HVAC/R

SUMMER EDITION

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Regulating HVAC with VRF systems

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Variable refrigerant flow systems have a lot to offer as an alternative HVAC system

Variable refrigerant flow systems use a refrigerant as the working fluid in the refrigeration cycle in direct expansion air conditioning systems. Leading VRF manufacturers have labeled their systems as variable refrigerant volume, or VRV.

VRF systems comprise several components:

- Direct expansion outdoor unit(s).
- Indoor unit(s) with a coil.
- Filter (ducted and ductless) and fan.
- Refrigeration piping with refrigerant.
- Thermostats.
- Condensate drainage.
- Power wiring connections.

Ensure that the refrigerant piping systems meet the installation requirements as listed in ASHRAE Standard 15 : Safety Standard for Refrigeration Systems. For example, piping is not permitted to be installed in enclosed stairways, landings of egress, elevator

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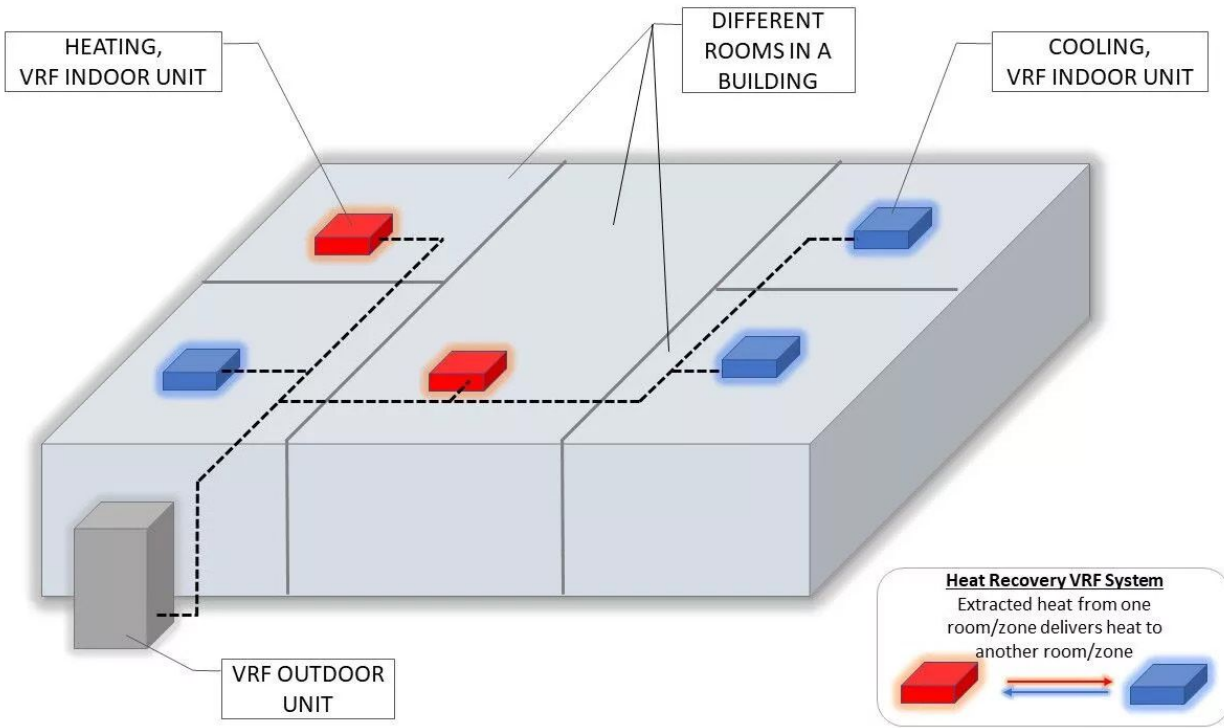

Figure 1: The energy efficiency of variable refrigerant flow systems have been significantly bolstered specifying the heat recovery VRF system that uses the waste heat generated during the cooling process of direct expansion systems and reuse it for heating, thereby providing independent cooling and heating to different zones from the same outdoor system. Courtesy: WSP

shafts or any shaft with moving objects or elevations lower than 7 feet 3 inches above the floor.

Outdoor VRF units: air- or water-source

Air-source outdoor units need to be installed in well-ventilated areas to prevent or reduce the possibility of recirculating of air through the outdoor unit because it reduces the system performance efficiency, however there were cases when installation in well-ventilated areas was not possible for air-sourced VRF outdoor units because of limits of refrigerant piping length.

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VRF outdoor units were traditionally only air-sourced. In 1990, water-cooled outdoor units were introduced to overcome the challenges with maximum refrigerant pipe length and provided more flexibility. Water-cooled VRF units use condenser water for heat exchange, therefore they can be installed in enclosed environments like underground mechanical rooms. Condenser water can be made by cooling towers, a campus loop or geothermal systems.

Energy efficiency

The system energy efficiency in air conditioning systems that use the principle to cool air and then heat it up (like VAV terminals) is poor compared to air conditioning systems that do not rely on this principle. VRF systems do not waste energy by cooling air and heating it up again to control the supply air temperature. Instead, a VRF system carefully regulates the temperature and amount of refrigerant flow in the indoor unit to achieve the desired leaving air temperature.

The power consumption for an air-sourced heat recovery VRF system ranges between 0.5 and 0.8 kilowatts/ton compared to 0.7 to 1.0kilowatts/ton conventional air-sourced chillers with VAV terminal units. Leading VRF manufacturers have established a unique refrigerant circuit that closely regulates the refrigerant flow for both heating and cooling to achieve individual air conditioning, even for buildings with both cooling and heating needs.

The overall fan energy for VRF systems is much less compared to central ducted systems like central or rooftop air handling units. The overall annual energy consumed by fans are wide-line underestimated in buildings and should get more focus in building energy consumption.

The third fan law stipulates that the electrical power consumed by a fan change with the cube of the airflow. For example, this means that a 10% increase in fan airflow results in a 33% increase in electrical power to do that work. The cubic nature of this relationship between power and the airflow or rotational speed shows how, even for small performance gains, large amounts of additional power are needed.

Ducted or ductless indoor VRF units have low-pressure fans that uses a fraction of the power compared to a central air conditioning system like VAV boxes and medium-pressure fans.

Heat recovery VRF

The energy efficiency of VRF systems has been significantly bolstered with the heat recovery VRF system that uses the waste heat generated during the cooling process of direct expansion systems and reuses it for heating, thereby providing independent cooling and heating to each zone from the same outdoor system. Heat recovery systems are identified by either using refrigerant branch controllers connected to two refrigeration pipes in the system or by using three refrigeration pipes with special y-pipe joints or headers.

Three-pipe technology comprise dedicated refrigerant pipes for suction gas, liquid and discharge gas. The dedicated refrigerant pipes provide smooth and efficient refrigerant flow during all main modes of operation and aid with the heating performance of the system.

In a two-pipe heat recovery system, where the gas and liquid travel as a mixture in the refrigerant pipes, the condensing temperature needs to be higher to separate the

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mixed gas and refrigerant. The higher condensing temperature that is needed means that the compressor has to work harder. In addition, the disturbed refrigerant flow in large pipes on a two-pipe system results in extra pressure drop, which can negatively impact the system capacity and efficiency.

Cooling only or heat pump VRF

VRF systems are offered as cooling only systems, heat pump systems and heat recovery systems. Cooling only systems should only be specified when all the internal zones require cooling all the time. Heat pump systems should only be specified when all of the zones are in either all heating or all cooling.

Because the indoor units of cooling only and heat pump VRF systems cannot independently cool or heat from the same system, it should not be considered when the internal zones require both cooling and heating, even if offered as value engineering alternative.

Occupancy comfort is vitally important and will be compromised if cooling only or heat pump systems are installed in climate zones where simultaneous cooling and heating is needed.

Variable refrigerant temperature control

Some of the latest VRF systems include variable refrigerant temperature control, which is a revolutionary method that adjusts not only the refrigerant flow, but also the temperature in relation to the space load and the ambient weather. This results in even higher energy efficiency and better comfort control.

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The evaporating temperature (in cooling) and condensing temperature (in heating) are automatically adjusted to minimize the difference with the condensing temperature and the evaporation temperature, respectively. This makes the compressors work less and also enables the system to always maintain the ideal compressor speed so that the VRF system can deliver the optimum efficiency. The user has the option to select three different variable refrigerant temperature modes:

- **Basic mode:** This mode is selected to maintain optimal occupancy comfort and the refrigerant temperature is fixed.

- **Auto mode:** This mode allows the VRF system to automatically optimize for either energy efficiency mode (reaction speed is slow), rapid cooling (powerful mode, reaction speed is very fast) or occupancy comfort (priority is given to keep the room temperature constant) and the refrigeration temperature is not fixed, but floating. This mode also allows the system to boost cooling capacity above 100% if needed.

- **High sensible mode:** Energy saving mode and the refrigeration temperature is not fixed, but floating.

Refrigeration concentration limit

The refrigerant in VRF systems migrated from R-22 to R-410a, which is a more environmentally friendly refrigerant. Refrigerants used in VRF systems are normally heavier than air and pose a health hazard to the occupants of a building if not carefully designed.

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The refrigeration concentration limit of every VRF system should be carefully calculated according to ASHRAE Standard 15 and ASHRAE Standard 34: Designation and Safety Classification of Refrigerants. The concentration limit shall not be exceeded as dictated by the ASHRAE standards and local or international building codes. The concentration limit is the total VRF system refrigerant charge (in pounds or kilograms) divided by the allowable internal space volume (cubic feet or cubic meter). The space volume is the floor area x false ceiling height.

ASHRAE Standard 15 classifies VRF systems as direct systems and high-probability systems, which means the indoor unit evaporator coils are in direct contact with the conditioned air stream and have a high potential to leak refrigerant into the occupied space. Most VRF systems sold in the U.S. market use refrigerant R-410A and ASHRAE Standard 34 lists R-410A as a safety classification group A1 are labelled as nontoxic and nonflammable.

