efficiency and occupant comfort, ventilation systems are regulated under mechanical codes, which concern occupant safety. In the United States, ventilation systems for commercial buildings must comply with state and local codes based upon ASHRAE 62.1 or International Mechanical Code (IMC). Both ASHRAE 62.1 and IMC use similar calculations to arrive at the amount of ventilation required by a building.



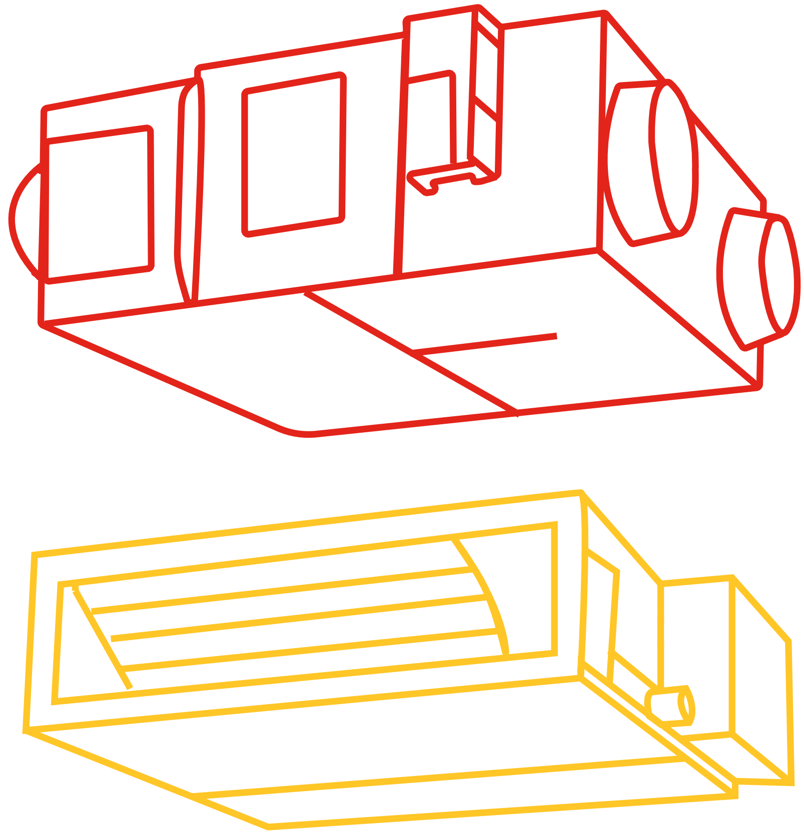
Growing Importance of IAQ

Indoor air quality (IAQ) is contingent upon the performance and proper specification of ventilation systems according to factors including climate, building size and occupancy type. For example, baby boomers transitioning toward retirement are relocating to states with warmer climates including Florida, Texas and the Carolinas. Ventilation systems in those regions must account for the climate, greater population density and the health and wellness impacts associated with IAQ in senior living facilities. As baby boomers drive population growth in warmer climates, economic pressures have led many young families to settle in and near cities for employment opportunities. These families are driving demand for affordable housing, schools, office buildings and retail establishments, which all require ventilation systems that reflect each facility's size and function.

The regular introduction of properly filtered outside air is essential to the well-being and satisfaction of all building occupants with IAQ being particularly important for children, hospital patients and other groups with special vulnerability to airborne contaminents. Greater awareness of IAQ and its impact is one of several trends driving demand for better-performing ventilation systems. Interest in more sophisticated ventilation systems is also being driven by some of the same trends that motivate architects, engineers and building owners to adopt Variable Refrigerant Flow (VRF) systems for a more efficient and intelligent approach to cooling and heating.

Ventilation and Energy Efficiency

Although ventilation systems are regulated under mechanical codes concerned with occupant safety, efficiency is more relevant than ever. Market-based incentives, sustainability concerns and government regulation are leading building owners to look for energy-efficient HVAC solutions. The HVAC industry's leading manufacturers have been ratcheting up system efficiencies in recent years and this trend is sure to remain at the forefront of product development well into the future. As we discuss in the sections to come, VRF is a leading exemplar of this trend, but an Energy Recovery Ventilator (ERV) or Dedicated Outdoor Air System (DOAS) is a necessary complement for a complete, high-performance HVAC solution.



Greater Need for High-Performance Mechanical Systems

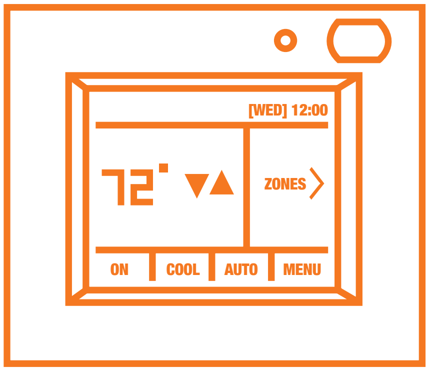
More efficient and sophisticated cooling, heating and ventilation systems are needed as architects design high-performance buildings to satisfy the requirements associated with LEED®, Green Globes®, Passive House, zero-net energy (ZNE), deep-energy retrofits and other sustainability programs. Without high-performance mechanical systems, high-performance buildings will not achieve their sustainability targets due to inefficient equipment. Additionally, high-performance buildings require tighter envelopes; with tighter envelopes, mechanical ventilation becomes even more critical for occupant safety. The need for better-performing HVAC systems will only increase as high-performance buildings become more prevalent due to ambitious sustainability goals set by private entities and state and local governments. For example, California's Energy Efficiency Strategic Plan calls for all new commercial construction to be ZNE by 2030 and for 50 percent of all commercial buildings to be retrofit to ZNE by 2030.[1]

Design Flexibility

A complete, high-performance HVAC solution that includes VRF and a decoupled DOAS, for example, will also offer greater design flexibility. Because the equipment is more compact than traditional systems, architects and building owners may design around an aesthetic vision without impacting the designs of engineers responsible for ensuring optimal performance of mechanical systems.

Centralized and Local Control

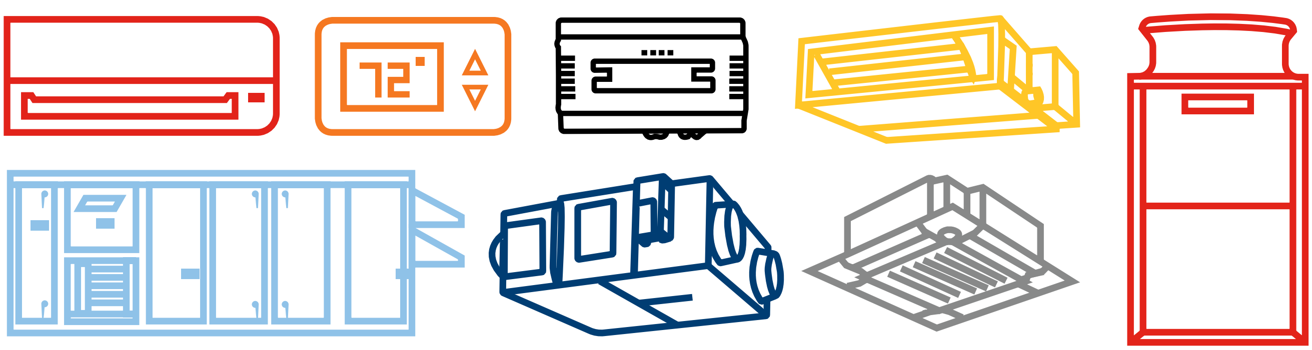
Demands for increased control have activated interest in HVAC systems that accommodate more advanced controls. Individuals accustomed to interacting with smart technologies that provide near-instant access to entertainment, commerce and information have developed expectations for personalized comfort control. While occupants are looking for personalized local control, building owners and facility managers are demanding better centralized control of equipment through more sophisticated controllers and building management systems (BMS). These systems allow for more efficient management, greater insight and reporting, and tighter control of utility costs.[2]



With our review of trends complete, we will now look deeper into the high-performance HVAC systems we have discussed. The next section will discuss VRF systems and how specialized ventilation technologies complement the systems. We will then discuss ERVs and DOAS, specialized ventilation technologies that can be applied with VRF.

What is Variable Refrigerant Flow (VRF)?

VRF is an HVAC technology designed to provide energy-efficient comfort control for a building's occupants according to the conditioning needs of a building's zones. Instead of moving conditioned air through ductwork, a VRF system moves conditioned refrigerant directly to each zone's indoor unit. Working in tandem with integrated controls and sensors that measure cooling and heating loads for each zone, the outdoor unit's compressor seamlessly adjusts speeds to maintain the zone's set point. While fixed-speed compressors in conventional HVAC systems are either running at full power or turned off, the INVERTER-driven compressor of a VRF system continually adjusts the flow of refrigerant to precisely meet each zone's conditioning requirements. VRF eliminates the energy-intensive process of turning a compressor on and off to meet loads, which are subject to change throughout a day.



Variable Capacity and Partial-Load Conditions

VRF's full-range variable capacity enables the system to maintain set points during partial-load conditions where conventional systems struggle, often resulting in poor set point satisfaction and energy fluctuations. This capability can increase energy efficiency up to 25 percent over conventional systems and help facilities satisfy the requirements of sustainability-oriented programs such as LEED® and Green Globes.

VRF and Design Freedom

Energy efficiency is not the only driver of VRF adoption. As a function of their sophisticated design, VRF units are relatively compact compared to traditional HVAC units and give architects and building owners a range of options for installation that maximizes usable space. Design freedom is additionally supported by how VRF systems keep operational noise to a minimum. VRF indoor units run at whisper-quiet sound levels between 19 and 34 decibels while VRF outdoor units operate at levels as low as 58 decibels, which is not louder than a typical conversation.

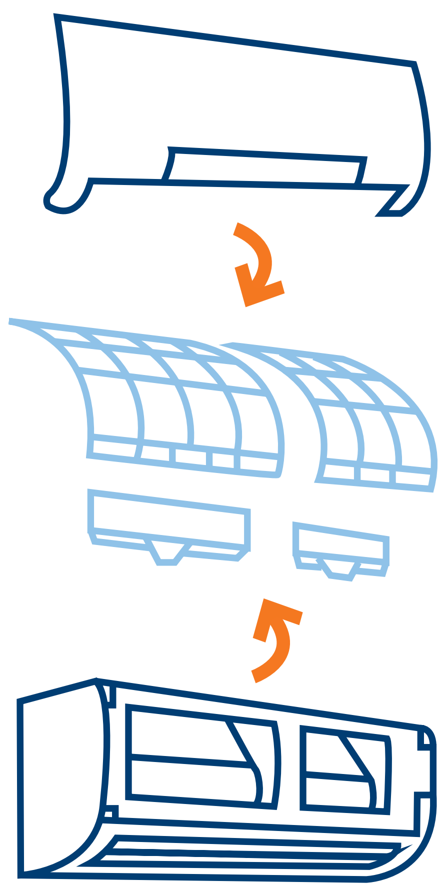
Comprehensive Control Across Spaces

VRF systems allow facility managers and owners to provide personalized control to occupants. One VRF outdoor unit can support a network of indoor units, with one, or many, indoor unit(s) for each zone. The occupant can personalize their own comfort by adjusting temperatures through the controller in their zone. With heat recovery VRF systems, which provide simultaneous cooling and heating, one zone can be in cooling mode while another is in heating mode. In the latter type of application, system capacity is distributed to each indoor unit via a branch circuit controller. In addition, VRF units are more electronics-based compared to traditional systems and have built-in controls logic to support centralized and local control. VRF systems use a "last command wins" method to adjust conditioning to user and occupant requests.