Refrigerant R-410A is heavier than air and will displace oxygen, hence Standard 34 dictates the maximum refrigerant concentration limit of 26 pounds/1,000 cubic feet of room volume for occupied spaces. Also refer to ASHRAE Guideline 41: Design, Installation and Commissioning of Variable Refrigerant Flow Systems for additional information.

ASHRAE 15 and 34 should be used when designing VRF systems. The following procedure can be followed to ensure compliance:

1. **Schematic design:** Once the heating and cooling loads have been finalized, prepare a schematic design showing the various VRF systems, including the location

of the outdoor units, indoor units, piping layout and circuit controllers. Consideration should be given to the correct zoning of the heat pump systems in various spaces to avoid combining spaces with different thermal load profiles (e.g., avoid serving a perimeter office from the same indoor unit as an indoor office and instead serve various indoor spaces from the same indoor unit and serve perimeter units from another indoor unit). A VRF energy recovery system that serves both perimeter spaces on the north and south of a building (provided it is practically possible) from the same outdoor unit is typically more efficient than a VRF unit that only serves perimeter spaces on the north of the building because the heat that is extracted from the south perimeter offices that needs cooling can be efficiently recovered and piped to the north perimeter office that may need heating. The overall system efficiency is higher. Ensure all the indoor units and branch controller have adequate access.

2. **Calculate total refrigerant charge:** Calculate the total refrigerant charge in each VRF system by adding the refrigerant quantity of the VRF equipment and the piping.

3. **Create room list:** Prepare a list of rooms served by each VRF system. List the floor area, ceiling height, volume and occupancy classification. Use ASHRAE Standard 15 to find the refrigerant concentration limit for each room.

4. **Calculate:** Calculate the minimum allowed room volume by first calculating the minimum allowed floor area based on the formula:

    - Minimum allowed floor area (square feet) = [Total system refrigerant

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charge (pounds)] / [(refrigerant concentration limit (pounds/1,000 cubic feet) x Ceiling height (feet)] x 1,000.

- Compare the room volume with the calculated minimum allowed room volume. Verify that the room volume is more than the calculated minimum room volume. Mark rooms that do not meet this requirement for corrective action.

5. **Corrective action:** There are various corrective actions that can be taken to ensure compliance, which includes (but is not limited to):

    - Increase the room volume by connecting it to other rooms and increase the room size.
    - Increase the room volume by raising the ceiling height.
    - Reduce the refrigerant charge by reducing piping length.
    - Reduce the refrigerant charge by serving less rooms from the VRF system and increase the amount of VRF outdoor units.
    - Serve very small rooms from a standalone direct expansion mini-split system.

VRF scalability

VRF systems are inherently scalable and can be built one system at a time or installed

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separately one floor at a time. This makes a VRF system ideal for large-scale construction projects, older buildings undergoing extensive renovations and hotels or apartment buildings with multiple tenants.

Figure 2: Installation of the indoor units and the branch controller (circuit controller) in progress. Courtesy: WSP

VRF manufacturers offer an advanced centralized multizone system controller that provides the most cost-effective way to control and monitor the complete system. The multizone controller features an LCD touch screen. Up to 128 indoor units can be monitored and controlled with individual cooling and heat setpoints, setpoint range limitation, setback setpoints and auto changeover. Up to 1,024 indoor units can be monitored and controlled with the addition of adaptors. The multizone system controller has the ability to store the following data for a few days:

- Unit operation data.
- BACnet client objects.
- Input/output system data.

The operation data can be exported through a USB drive or through the web browser remotely. The building automation system can monitor the BACnet objects of indoor and outdoor unit operation data with the BACnet server gateway option.

Ancillary equipment like interlock sensors, switches, dampers, fans, pumps and lighting can be integrated into the multizone system controller.

With the addition of the tenant billing module, the multizone controller determines the energy consumption of shared condensing units based upon tenant indoor unit demand.

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Other functions of the multizone controller includes the following (but not limited to):

- Optimum start and timed override
- Advanced Auto changeover with fixed, individual, average and vote methods
- Web accessibility and alert email (standardized): all screen views and configuration menus can be accessed through web.
- I/O: monitor and control third party equipment with digital input, digital output, analog input and analog output) signals; up to 512 management points; interlock function with indoor units and ancillary equipment.
- Power proportional distribution option: calculates apportionment of outdoor unit's total power consumption to individual units on the system.
- BACnet client option: enables the controller to use the BACnet/internet protocol; allows for full monitoring and control of third-party BACnet capable equipment.

VRF installation

Like most HVAC systems, VRF systems needs to be installed correctly and comply with the manufacturer's installation requirements. The installation of refrigeration piping systems for VRF systems are more sophisticated compared to chilled and heating water systems and therefore requires specialized training and skills.

VRF manufacturers offer quality training and certification programs. The manufactur-

er should always inspect the finished VRF system installation and confirm compliance to its installation guidelines. VRF systems also require regular maintenance to ensure optimal functionality and performance, and past experience demonstrates that maintenance intensity is less compared to chilled and heating water VAV air handling unit systems.

Based on popularity of VRF systems worldwide, coupled with the improved energy efficiency and competitive or lower first cost, VRF systems are here to stay for the foreseeable future.

Pieter de Bod

Pieter de Bod *is a senior mechanical engineer at WSP.*

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Air Solution COMPANY
Cottonwood Filter Screens

Pulley Mount Air Inlet Filter Screen

Protecting cooling towers from airborne debris simply doesn't get any easier than this. Simply raise the filter screen and it will stop airborne debris at its point of entry thus protecting the entire loop (Fill, Sump, Strainers & Heat Exchangers). Also diffuses sunlight to help thwart algae growth. The non-stick surface enables easy cleaning without removal from the tower. Simply spray with a garden hose - even rain can rinse the filters clean. Saves maintenance time & effort, helps reduce water treatment chemical cost, reduces energy cost at the tower & chiller and contributes to green building initiatives.

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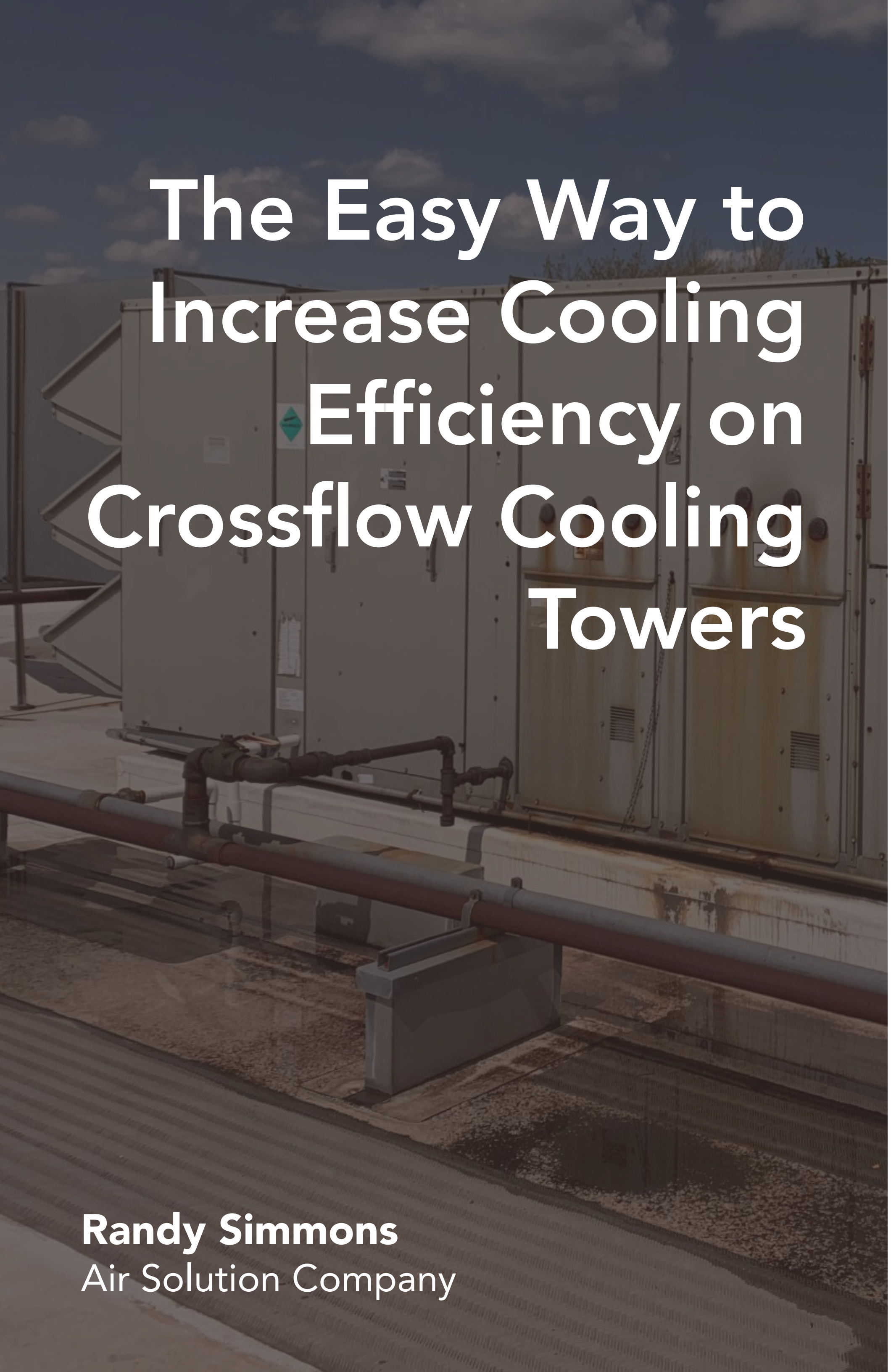
www.airsolutioncompany.com



The Easy Way to Increase Cooling Efficiency on Crossflow Cooling Towers

Randy Simmons
Air Solution Company

Metaphorically speaking, the Fill Pack and Heat Exchanger in a cooling tower system is what the lungs and heart are to the human body; when either fail or, aren't working fully, it effects other parts of the body and one's health suffers. Similarly, when a cooling tower Fill Pack and Heat Exchanger isn't kept clean, the heat exchange process doesn't work efficiently, and the health of the cooling system and its supported systems (environmental/process) suffers due to reduced heat transfer.