VRF and IAQ

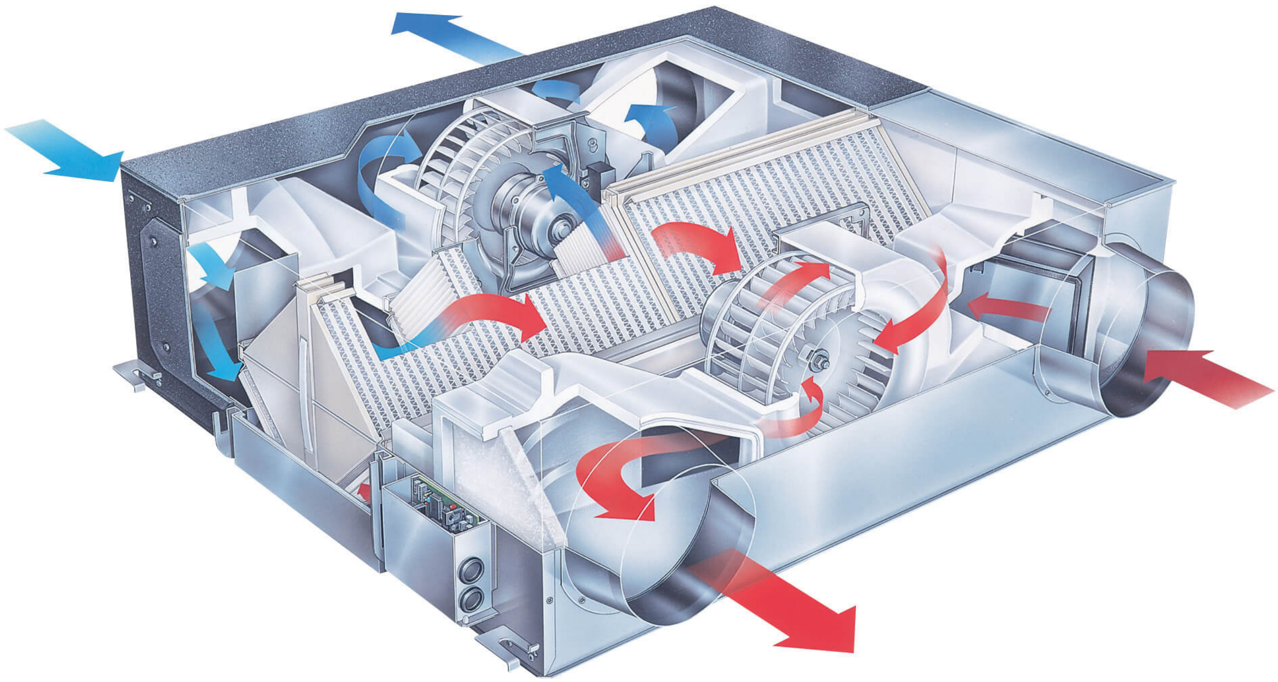
VRF systems can positively contribute to IAQ. Filters installed in VRF indoor units capture and remove contaminants that trigger asthma and allergy symptoms, spread illness and otherwise impact air quality. These filters are easily accessible, washable and last up to 10 years, simplifying routine system maintenance. The zoning functionality of VRF systems allows air handlers to be isolated to individual spaces, such as a classroom, further helping to contain the spread of contaminants.

For some applications, with very modest amounts of ventilation required, the indoor units of a VRF system can process ventilation air directly. That said, VRF is not purpose-built for ventilation. For example, VRF does not have much latent capacity at part load conditions. As a VRF system's compressors run slower during partial load conditions, the coil has less refrigerant and is less active. This is great for energy efficiency, but since a warm coil in cooling mode does not dehumidify, a specialized complement is needed. Consulting engineers who have adopted VRF for energy efficiency often consider specialized ventilation systems such as decoupled DOAS to handle ventilation and moisture removal. Together, VRF and DOAS allow engineers to design complete, energy-efficient HVAC systems well-suited for today's high-perfomance buildings.



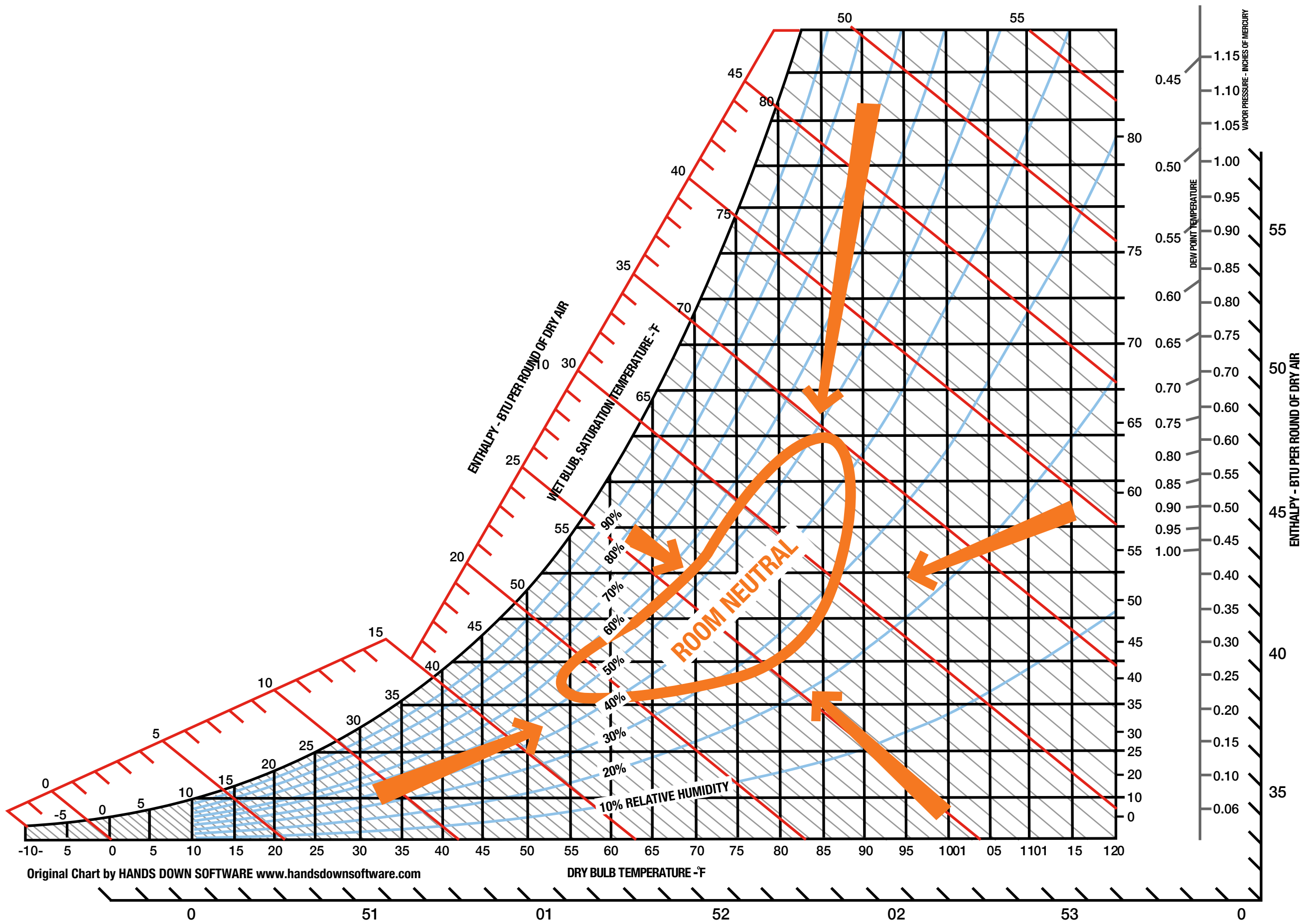
What are Energy Recovery Ventilators (ERVs)?

ERVs are designed to recapture cooling and heating energy while ventilating and equalizing humidity levels. These devices recover sensible and latent energy from building exhaust air by indirectly crossing air streams through a rotating wheel or fixed plate heat exchanger. ERVs move a building's exhaust air through the heat exchanger where it meets and tempers a stream of outside ventilation air that the ERV moves into the building from another direction. Through this crossing of streams at the heat exchanger, the ERV recovers about 70 percent of sensible energy and 60 percent of latent energy. The ERV also keeps the building from becoming overly pressurized as outside air is introduced through the use of individually controlled supply and exhaust fans.



How ERVs Enable High Performance

ERVs reduce the variability of incoming ventilation air and help bring it closer to room neutral conditions. Room neutral conditions are defined as within the range of temperatures where humans experience comfort without shivering to produce heat or sweating to cool off. In practice, room neutral is complicated by factors including age, body type, weight, metabolism, fitness, clothing, activities and environment. For example, a study conducted in Japan found that Japanese women prefer rooms at 77.36 degrees Fahrenheit while European and North American men prefer rooms at 71.78 degrees.[3] A subsequent study, conducted in The Netherlands, suggests that men prefer rooms at 72 degrees Fahrenheit while women prefer rooms at 77 degrees Fahrenheit.[4] ASHRAE Standard 55 includes guidance concerning acceptable thermal comfort based on variables including air temperature, mean radiant temperature, air speed, humidity, metabolic rates and clothing.



An ERV will handle approximately half of the load required to help bring outside ventilation air to the required temperature. In other words, facilities with a ventilation system that does not include ERV capabilities will require double the tonnage of mechanical cooling and heating. Even if an application uses VRF — one of the most efficient mechanical cooling and heating systems available — the building needs an ERV to achieve its high-performance potential. For this reason, codes and standards have been trending toward requiring ERV capabilities in a greater number of applications and at lower airflow thresholds.

What are Dedicated Outdoor Air Systems (DOAS)?

DOAS are dedicated ventilation systems designed to condition outdoor air during ventilation. Depending upon the application, a DOAS may also have energy recovery capabilities. While an ERV can handle approximately 50 percent of the load to bring outside air to room neutral temperature, the addition of mechanical cooling and heating allows a DOAS to fully condition the incoming outside air. For example, in a humid climate, a DOAS unit could cool 95-degree outside air down to the dew point — which is typically in the 50-to-55- degree range — and then reheat it back to 77 degrees, before introducing it to the building as room neutral ventilation air.

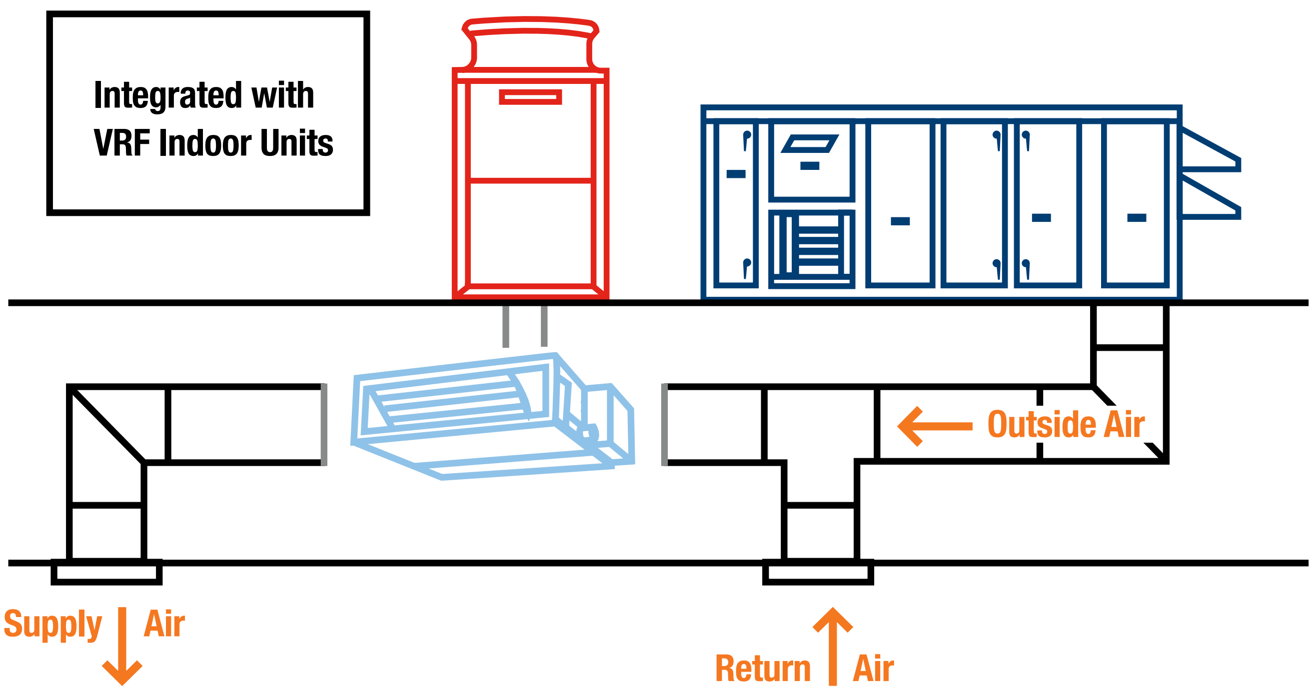
DOAS are available as packaged equipment or as a split system to support decoupled designs. Packaged equipment accounts for most of the current DOAS market. While cost effective at startup, and simpler to install, packaged equipment does not offer the same design freedom as a split-system DOAS. With split-system DOAS, architects and building owners can separate and strategically arrange VRF outdoor units and DOAS equipment.