Cooling systems that rely on cooling towers to dissipate heat in a process or environmental application accomplish this by drawing in massive volumes of air and water into the cooling tower — as the water in the loop travels through the Fill Pack on its way back to the water basin, air is simultaneously pulled through the fill pack causing some of the water to evaporate — it is through this evaporation that heat is released.

Important Note:
The greater the Fill-to-Air exposure, the faster and more efficient the evaporation and the lower the temperature of the returned water at the basin.

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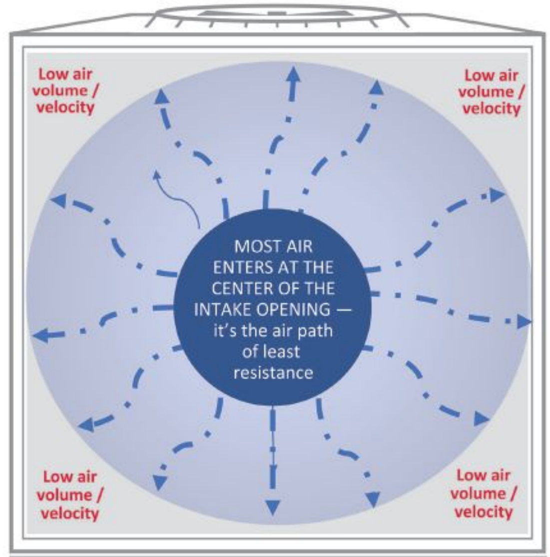
(Interestingly, Cooling towers perform the mechanical equivalent of the human body cooling system; when one sweats, the air passing over the skin causes the perspiration to evaporate, thus pulling the heat away from the body resulting in cooling — when goosebumps naturally form on the skin, it's the body's way of increasing surface-to-air contact which speeds evaporation and cooling.)

Towers *Without* Intake Filtration Have Less Fill Utilization



The further away you get from the center of the tower, the lower the air volume and velocity entering the cooling tower fill; upper and lower corners have the lowest air volume and velocity entering the fill.

The laws of physics tell us that air always moves by taking the path of least resistance — hence, the air draft created by the giant fans on top, pull air into the tower, through the fill and out the fan in a roughly tubular formation. The path of least resistance is typically the center of the intake opening/Fill Pack and where the highest air-volume/velocity will be found. As you move further from the center, air volume and velocity decreases, resulting in reduced Fill efficiency and evaporation around the edges and corners of the Fill. (See Fig #1 above)

Selecting the Correct Filtration Method.

When cooling towers are certified for designed cooling performance, they are certified based on how they will be delivered from the factory without filtration. Increasing

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capacity and efficiency beyond its design usually requires a design change commonly requiring resizing the fans/water supply and/or adding more modular cells.

One thing is certain, the cleaner the Fill/Strainers and Heat Exchangers are kept, the better and more efficient the cooling will be — this of course means that on-going maintenance is critical for optimal cooling tower performance no matter its designed capacity.

Because cooling towers are gigantic air scrubbers that captures airborne debris floating past the draft zone — the debris can circulate and clog the fill, plug strainers, heat exchangers and blow-down valves, restricting water-flow and causing significant loss in cooling capability.

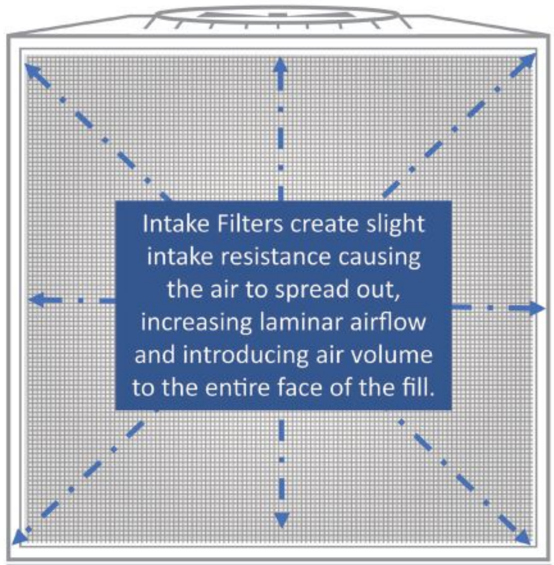
It's important to realize that optimizing the ecology and operational efficiency of a cooling tower is best accomplished by combining good physical maintenance with a chemical water treatment regimen and some form of filtration. Chemical treatment specifically targets organic matter, suspended solids/bacteria/water PH and conductivity, while filtration systems are designed to capture larger debris that can impact cooling performance.

Over 90% of fouling is a direct result of airborne debris being pulled into the cooling tower.

There are two general technologies used for filtration: **Side Stream Water Filtration** and Air Intake Filtration Systems (also called Cottonwood Filter Screens). Engineers designing NEW cooling systems or retrofitting existing systems, should understand that in most towers, over 90% of fouling is a direct result of airborne debris being pulled into the cooling tower. If you are considering a cooling system which includes Side Stream Water Filtration, it's important to realize that it won't protect

the Fill Pack, nor fully protect Strainers and Heat Exchangers — it is there to help manage airborne and waterborne debris only AFTER it gets into the tower.

Towers *With* Intake Filtration Have Complete Fill Utilization



Intake filter screens create minor air resistance at entry, increasing laminar airflow which forces the air to spread out over the entire face of the intake opening — resulting in increased fill utilization and lower water temperature at the basin.

In contrast, **Air Intake Filter Screens** are an effective, low cost approach that mounts over the intake opening stopping debris at its point of entry, keeping it out of the system in the first place and helping to reduce maintenance and water treatment chemical cost.

In addition to stopping airborne debris at it's point of entry, Cottonwood Filter Screens by design, slightly increases airflow resistance causing the air to spread out over the entire intake opening resulting in an increase in "Laminar Airflow." In other words, it creates a "Wall of Air" that fully covers the intake opening thus exposing the entire fill pack to more air volume and velocity versus not using screens and having lower Fill Pack utilization. (See Fig #2 above)

Increasing laminar airflow using Cottonwood Filter Screens is very significant because it naturally increases the efficiency of the Fill Pack in two ways. First, it provides greater Air-to-Fill exposure over the entire Fill Pack thus increasing the evaporative capacity of the Fill and Second, it stops airborne debris from infiltrating the Fill, Basin, and Heat Exchanger for optimal performance all season long.

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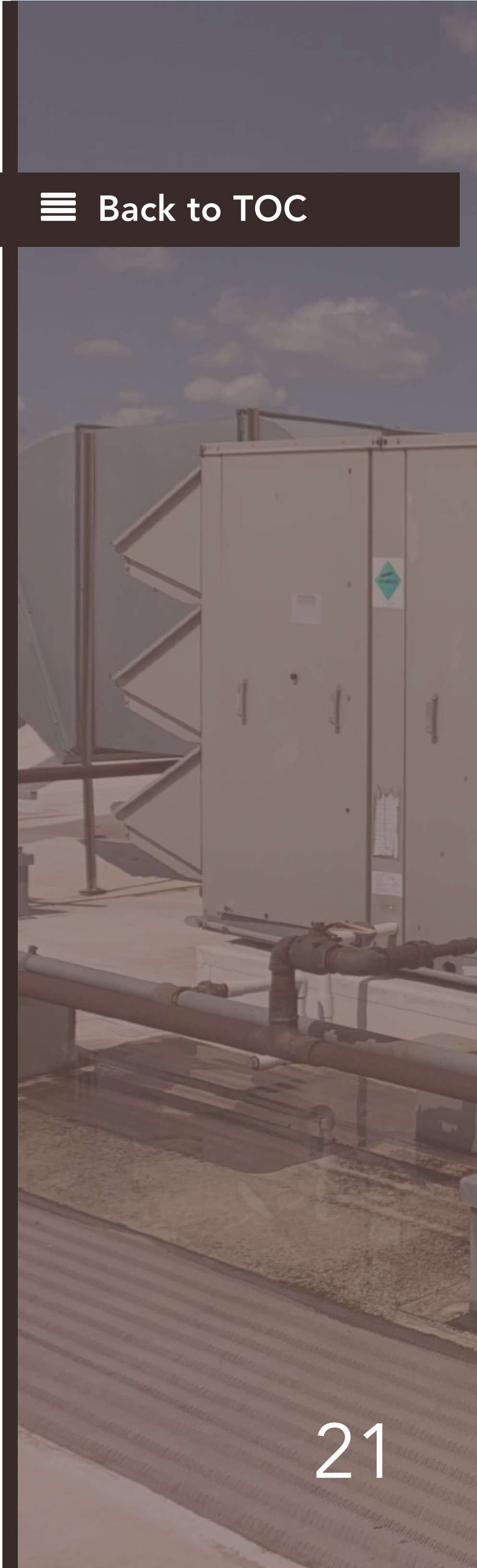

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So, what's the big upside of this? Cottonwood Filter Screens increase the evaporative capacity of the Fill, reducing water temperature at the basin by 1 to 2 degrees Fahrenheit beyond its original design temperature. This translates into a significant reduction/elimination in downtime, lost productivity and energy savings.

Cottonwood filter screens help reduce water temperature at the basin by as much as 1-2 degrees F beyond the design temperature.

When considering filtration options, the following questions should be asked.

- What filter systems (air vs. water) provides the greatest overall benefit given the operating environment?
- Which system provides the greatest filtration surface area *(this can directly impact frequency of cleaning — the smaller the filter, the more frequently it needs cleaning).*
- Specifically what parts of the cooling system does each filtration method protect vs. the other?

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- What is the cost associated with downtime due to heat exchanger or cooling tower fouling or clogging? *(Knowing this will help you justify filtration system cost)*

- Can filtration be installed without shutting down the cooling tower? *(If the cooling tower must be shut down for installation, you need to factor lost productivity into the cost of your filtration system if it's not being installed during shutdown periods).*

- What is the cost associated with both the filter and installation?

- How easy is the system to install and maintain — Air vs. Water Filtration?

Answering the above questions will help you to fully understand your options and to make the best choice.