Modern DOAS versus Old Ventilation Technologies

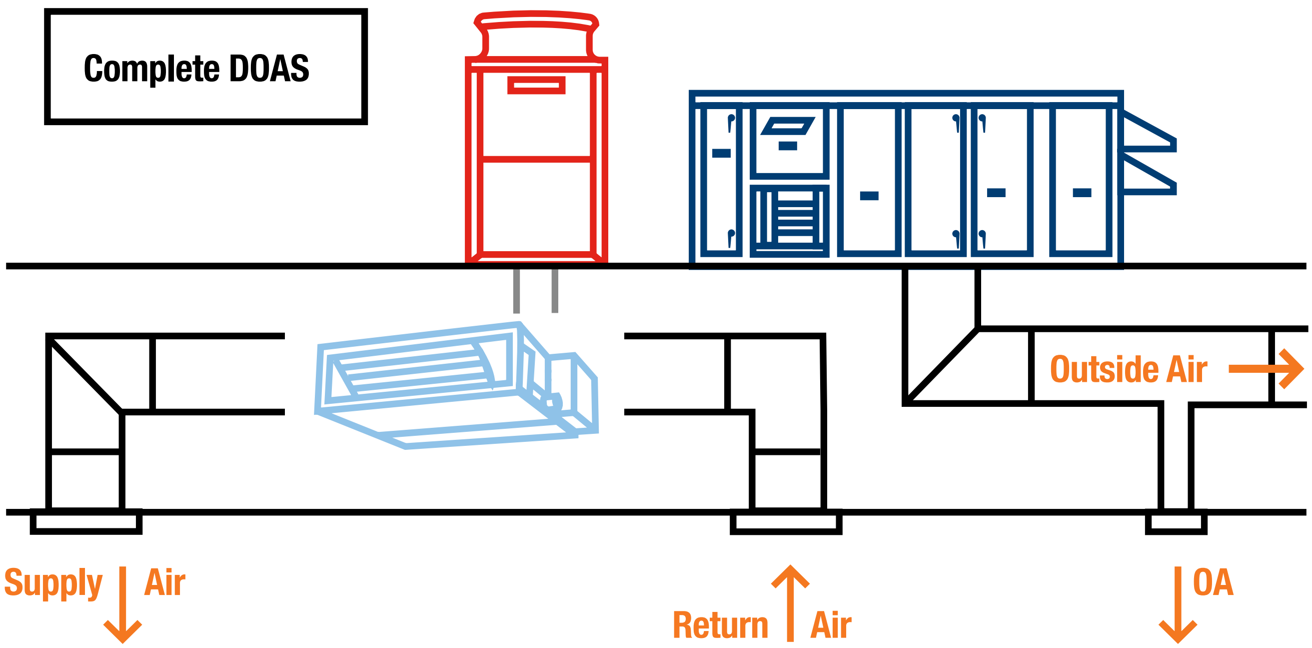
Historically, older technologies such as rooftop unitary systems handled cooling, heating and ventilation within a single system. Traditional equipment does not perform any of these functions as well as specialized technologies in terms of energy efficiency and occupant comfort and also makes it difficult for engineers to model the amount of ventilation delivered to a space. In a scenario where 30 percent of the air coming into the traditional rooftop unit is outside air and 70 percent is returned air, it is a challenge to distinguish the amount of ventilation delivered from the total airflow. While attempting to meet the requisite ventilation rate in one zone, facilities often over ventilate others, resulting in over-ventilation and wasted energy. Smarter DOAS systems eliminate these issues by decoupling the ventilaton load from the cooling and heating loads.

Design Considerations

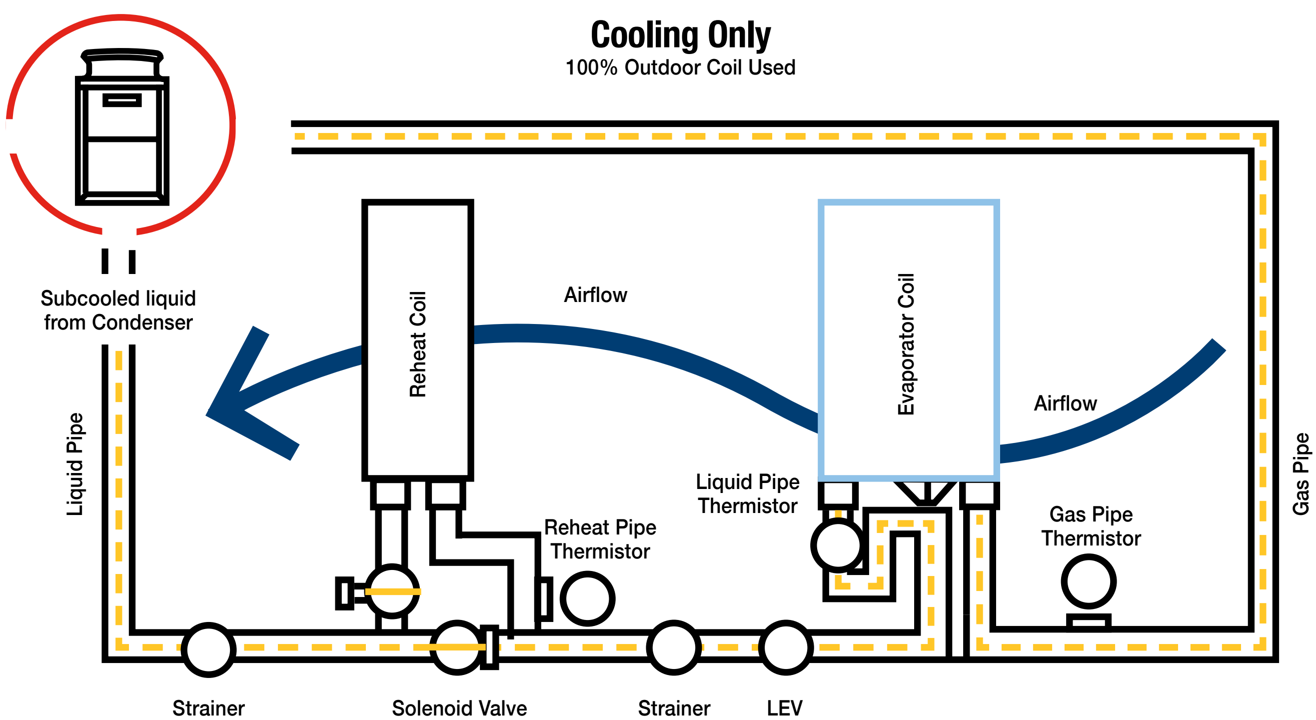
DOAS may be integrated with VRF systems in a design where ventilation is ducted directly from the DOAS to the VRF indoor units. This approach requires additional design considerations when both the DOAS and the VRF system use variable speed fans.