If one isn't currently using filtration as part of the cooling system, then any filtration is better than nothing, however, selecting a solution best suited to the operation should be the goal and that requires knowing what kind of debris is the problem and where it is getting into the system. As previously stated, "Over 90% of debris entering a cooling tower is Airborne not Waterborne." As a rule of thumb: "Don't select an air intake filter to solve a waterborne problem." And, conversely, "Don't select water filtration to solve an airborne debris problem."

Randy Simmons is President at Air Solution Company.

For additional information, call 1-800-819-2869
or visit **www.airsolutioncompany.com.**

Applied versus packaged rooftop units — does it matter?

The line between applied and packaged rooftop units is sometimes blurred, and ultimately the needs of the project will dictate whether applied or packaged should be recommended and specified based on the wide array of available options

Rooftop units offer multiple opportunities to deliver robust designs with increased energy savings and have come a long way even within the past decade. Technological advances within the past 10 years of the industry have transitioned across multiple heating, ventilation and air conditioning systems to provide options for energy savings without breaking the bank.

With tons of options, each rooftop unit can be as unique as larger, more complicated HVAC systems. Traditional "packaged" rooftop units would typically comprise only the necessities — a heating coil, direct-expansion (known as DX) refrigerant coil, fan and filter.

"Applied" rooftop units comprise many different options above and beyond the traditional packaged such as energy recovery wheels, chilled water-cooling coils, hot water heating coils, hot gas reheat coils on DX units, fan arrays and more.

Many manufacturers provide packaged rooftop units as an economical option and, if not specified correctly, vendors often jump at the opportunity to substitute a bottom-end alternative as a cost savings. Specifier beware though; these lower quality alternatives may not live up to the needs of the client.

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Recently, the higher end of packaged rooftop unit lineups from manufacturers has allowed for additional options previously offered only in the more costly applied market. The line between packaged and applied is blurred, but that shouldn't stop you from specifying rooftop units with options to better benefit the requirements of your client.

If a higher-end packaged rooftop unit is the baseline, an applied rooftop unit with all the benefits and features may cost as much as two times a packaged unit with most features adding 10% to 20% and an energy recovery wheel adding approximately 50%. As specifying engineers, it is our job to educate our clients to the benefits of these added features along with the total cost of ownership. It may not make sense for short-term leases, but long-term owners may find benefits over the lifetime of the unit.

There are some common options that allow specifying engineers to select product to meet their client's needs.

Rooftop unit cabinet construction

Given the name, rooftop units are commonly located outside and thus insulation can be a major factor in energy use of the unit. Cabinet construction becomes important with regard to leakage rates and heat transfer. Airflow through the unit is transient so the cabinet's effect on heat transfer is often an afterthought and any derating of the unit is done by the manufacturer when selecting a unit to accommodate a building's heating and cooling load.

More economical cabinets are constructed with insulation values as low as R-4 but better insulated units can use double-wall construction with R-13 foam construction. The higher R value will provide a slower heat transfer between the outdoors and within the

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unit during heating and cooling design days and everywhere in between.

Better designed thermal breaks reduce direct conduction paths and creative manufacturing techniques virtually eliminate seams and reduce air leakage to further reduce wasted energy. Reducing air leakage also improves indoor air quality by reducing unfiltered air from entering the air stream. This can be even more important for critical spaces which require air supplied through a high-efficiency particulate arrestance, commonly known as HEPA, filtration system, for example.

Figure 1: A simple packaged rooftop unit with refrigerant based cooling coil, natural gas heating and supply air fan on top of a roof in Chicago. Courtesy: McGuire Engineers

Compressor efficiency

Chilled water coils and water-cooled compressors are certainly an option for rooftop units and they each come with their own benefits and drawbacks. When specifying an air-cooled, refrigerant-based cooling system, compressors are a significant energy consumer.

The difference in compressor efficiency is the classic driving analogy we've all heard so much in the industry regarding variable speed drives. Slamming on the accelerator on your way to work only to hit the brakes and come to a screeching halt at the next stop light will still get you to work, but it's hardly an efficient way to travel and much less comfortable than using the pedals to closely match the given driving requirements. Similarly, operating compressors to match building load requirements more closely is much more efficient with less wear and tear on system components.

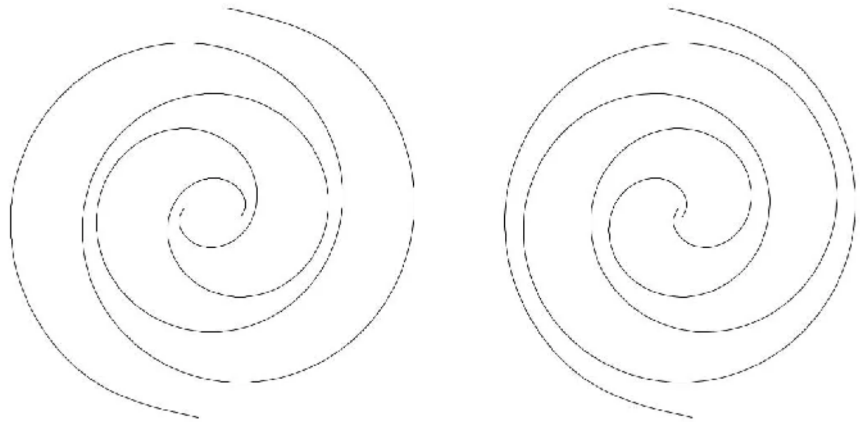

Figure 2: Scroll compressors work by using two Archimedean spirals where one is fixed and the other orbits and compressing fluid (refrigerant). Digital scrolls engage and disengage the orbiting spiral to control the amount of compression. Courtesy: McGuire Engineers

Multiple fixed-speed compressor systems offer some turn-down capabilities. By staging compressors and loading and unloading individual compressors in the system, output can more closely match the load. For example, using a combination of four fixed-speed compressors offer 4:1 turndown capability and can provide 25%, 50%, 75% and 100% cooling capacities.

However, when cooling requirements are between stages, a compressor will inevitably cycle on and off to meet the cooling demand. Internal controls by the manufacturer

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can help reduce stress from cycling by alternating compressor operation, but efficiency is still lost compared to a system with greater turn-down.

Two-stage modulating compressors are an alternate option to reduce the number of compressors, improve part-load efficiency and reduce on/off compressor cycling. Two-stage compressor modulation in scroll type compressors is provided by bypassing a portion of the refrigerant gas and reducing volumetric flow. Doing so allows the compressor to continually operate but at a reduced capacity to reduce compressor cycling issues.

Digital scroll compressors or continuous modulating compressors, operate by continuously engaging and disengaging the "scroll." Be forewarned though: acoustical care should be taken. Digital scroll compressors are not necessarily louder than scroll compressors, but the constant engagement and disengagement of the scroll provides changes in pitch that is much more noticeable. However, digital scroll compressors offer greater turndown by varying the time in which the scroll is engaged.

Specifying inverter (variable speed) compressors will provide the greatest efficiency by continuously operating close to the demand load point, reducing wasted energy. Energy efficiency ratings stay roughly the same of course as it is ratio of cooling capacity to energy, but the integrated EER increases dramatically.

Variable speed compressor output improves not only temperature control, but humidity control as well by continuously cooling. Cycling the compressor on and off reduces the run time of the compressor, which reduces humidity control as cooling turns on and off. The resultant dewpoint of the air is higher than with a continuously operating compressor.

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Manufacturers have offered options to integrate multiple compressor options to keep both costs lower with the same turndown capabilities. For example, a variable speed compressor in combination with a standard scroll compressor can operate to maintain similar turndowns as full variable systems by operating the variable speed for the first 50% of capacity and then operating a fixed-speed compressor and then varying the initial compressor to reach capacities between 50% and 100%.

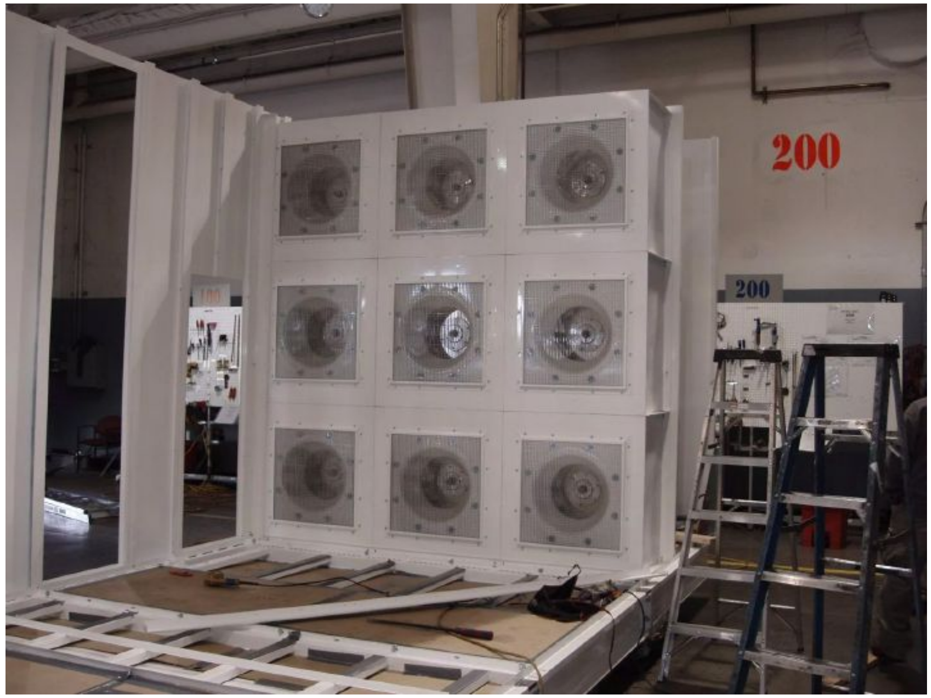

Figure 3: Fan array from 2007, which would eventually be outfitted with variable frequency drive control before electronically commutated motors became more readily available. Courtesy: McGuire Engineers

Hot gas reheat coils

Large assembly-type spaces and other spaces with larger outside air (known as OA) requirements in many geographic locations often fall victim to incorrectly specified systems and suffer high humidity issues. Many do not have dehumidification cycles and have heating coils located upstream of the cooling coil. In these instances where units have been specified for large load requirements but are in much lighter use, high relative humidity results in mold and bacterial growth problems.

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Space temperatures are satisfied so compressors are cycled on and off, but moisture remains in the air. Traditional dehumidification scenarios require the air to dry out by lowering dewpoint (cooling) to wring out the moisture (condensation). Overcooling can become an issue when actual cooling load is low, so heating needs to be provided to maintain space temperature. This energy-intensive scenario is mitigated by reducing fan speed, but high OA units still suffer because of higher latent loads.

Providing a hot gas reheat coil in DX systems alleviate these issues by operating a solenoid valve (i.e., three-way valve) and diverting hot refrigerant gas from the compressor to reheat the air. The evaporator coil is still used to drive down the dewpoint temperature and dehumidifying the air, while the hot gas reheat coil operates to maintain space temperature.

Modulating hot gas reheat valves can optimize the system even further by closely matching the coil requirements to prevent overheating.

Fan arrays for rooftop units

Specifying fan array systems increases fan efficiency while also increasing fan redundancy by using multiple, smaller, more efficient fans with electronically commutated, direct-drive motors. EC fan arrays also allow for a reduction in fan section length.

Initial offerings of fan array technology used variable frequency drives to operate the fans and, if individual fan control was required, each fan would be provided with its own VFD, which could take up significant space. EC motors allows for additional space savings not only within the cabinet, but outside the cabinet as larger or multiple VFDs are not required. A motor control panel is still needed.

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With smaller fans and motors, the energy draw is less than what was previously used in belt-driven centrifugal fans or even single direct-drive fans. Fan array systems also allow for fan redundancy, so should a single fan fail, the remaining fans can increase their speed to prevent minimal loss in air volume. Downed fans can even be replaced — while the other fans are still operating — with wiring harnesses that allow for quick power connections if continuous operation is required for critical environments.

Backdraft or isolation dampers can be added to each fan to prevent backflow through an inoperable fan. An increase in pressure drop may not be desirable and for a building with a full maintenance team a blank off panel installed for a down fan may be the more preferred option.

Smaller EC fans with their use of permanent magnetic, brushless motors equates to higher efficiency and better control. Replacing smaller, 7.5- or 10-horsepower fans are much easier than replacing a single 50-horsepower fan and motor.

EC fan arrays also allow for shorter cabinet lengths as they require less physical room due to their design. Fan arrays also naturally allow for more uniform distribution of the air, which helps with airflow over heating and cooling coils.

Beware: There may be other factors that begin to creep in and cause issues. If the airflow doesn't enter the fan section correctly or there is too much internal stratification, the fans can operate unbalanced and can cause whirring noises. Air blenders are a relatively inexpensive option to mitigate these issues.

Adding EC motors to condenser fans also increases control capabilities and energy efficiency in the condenser section and the overall unit.

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Energy recovery systems in rooftop units

Increasing energy efficiency requirements and measures are continuously added to the International Energy Conservation Code. Most notably, the 2012 version of the IECC began to require energy recovery systems if installation met certain requirements which then propelled to be more widely used in the market. Energy recovery wheels and ventilators (ERW, ERV) are more common now and can be specified as an option on rooftop units.

ASHRAE 62.1: Ventilation for Acceptable Indoor Air Quality limits air leakage between the exhaust and OA streams at 10% for Class II air and 5% for Class I air. When using desiccant wheels, most of the cross contamination occurs around the outer edge of the wheel and at the center. If lower leakage rates are required, rooftop units can also be outfitted with fixed plate ERVs.

Added cost of energy recovery components have longer payback periods but depending on local energy codes they may be required.

Packaged controls

Prepackaged controls are a large benefit to owners using rooftop units because they have been engineered and tested at the factory. End users can then be less reliant on outside sources to provide and install sensors and control programming within the packaged unit during construction. More time spent in a closed environment in the factory means less time spent in the field. Additional cost savings can be realized by the client with the reduction in potential troubleshooting exercises.

For example, dehumidification becomes much easier to manage with prepackaged

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controls for the operation of the hot gas reheat coil. ERWs are much easier to control as the rooftop unit can take in information from many different sensors to efficiently operate the speed of the wheel.

OA monitoring stations installed directly in the OA stream of the packaged unit allows for better monitoring and control of the dampers to reduce excess air. As a result of better OA damper control, energy usage is further reduced as tighter controls allow the system to provide only what is required.

Coupled with a carbon dioxide (CO_2) sensor, demand-controlled ventilation can be implemented to reduce energy costs. Measuring both CO_2 and OA, OA dampers can be controlled to provide reduced amounts OA while keeping within reasonable CO_2 concentration levels. Only time will tell how desirable energy conservation measures such as DCV will be viewed with the recent COVID-19 pandemic, but we calculated a conservative payback of approximately two years for a 15-ton rooftop unit on a recent museum project.

ERWs, ventilators and their bypass operation when economizing can be difficult with lots of different moving components and sensors. Relying on custom control systems can be difficult to program, commission and troubleshoot if there are problems. ERWs require defrost control, depending on the temperature and enthalpy between air-streams. Prepackaged controls more easily mitigate issues during operation of these complicated components.

A higher education client of McGuire Engineers requested a study to determine the approximate difference in installation cost when using a system with controls packaged

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at the factory versus a custom control solution installed in the field. The savings were found to slash two-thirds of the cost in controls as the packaged control system allows for installation in a factory-controlled environment rather than in the field. More complicated programming at the BAS was virtually eliminated as only integration of the new unit into the BAS was required with the packaged controls.

Using packaged controls comes with its own drawbacks and does not absolve the specifying engineer from reviewing the manufacturer provided controls. In VAV systems, some rooftop unit vendors will push to have the duct static pressure sensor installed close to the discharge of the unit versus the typical two-thirds downstream. There is inherent difficulty in maintaining proper VAV control when pressure sensors are located at the discharge as its measurements will not accurately reflect duct static at the end of the system.

Acoustical concerns in a rooftop unit

Technological advances have reduced some typical concerns from the past, but others are still prevalent and sometimes even more so than before. Fan acoustics are significantly reduced with EC fan array as there is less vibration than their belt-driven counterparts, but compressors are still the largest noise producing component.

Sound attenuation can be added to the compressor section, but can become quite costly if the unit is to be located near a property line or worse, above a sound-sensitive space (e.g., conference rooms or private offices).

Tenants can hear continuous pitch changes with digital scroll compressors and generally the biggest offender is usually the low-end octave bands that are more difficult

to absorb with their longer wavelengths. Additional sound deadening material is highly recommended between the unit and the roof. An acoustic consultant is, of course, highly recommended for sound-sensitive scenarios.

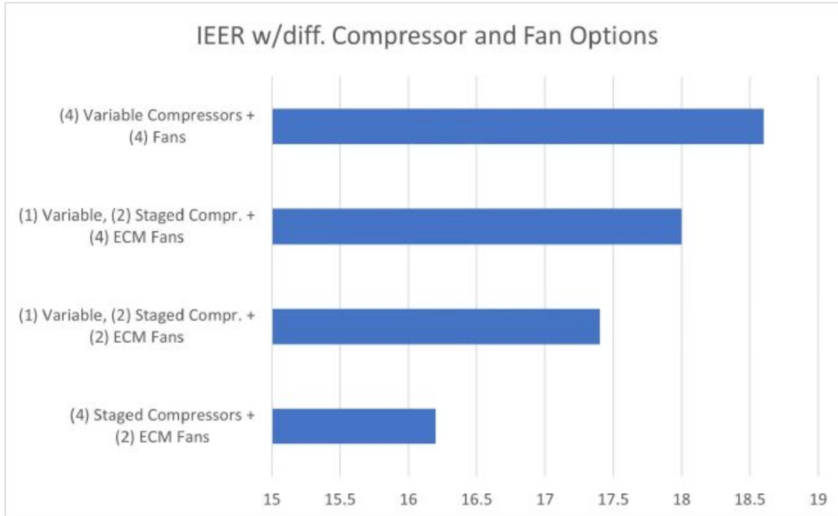

Figure 4: Integrated energy efficiency ratings increase when selection fan array options and variable speed compressors options. Combining both options further increase efficiency. Courtesy: McGuire Engineers

Some rooftop units have the option to add sound absorption in the cabinet. Roof curbs with sound and vibration deadening material can decrease transmission through the roof structure.

Equipment efficiency

Air-cooled air conditioners in the 2021 edition of IECC require minimum EER ratings and have increasing IEER ratings depending on the year. IEER, arguably the more important efficiency rating as it factors in part-load use instead of total capacity, is not difficult to meet by implementing any of the aforementioned options.

Reviewing 30-ton unit selections with three different compressor options from one manufacturer, yielded IEER ratings with increasing value. Multiple options were viewed (see Figure 4):

- Four single-stage compressors with two ECM fans, IEER = 16.2.

- Variable lead compressor and two single-stage compressors with two ECM fans, IEER = 17.4.

Figure 6: An existing packaged rooftop unit for a confidential theater in Chicago. This theater also had issues with mold and high humidity with an incorrectly specified unit. Courtesy: McGuire Engineers

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- Variable lead compressors and two single-stage compressors with four ECM fans, IEER = 18.0.

- Three variable compressors and four ECM fans, IEER = 18.6.

EER values stayed relatively the same, but a noticeable increase in IEER numbers were found. Operating equipment that more closely matches load requirements increases operating efficiency by reducing unneeded energy usage.

Total brake horsepower is reduced when using a four-fan array system rather than two fans. While working through a rooftop unit selection with 12,000 cubic feet per minute of air movement, two supply fans provided approximately 10.1 total BHP while only provided 60% of the airflow with one fan failure. Four supply fans provided 8.70 total BHP while providing 100% redundancy in case of one fan failure.

Many standard options available with packaged rooftop units continue to blur the lines between packaged and applied rooftop unit products. When specifying rooftop units, as with any product, it is important to understand the needs of the client. The name "packaged" or "applied" shouldn't matter.