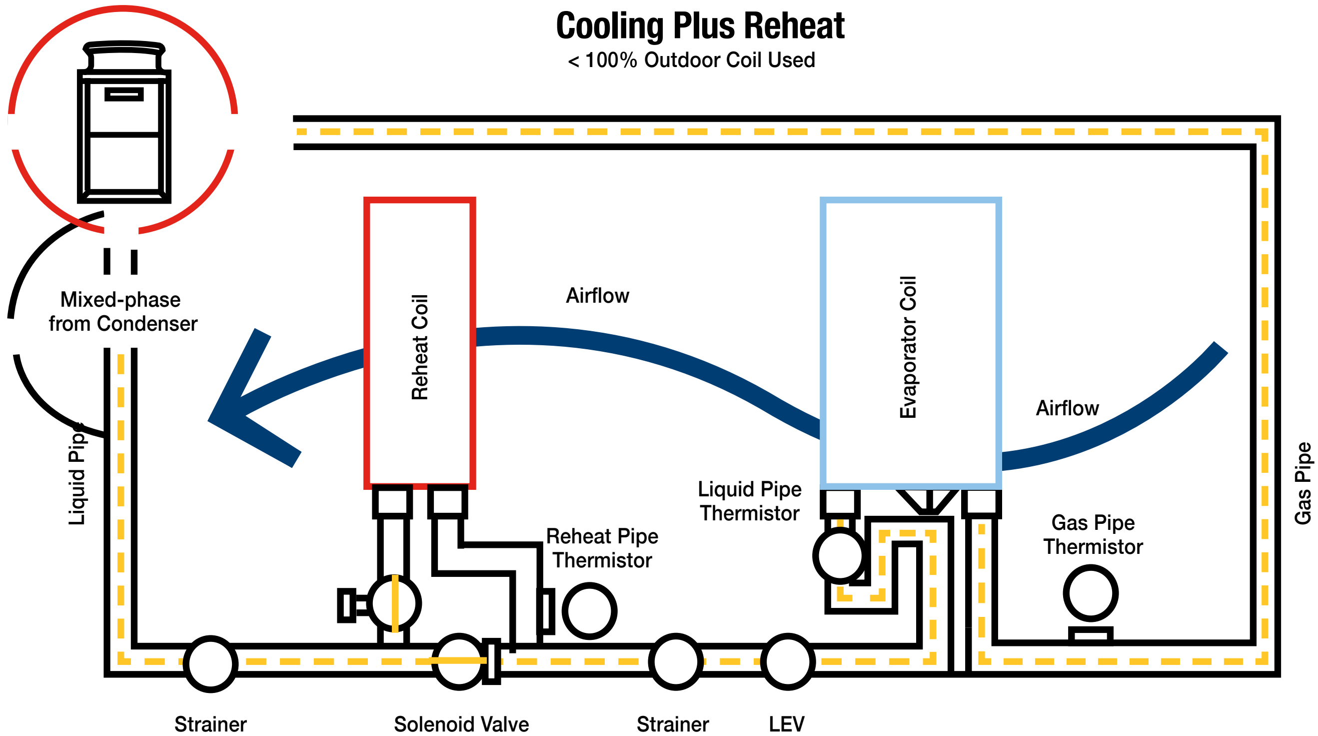


In decoupled designs, where DOAS handles ventilation and the VRF system handles cooling and heating, ventilation air is delivered directly to conditioned spaces at a room neutral temperature. While requiring two duct distribution networks, this approach makes it easier to complete fan balancing, verify proper ventilation rates and prove compliance with ASHRAE 62.1. A balancer can go to each diffuser and measure the ventilation rate in cubic feet per minute (CFM). Engineers can also incorporate energy-efficiency measures such as demand-control ventilation (DCV). With DCV, the amount of ventilation delivered in a space is continually varied by a measured variable, which is typically carbon dioxide. More sophisticated DCV applications vary ventilation to each individual zone according to each zone’s CO2 sensors. For example, in an office space with several conference rooms, the CO2 sensors would enable the DOAS to provide appropriate ventilation when 30 people are in a conference room and appropriate ventilation when only two people are in a conference room. The ability to assess and deliver the appropriate amount of ventilation in real time benefits occupant comfort, improves IAQ and saves energy.



Decoupled designs that include a VRF system with an advanced refrigeration circuit can further increase efficiency as the DOAS conditions outside air to room neutral temperature.





In the standard refrigeration circuit depicted above, a full-column of sub-cooled liquid refrigerant travels from the condenser to the evaporator coil while bypassing the reheat coil. Once the liquid reaches the evaporator coil, it is boiled into a low-pressure gas which then returns to the condensing unit.

With an advanced refrigeration circuit, instead of sending a full column of sub-cooled liquid from the VRF condenser to the DOAS evaporator coil, the system regulates the amount of condensing done by the VRF system to create mixed-phase refrigerant that is part liquid and part gas. Instead of bypassing the DOAS reheat coil, the mixed-phase refrigerant flows through the reheat coil where the rest of the condensing takes place, producing sub-cooled liquid. This allows the circuit to reject heat into the air stream where it can be used for reheat rather than rejecting that heat outside at the VRF condenser. From the DOAS reheat coil, the sub-cooled liquid refrigerant will then travel to the VRF evaporator coil where it will be boiled into a low-pressure gas and the cycle begins again. In effect, the DOAS reheat coil functions as the last section of the condenser. This method, made possible by a decoupled DOAS and VRF design, is an energy-efficient and cost-effective way to handle cooling plus reheat during ventilation.

More Efficient Compressors

In response to the growing demand for energy-efficient ventilation, some manufacturers have started to offer split-system and packaged DOAS equipment with INVERTER-driven compressors such as those found in VRF systems. Most DOAS have compressors that use single-speed scroll with hot gas bypass for capacity modulation or digital scroll. These conventional DOAS generally perform well from an occupant comfort perspective but are approximately 25 percent less energy-efficient than DOAS with variable capacity.

As with VRF systems, a DOAS with an INVERTER-driven compressor will be best in its class in terms of efficiency, sound transmission and equipment longevity. This DOAS equipment is especially suitable for applications where noise levels must be tightly controlled such as in healthcare facilities and schools.

DOAS with INVERTER-driven compressors provide an advantage in terms of delivering room neutral air for IAQ. Because reheat is typically only available on the lead refrigeration circuit, conventional DOAS produces room neutral air in a limited range of outside air operating conditions. With an INVERTER-driven design, there is only one refrigeration circuit regardless of tonnage. The result is a proportional amount of hot gas reheat to the cooling load, and the ability to deliver room neutral air to a wide range of applications.