John Song, PE
John Song *is a mechanical engineer and project manager at McGuire Engineers with 10 years of experience in the HVAC industry.*

ELECTRIC TANKLESS WATER HEATERS

THE RIGHT TEMPERATURE.
AT THE RIGHT TIME.

Bradley's Electric Tankless Water Heaters ***POWERED BY KELTECH*** are the industry's most precise, durable and reliable products for emergency safety and other tankless heating applications. These tankless water heaters have the industry's longest warranty and are the only ones with an ASME HLW stamp and to be recognized by the National Board of Boiler and Pressure Vessel Inspectors. Bradley Tankless Water Heaters deliver performance, precision and safety. **Tankless Water Heating Solutions. Brought to Life.**

For easy-to-use sizing calculator visit bradleycorp.com/water-heater-sizing

Bradley®

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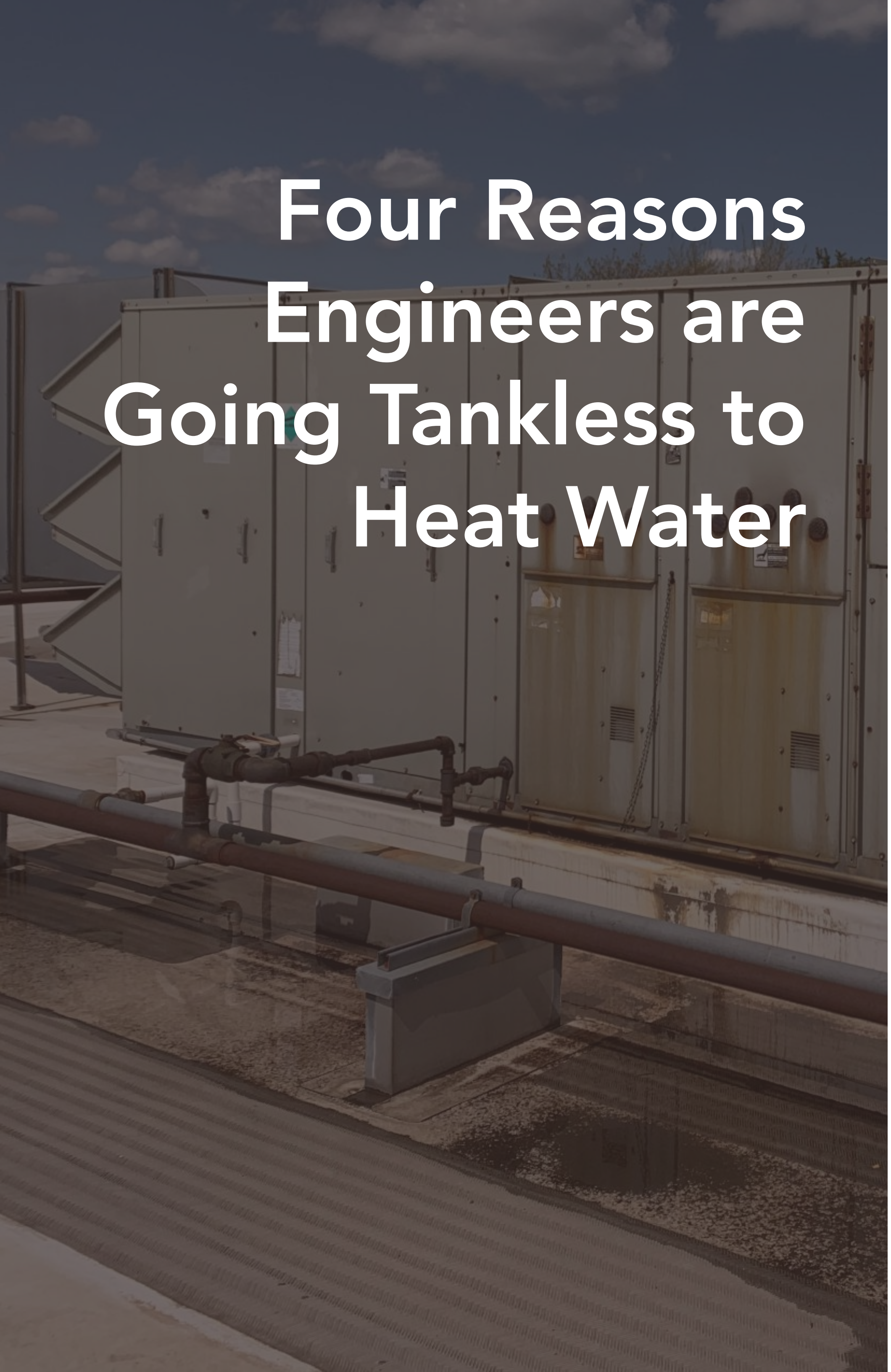

Four Reasons Engineers are Going Tankless to Heat Water

Today's specifiers and plumbing engineers are feeling greater pressure to cut energy consumption and costs while improving performance in their operations So, when it comes to heating water for applications, such as emergency safety showers and eye/face washes, many are seeing the benefits of "going tankless."

Using tankless electric water heaters make operations more efficient and functional because they provide:

1) Reliable, on-demand hot water

2) Dependable, consistent water temperature

3) High energy efficiency

4) Easy installation

Bradley's Electric Tankless Water Heaters, powered by Keltech™, deliver on-demand ANSI/ISEA-required tepid water to emergency safety showers and eye/face washes and other tankless heating operations. Drawing energy only when needed, these tankless water heaters are efficient and precise in consistently supplying tepid water, saving energy and utility costs. The **ANSI/ISEA Z358.1–2014 American National Standard for Emergency Eyewash and Shower Equipment** recommends that tepid water for plumbed

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emergency equipment be between 60-100° F or 16-38° C. Tankless water heaters ensure that the water temperature is heated within this temperature range at all times.

Compared with traditional water heaters that require energy to maintain tepid water at all times – continuously having to heat and reheat water – Bradley's tankless water heaters use energy only when the safety units are activated, resulting in significant cost savings.

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Since tankless water heaters heat water on-demand, eliminating the need to store hot water in a tank, there is reduced risk of bacterial growth in stagnant water. Plus, in emergency situations, having clean, on-demand heated water readily available can make all the differences in preventing bodily exposure, injuries or harm.

Bradley Tankless Water Heaters deliver performance, precision and safety

Designed to meet the needs of today's complex operations, Bradley's Electric Tankless Water Heaters are the industry's most precise, durable and reliable products for

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emergency safety and other tankless heating applications. These tankless water heaters have the industry's longest warranty and are the only ones with an ASME HLW stamp and to be recognized by the National Board of Boiler and Pressure Vessel Inspectors. Bradley's Tankless Water Heaters deliver performance, precision and safety.

"Designed for long-lasting performance, all Bradley models are precision-engineered with durable materials, such as copper tubing and robust brass castings, exceeding the standards of any application and setting the bar for other technologies in the tankless category," says Tony Clouse, Industrial Business Development Specialist, Bradley Corp.

Using state-of-the-art technology, Bradley's tankless CLE and SNA models feature the lowest pressure drops in the industry, providing greater reliability and performance than competitive models.

Installation of these units is easy since only one electrical connection and a cold water line are needed, saving labor time and additional costs. Bradley's tankless water heaters also have a smaller footprint than large commercial tank water heaters, making them easier to retrofit existing eyewash stations and emergency showers.

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Another advanced feature of Bradley's water heaters is TepidGuard™, which is an anti-scald feature, standard on all SNA-Series Safety Shower Heaters. "This overshoot purge will automatically open and purge excess temperature water, and actively monitors temperature within the heater while operational," Clouse said. "It also passively monitors water temperature while the heater is inactive. This is beneficial for outdoor installations where sun and weather can cause water temperature to exceed ANSI standards."

Not only are the heaters ideal for instantaneously providing ANSI/ISEA-required tepid water to emergency safety showers and eye/face washes, they also deliver heated water for a wide variety of industries and applications that require an immediate, on-demand and unlimited supply of water at a specific temperature.

"Operations don't want to have to constantly heat 500 to 1,000 gallons of water when they may not need constant access to heated water," Clouse explained. "Our customers have responded very positively to the fact that Bradley's electric tankless water heaters provide measurable cost savings due to their efficient operation, and can also achieve sustainability goals for the facility."

Learn more at **https://www.bradleycorp.com/tankless-water-heaters**

Understand the physics of air

How does air density affect fan performance?

Air is a physical mixture of gases (not a chemical compound) consisting primarily of nitrogen (78% by volume), oxygen (21%), other gases (less than 1%) and some amount of water vapor. Air does not have a uniform standard composition in all places and its density (mass of a unit volume) is always different. Density is important in air movement and air handling systems because density affects fan performance.

The density of air or any gas varies per the temperature and pressure conditions, governed roughly by the ideal gas density equation ($\rho = PM/RT$). Air density is directly proportional to pressure and inversely proportional to temperature. As temperature increases, air density decreases. At higher altitudes as the air pressure drops, there will be a significant decrease in air density.

And in the case of air, moisture content present in the air increases its density and makes it heavier. Because of this variability in density, many applications use a benchmark or a concept of “standard air density,” which is simply air density calculated at standard temperature and pressure conditions. The STP standard used in engineering is the density of 0.0765 pounds per minute/cubic feet for air. This is the density of dry air at an atmospheric pressure of 29.92 in Hg or 14.70 pounds/square inch at sea level.

Because air acts like a fluid, it will move from areas of higher pressures to areas where the pressure is lower. As air temperature increases, the volume increases and pressure decreases and it will also move up and possibly out of a space — similarly to ancient man’s air handling attempts. These passive movements of air as a function of pressure differentials in the environment or with thermal buoyancy using spaces with entry

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openings at the bottom and exits near the top can be fundamental strategies used in air movement. However, mechanical means using motorized fans or other equipment is most commonly used to induce the flow or movement of air.

Randy Schrecengost

Randy Schrecengost *is a senior project manager and principal mechanical engineer with Stanley Consultants. He has extensive experience in design and in project and program management at all levels of engineering, energy consulting, facilities engineering and commissioning. He is currently ASHRAE Director Regional Chair for Region VIII and is a member of the Consulting-Specifying Engineer editorial advisory board.*

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MYSON

iVECTOR S2

A new generation of hydronic fan convectors for heating & cooling

iVector S2 Series: a hydronic fan convector unit with intelligent cooling & heating capability

A smart way to improve indoor climate

Today, both renovation and new building projects have strict standards that raise the bar for overall efficiencies. At the same time, there is a demand to reduce dependence on finite energy sources, cut emissions and lower overall costs. Modern hydronic heating systems are designed to work at significantly lower temperatures to help improve system efficiency, achieve meaningful energy savings and improve indoor climate comfort.

Meet the newest generation of fan convectors

Advanced European technology adapted for the North American market. The iVECTOR S2 is the newest energy efficient fan convector from MYSON, designed specifically to address emerging demands for comfort and energy efficiency. Boasting an attractive, compact design the iVECTOR S2 can provide high heating performance even when operating at low temperatures and with low water content. This provides efficient energy use without sacrificing outputs. When combined with a reversible heat pump or a separate cooling source, the iVECTOR S2 can offer both heating and cooling functions, making it a perfect solution for both commercial, multifamily and single family residential use.

Built with flexibility in mind

With iVector S2 it's all about design flexibility. Installation options include both surface mounting as well as built-in options (walls or ceiling). Controls are available in either onboard or remote options, along with solutions for fully autonomous control, 0-10V control for BMS systems or fixed fan speed control. With a choice of either 2-pipe or 4-pipe heat exchangers, iVector S2 is available in 5 different sizes so specifiers won't have a problem finding an iVector S2 model to meet their project's needs.

Combining iVector S2 with other low temperature systems, for example hydronic panel radiators or a radiant system, provides an ideal combination for optimum in-door climate comfort all year long. The iVECTOR S2 is also the perfect solution for rooms not in regular use such as guest rooms or hobby rooms thanks to rapid heat-up and cool-down times.

Modern/Slimline Design

With inspiration from leading Italian designers, the aesthetically pleasing iVector S2's slimline design allows for discreet positioning without compromising performance. Whether it be wall or ceiling mounted, or a recessed/built-in installation, iVector S2 will blend into its environment seamlessly. For maximum design flexibility, all casings and grilles can be produced in virtually any RAL color (standard is RAL 9003).

Controls with a high IQ for smart buildings

The heart of the iVector S2 is its ingenious and highly accurate controls with PID logic and specially designed algorithms that intelligently drive optimal performance all year long. Combined with a high efficiency DC fan motor, the result is ideal comfort and energy efficiency.

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User interface flexibility

Whether selecting the intuitive onboard SmartTouch user interface or the remote wall mounted SmartTouch user interface, specifiers have choices when specifying iVector S2. The onboard control is capable of controlling a single unit while the remote SmartTouch can control up to 30 similarly equipped iVector S2 units. If these solutions aren't optimal, then iVector S2 can be fitted (field or factory) with the available 0-10V control board for use with suitable 3-party thermostats or BMS systems.

Performance versatility

iVector S2 is available in either a 2-pipe or 4-pipe version with standard connections on the left side of the unit (field or factory changeable to right side). Depending upon unit size, heating outputs range from 7,541 btuh to 32,552 btuh at 176/167/68oF (2.21 kW – 9.54 kW at 80/75/20oC). Total sensible cooling ranges from 3,106 btuh to 12,659 btuh at 45/54/81oF (0.91kW – 3.71kW at 7/12/27oC). All values at high fan speed.

Consider iVector S2 for your next project and enjoy all of these benefits;

- **High heat outputs at low system temperatures**
  The iVECTOR S2 provides high outputs in low-temperature heating systems. Ideal in combination with heat pumps!

- **Fast, responsive heat-up times**
  The iVECTOR S2 has considerably less water content than conventional panel radiators. Its low thermal mass ensures fast heat-up times and efficient operation.

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- **Cooling**
  Cooling is possible with the iVECTOR S2 when connected to a reversible heat pump or a separate chilled water source.

- **Intelligent control**
  The iVECTOR S2 is equipped with an intelligent control system. It allows easy operation and integration with other building management systems

- **Whisper quiet operation**
  The latest in modulating fan technology offers the best heat output with the lowest imaginable noise level.

- **Space-saving installation**
  Thanks to its compact dimensions the iVECTOR S2 provides high heating and cooling performance with minimal size.

MYSON is a brand of Purmo Group (www.purmogroup.com) and is one of the oldest and most respected names in the HVAC industry. We have been manufacturing fan convectors for over 50 years. With a reputation for maximizing the role of innovation and technology in our operations, we are committed to helping reduce CO_2 emissions by developing energy efficient heating and cooling products that are capable of operating effectively at low flow temperatures.

Contact us today to for complete information about iVector S2 including model specifications, submittals, iVector S2 performance metrics and more.

Manufacturing and industrial building HVAC, plumbing trends

Several new and retrofit manufacturing building projects show trends in HVAC and plumbing systems

MEP ROUNDTABLE

Brian Arend, PE, LEED AP, Electrical Engineering Manager, SSOE Group, Toledo, Ohio – Shane R. Eckman, PE, LEED AP, Vice President, Industrial & Institutional Practice Leader, Stanley Consultants Inc., Minneapolis – Kevin LaPlante, PE, LEED AP, Mechanical Group Leader, CRB, Medford, Massachusetts – Sunondo Roy, PE, LEED AP, Director, Design Group, Romeoville, Illinois

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What unique cooling systems have you specified into such projects?

Shane R. Eckman: The HVAC systems we design for our clients vary significantly. They include: Office meeting and break rooms, bathroom and locker rooms, laboratories, general warehouse, chemical storage, chemical vapor and storm shelters and lower flammability limit systems to address the potential for explosions. Each type brings its own challenges and code requirements.

What unusual or infrequently specified products or systems did you use to meet challenging cooling needs?

Sunondo Roy: An interesting application we've recently faced is not with cooling, but rather dehumidification. The problem was that the process involved heating humid outside air in a large, industrial scale oven to a high enough temperature to complete the drying process for the product. As such, having the air as hot as possible was key. In the hot, humid summer months, it made no sense to achieve dehumidification with mechanical refrigeration as all the energy to sub-cool the air would be completely wasted as the airstream was being heated up the oven's gas burners to create the product drying media. Instead, the right approach was to use desiccant dehumidification to remove the moisture in the air without using excessive energy to sub-cool the process air and then reheat it in the oven.

Describe an industrial or manufacturing project in which process piping was required. What were the challenges and solutions?

Shane R. Eckman: Challenges related to process piping will vary depending on a variety of factors. The gas or fluid being conveyed and line size may dictate the type

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of piping material, the type and spacing of supports and anchors and the necessity to accommodate expansion through expansion joints and loops. Routing of the lines may be dictated by the capacity of the supporting structure as well (e.g., roof framing) and may require strengthening the roof system or designing a separate support structure (pipe racks).

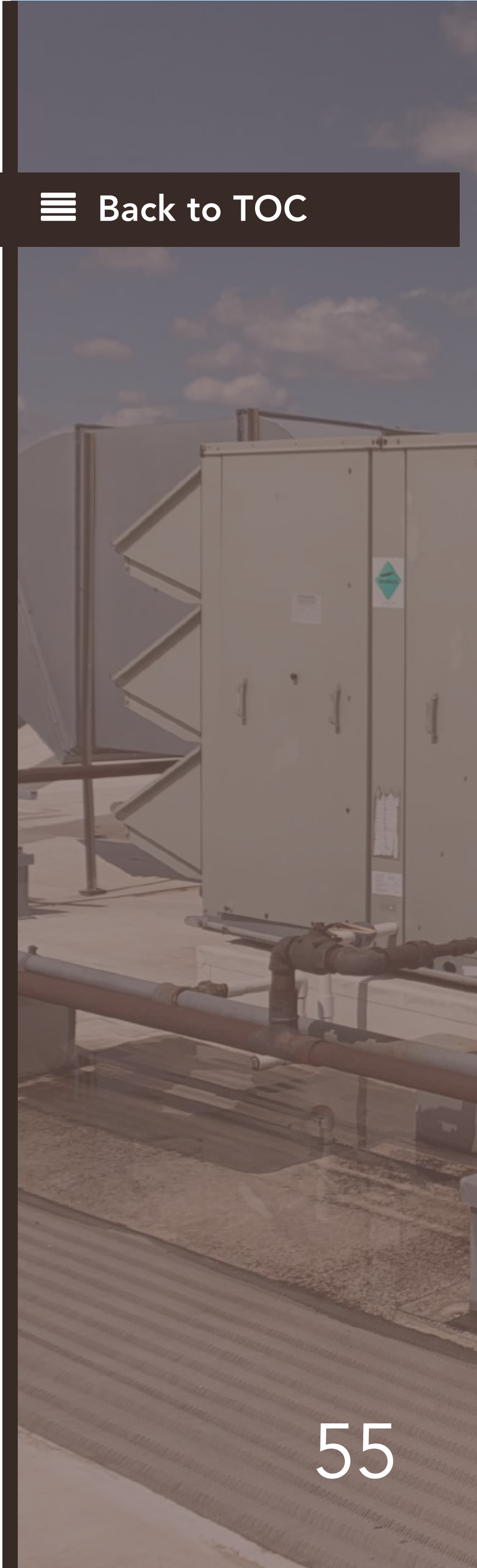
Describe a facility in which there were specialty air movement requirements, such as unique air pressure needs or high-velocity low-speed fans.

Kevin LaPlante: Pharmaceutical manufacturing facilities depend on maintaining specific filtration levels, air change rates, space pressure relationships and directional airflows. All of which help ensure product integrity, minimize risk and protect occupants from potentially harmful environments. Careful attention is given to placement of ceiling mounted HEPA filter terminals and low wall returns to capture airborne particles while providing uniform space temperature and humidity. Computational fluid dynamics and continuous dilution modeling are common tasks when designing for these critical environments.

Consulting-Specifying Engineer

Meeting New Industry Standards with Rooftop Systems and Intelligent Controls

In a world of ever-changing regulations and expectations, Trane's robust rooftop systems provide flexible and reliable solutions that are simple to design and maintain. Pair them with intelligent control solutions to create highly efficient and future-forward buildings. Trane is engineering excellence - without complexity.