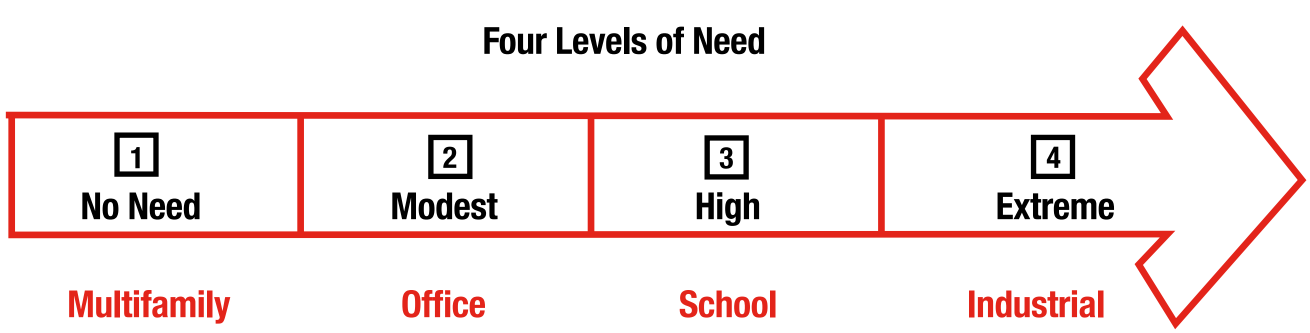
New Efficiency Metrics

Ventilation is historically governed by mechanical codes, but AHRI Standard 920 introduced two new efficiency metrics for DOAS. Moisture Removal Efficiency (MRE) is a full load efficiency metric while Integrated Seasonal Moisture Removal Efficiency (ISMRE) is a part load efficiency metric. Think of these metrics as being like Energy Efficiency Ratio (EER) and Integrated Energy Efficiency Ratio (IEER) for cooling. In the near future, architects, engineers and building owners will be able to find information at AHRIdirectory.org to compare products. The trend toward the regulation of efficiency is likely to drive more manufacturers toward including INVERTER-driven compressors in ventilation equipment. If manufacturers opted to increase efficiency by making coils larger, the coils would take up more cabinet space, possibly to the point of becoming cost prohibitive and unattractive in terms of design. Some manufacturers have adopted microchannel coils that are more efficient than conventional copper tube and aluminum fin coils but have a smaller footprint. Using INVERTER compressors to increase efficiency may ultimately be the most cost-effective option.

Choosing Between Ventilation Technologies

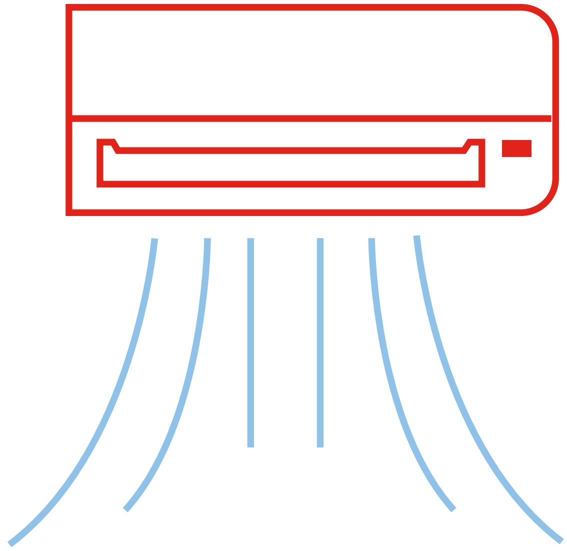
The application dictates which ventilation solution should be specified. For example, in some jurisdictions, codes and standards do not require ventilation for multifamily residential applications provided that there are operable windows. Air could be conditioned directly by the cooling and heating system and the VRF indoor unit. Typically, in these applications, it is recommended that ventilation air flow constitute no more than 15 percent of the total supply air volume of the indoor unit. While this is a rule of thumb, the threshold will vary from one climate to another based upon design conditions and the level of humidity. This recommendation may evolve as high-performance buildings become more prevalent and tighter envelopes increase the need for specialized ventilation.

For buildings with a moderate ventilation requirement such as an office, ERVs are common. An office might only require a blended ventilation rate of .15 CFM per square foot. The need for ventilation increases with the number of occupants and is a function of the activities and characteristics of the occupants. Theaters, malls, industrial facilities and schools all require greater ventilation than the typical office.



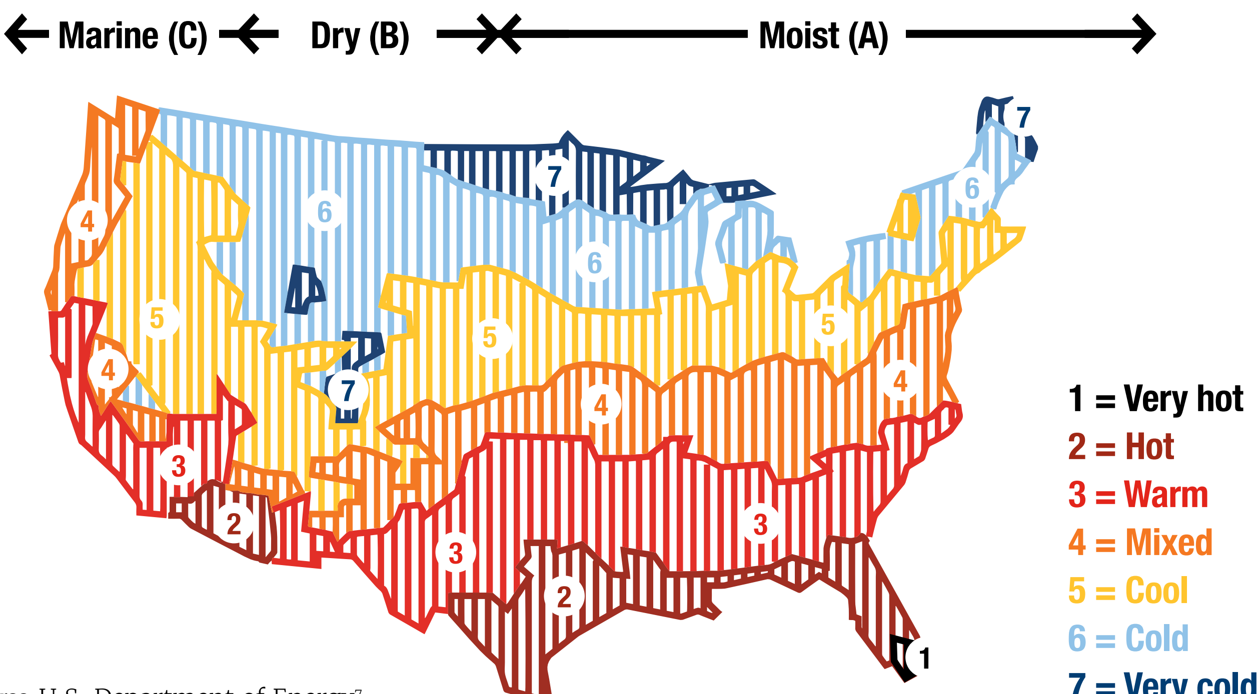
IAQ and Academic Outcomes

In K-12 educational facilities, for example, ventilation and IAQ have significant impact on wellness and academic outcomes. According to a study on the effects of HVAC on student performance, increasing the ventilation rate from 7.5 CFM to 15 CFM led to an eight percent increase in academic performance.[5] A separate study of fifth grade classrooms found that for each 2 CFM increase in the ventilation rate across the range of 2 to 15 CFM, there was nearly a three percent increase in proportion of students passing standardized math and reading tests.[6] Depending upon school size and climate, a DOAS may be preferred. Viruses, bacteria, allergens, dust, gases and other contaminants circulate indoors creating breathing hazards and contributing to conditions such as asthma if not addressed. According to the Centers for Disease Control and Prevention (CDC), the economic cost of asthma amounts to more than $56 billion annually, which includes direct medical costs and indirect costs from missing work and school.



Climate and Ventilation

Climate is a consideration when specifying ventilation systems. Humidity increases the need for DOAS and ventilation requirements rise with occupant density. Occupants replace O_2 with CO_2 and latent loads from people add moisture to indoor spaces. States from Florida to Maine, all along the eastern corridor of the United States, are prime locations for DOAS adoption. In moderate and dry climates, such as in Los Angeles, a DOAS would work, but an ERV would be more cost-effective and better performing.



Source: U.S. Department of Energy[7]

Case Study

After breaking ground on a new, 56,000-square-foot office space in 2015, The Bank of San Antonio, San Antonio, Texas needed to find an energy-efficient HVAC system that offered quality comfort and control. The search ended by selecting VRF technology from Mitsubishi Electric.

Tom Moreno, executive vice president of operations and technology for Bank of San Antonio, oversaw the project from start to finish. As the liaison for the bank, Moreno knew it would be a challenge to find an HVAC system that would meet everyone's needs. "We were looking for a system that was energy-efficient but that could also provide comfort and produce the temperatures that we needed throughout the organization." Moreno and his team originally planned to install traditional HVAC technology, but with the assistance of local HVAC contractor, Flo-Aire Service Inc., San Antonio, and engineering consultant, Cleary Zimmermann Engineers, San Antonio, they decided to consider VRF.

Eddie McDuff, vice president, Flo-Aire Service, knew VRF would be suitable for the building since it would meet the bank's initial requirements for an HVAC system. He said, "They needed a very energy-efficient system, and VRF would give them not only energy efficiency but also zone control. It's a newer way that we've been seeing a lot of offices

use air conditioning." Moreno agreed that VRF's ability to zone would allow the bank to offer comfort to every person in the building. "We needed control in the offices, conference rooms, lobby area and other communal spaces in the building. We needed to be able to manage the fluctuation of people."

As a specialized ventilation complement for VRF, The Bank of San Antonio selected a PremiSys® DOAS unit, which provides up to 100 percent outside air with energy recovery, from Mitsubishi Electric.

Since project completion, the VRF system has provided precise control and comfort for the bank. Moreno said, "We've all been in places where it's too hot or too cold but not with this system. We like the flexibility and being able to set standardized temperatures throughout the organization. We can lock specific thermostats to control cost, but we can also unlock some thermostats when clients come into conference rooms."

Not only does the VRF system keep the employees comfortable, but it also keeps the bank's technology safe, and most importantly, cool. Moreno said, "They installed wall hung units in the information technology equipment office, which is essential to operation of the organization. They can't overheat."

According to McDuff, he has only heard praise from the bank about the system's performance. "There are no complaints. I have reached out to a few people and they seem to love it, and sometimes, no news is good news. From the installation to the operation of the equipment, there has been nothing but good things."

Moreno also commented on how the system accomplished the one true goal for the bank – comfort everywhere, at any time. "We've liked how we can set the temperature an hour before guests walk in during an event and immediately they can be comfortable. Once we learned the system, it has been easy to manage it and helps us make sure the folks here are comfortable."

The Bank of San Antonio's new office space, complete with Mitsubishi Electric VRF, has been an overall success. The new space provides employees with a comfortable place to serve clients effectively and efficiently. Moreno said, "If our team is too hot or too cold, it will affect productivity. Our clients should also get good service, and ensuring that our team is comfortable allows us to fulfill our promise to our clients that they will receive an exceptional experience."

Case Study

Hamilton STEM Academy in Columbus, Ohio is an alternative elementary school focused on reading, math and science instruction. Located in a 48,000-square-foot building constructed in the early 1950s, the school needed to replace its nearly 70-year-old HVAC system which included hydronic baseboard heating via convectors in classrooms and a total absence of air conditioning except during the winter when the ambient temperature was low enough for the centralized ventilation system to provide cooling.

After voters in Columbus passed a bond issue in 2016,

$75 million was made available to upgrade the HVAC systems of Columbus City Schools including Hamilton STEM Academy (Hamilton). Hamilton was chosen as a pilot project that would serve as a proving ground for the designs and technologies that might be used to retrofit 40 school buildings in Columbus. Work began during the summer of 2016.

Several factors led Hamilton to select VRF from Mitsubishi Electric, starting with the low life cycle cost and low utility bills associated with the system. Sound transmission was another consideration. VRF units operate at low decibels so sound will not disturb students and faculty. The school also considered the cost and ease of maintenance. In this category, the school noted how janitorial staff are able to clean rather than replace the filters of VRF indoor units. Lastly, VRF proved to be practical in terms of scheduling time for the retrofit project. Unlike traditional HVAC systems, VRF could be quickly installed while students are on summer vacation with the retrofit complete by August, before the school year begins.

Additionally, VRF is the only system that would allow Hamilton and other Columbus City Schools to add air conditioning without causing total utility bills to go up. VRF heat pumps allow facilities to save enough money on heating bills to cover the cost of the additional air conditioning. Given the tightness of school budgets, this proved especially attractive.

The school installed three DOAS units on the roof and connected the DOAS to the existing ductwork which had once connected the old centralized ventilation system to each classroom. The DOAS is able to deliver conditioned air at an appropriate CFM for each classroom and there was no need to run additional ductwork.

As installed, the DOAS can also use Hamilton's gas heating to serve as a backup heating source. Typically, facilities will bring in 100 percent fresh air that is cooled for dehumidification during the summer and heated during the winter. Outside air passes through an energy wheel where it crosses streams with exhaust air and is tempered before being introduced to rooms as ventilation air. After the energy wheel, the tempered air is usually moved to a cooling coil or gas heat exchanger but the application at Hamilton included a recirculation air damper which allows the DOAS to draw on the gas heating to provide morning warm up or emergency backup heating. In the latter scenario, Hamilton would close the outside air damper and open the recirculation air damper so that the DOAS could provide emergency heat.

Conclusion

Motivated by new codes and standards, market-based incentives, sustainability concerns, and a global movement toward better building design, VRF manufacturers will continue to develop ERV and DOAS systems to meet the need for energy efficiency and IAQ. As adoption of VRF becomes more wide-spread, expect specialized ventilation systems to become more widely recognized as a necessary component for comfort and a complete, high-performance HVAC solution.

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