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Meeting New Industry Standards with Rooftop Systems and Intelligent Controls

Learn why you should package rooftop units and controls together, and how delivering "best practice performance" can be easier than you think.

Can rooftop units still provide the performance that customers need when expectations are so much higher? Can engineers meet those needs and deliver engineering excellence without getting bogged down in complexity? Absolutely. By bringing equipment and controls together from the beginning, you can deliver intelligent rooftop systems.

Packaged rooftop units have been the industry go-to for simple and reliable comfort in a wide range of commercial buildings. However, in today's world, many rooftop HVAC projects don't feel so simple anymore.

Industry regulations are more demanding. ASHRAE® 90.1 energy efficiency standard is more stringent. During the pandemic, attention to indoor air quality was heightened. Plus, every client has different expectations for how their building will perform, creating more design and applications challenges to account for.

Rooftop unit manufacturers have been updating products to deliver the higher performance today's market is demanding. But equipment only delivers the performance that controls command… leading to the introduction of ASHRAE Guideline 36, High-Performance Sequences of Operation for HVAC Systems. This "how to" for best practice controls programming requires expertise that can be difficult to find.

Packaging the performance that each customer requests.

But guess what? The pressure isn't all on you. Trane's newest approach merges our mechanical knowledge and programming expertise to deliver state-of-the-art equipment and controls together in packaged solutions. The resulting "intelligent systems" are pre-programmed to match customer priorities whether that means energy efficiency, indoor air quality, flexible comfort or something else. Usually, it becomes a balancing act to serve multiple KPIs.

Other OEMs are approaching today's higher performance requirements in a variety of ways. In Trane's quest to keep it simple for engineers, we wrangled the complexities into an easy three-step process.

1. An online tool called **Trane® Design Assist™** guides engineers through control system specification and performance definitions.

2. From the factory Trane's system control applications allow the easy implementation of Guideline 36 appropriate sequences to meet the engineer's specified requirements.

3. The end-customer/building owner receives a performance-built system that operates according to the defined specifications, with the intelligence to sustain that performance over time.

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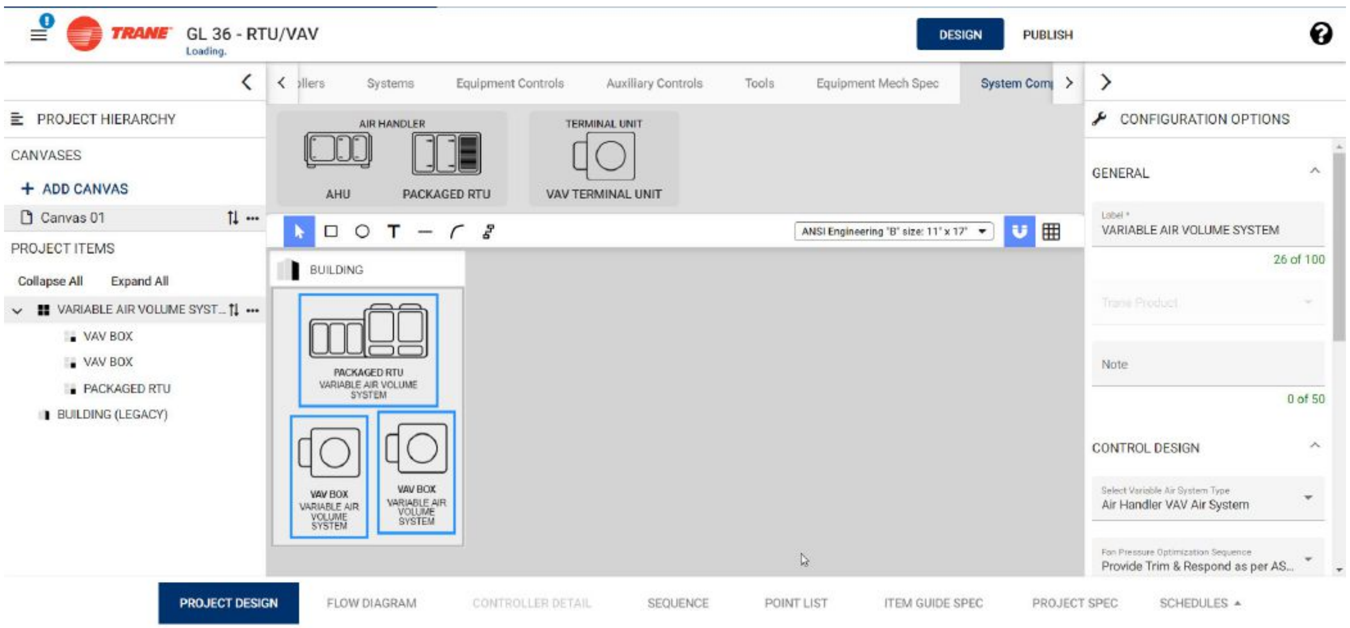
It's fast, easy and virtually risk free. The performance you specify comes together in a matter of minutes. With multiple add-ons available for ventilation, filtration, VAV, heat-pump heating and more, intelligent rooftop systems can rival applied systems for overall performance and flexibility—and the software holds the responsibility for most of the complicated, time-consuming, risk-inducing technical work.



Use Trane Design Assist to plan your next project. Get started today at ***tranedesignassist.com.***

Solving for what matters.

Intelligent rooftop systems are the answer to new expectations that demand more rigor from HVAC. Here are some of the current trends that are making equipment/controls synergies even more important today.

New energy efficiency standards. Once again, the bar has been raised. This time it's all about meeting **U.S. Department of Energy regulations**. The new 2023 system cooling efficiency minimums increased on commercial units above 65K BTU by approximately 15%. Natural gas heating efficiency (> 225,000 btu/h) increased from 80% to 81% steady state efficiency.

> Trane has introduced new rooftop products with optional features and optimization programming that bring projects into compliance. All rooftop units meet or exceed current standards. Our large commercial rooftop tiered offering allows you to select units that exceed the minimum IEER efficiency requirements by 11% up to 30%. In the light commercial offering, **Precedent® eFlex™** efficiencies are up to 85% higher than standards established by the Department of Energy and ASHRAE.

Decarbonization. Conventional fossil fuel heating methods are falling out of favor in many parts of the world. More building owners are striving for carbon-neutral buildings to meet local mandates or sustainability goals. Low- and no-cost control methods, like scheduling and optimization strategies, can be deployed in existing building automation systems as first steps in the **decarbonization journey**. Simple changes can increase the overall energy efficiency of the building and, therefore, reduce its carbon emissions. The money saved by spending less on energy can be funneled into capital projects (such as upgrading to more energy-efficient equipment) to take decarbonization further.

Optimized indoor air quality. The public became more sophisticated about indoor air quality (IAQ) during the COVID-19 pandemic, changing expectations for commercial buildings forever. Increasing ventilation and filtration can help to optimize indoor air quality, but it results in higher energy use and operating costs, too. Some rooftop systems offer a range of filtration options, including MERV 13 and higher. Applying the right control sequences can minimize the potential cost consequences that may be necessary to achieve higher IAQ.

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Improved occupant comfort. Zoned rooftop systems are an improved way to deliver more targeted comfort control in spaces like health care facilities, schools and office buildings. Zoned systems inherently require more sophisticated controls—intelligent systems include features that simplify installation, commissioning and service while maintaining performance parameters continuously.

Contractor and service provider challenges. With experienced technicians retiring and new skilled employees scarce, contractors want to keep projects simple and fast. Packaged rooftop units feel familiar. Packaged rooftop *systems* ease the transition to the more complicated solutions the market is demanding. Next-generation controls make system setup, service and maintenance as easy as ever, with digital interfaces and mobile apps that make sense to a younger workforce.

Packaged components are better together.

So, what goes into an intelligent rooftop system? With Trane, everything that is required for you to meet customers' performance expectations can be included in the package. We have a complete portfolio of rooftop units with performance features and options; controls from unit controllers to building automation; and a service portfolio that spans from installation and commissioning through ongoing performance support. Power meters, valves, actuators, equipment and BAS can typically be integrated, too. Building everything on open, standard protocols allows for multi-vendor installations and easy connectivity throughout the building ecosystem.

As a starting point, a typical basic system includes the rooftop unit, VAV terminal units, system controls wireless sensors.

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Rooftop System Essentials

Packaged rooftop units have factory-mounted controls, and we can factory-assemble a wide range of options for managing temperature, humidity, ventilation and indoor air quality to serve almost any specification (gas packs, heat pumps and hybrid dual fuel systems). Optional features include variable speed fans and compressors, modulating hot gas reheat, modulating gas heat, high MERV filtration, and many more.

Features	System Benefits
Higher Efficiency Units	Energy Savings
Multi-Speed or Variable Speed Fans	Quieter - Fan Energy Savings
Better Humidity Control	More Comfortable Spaces
Modulating Gas/Electric Heat	Mitigates Overheating in Off-Peak Conditions
Heat Pumps/Dual Fuel	Lower Carbon Emission Systems
Integrated Modern Controls	Secure, Remote Connection, More Serviceability

Heat pump options: All-electric or dual fuel

The electrification of heat is an important tactic in an overall building decarbonization strategy. Many rooftop units can reverse the refrigeration system to operate as a heat pump—delivering all-electric, all-in-one cooling and heating. Some units can be fitted with a separate gas heater with greater turndown, a hot-water coil with modulating valve, or a modulating (SCR) electric heater.

Some customers, particularly those in colder climates, may be hesitant to go all-in on electric heating. Similar to hybrid cars that provide the reassurance of a combustion-engine "plan B," hybrid dual-fuel rooftop systems include a supplementary gas heating system. They operate primarily using the heat pump for electrified heating. Gas heating kicks in only as needed with an adjustable changeover temperature range from 45°F to 15°F. In many cases, the biggest benefit to the customer is peace of mind. Building operators are often surprised by how infrequently gas heating actually gets used.

Building automation and system controls provide the necessary coordination and management of all the system components in a manner that delivers (and maintains) your specified performance. Building automation systems orchestrate equipment performance using pre-engineered applications that can be altered for each project—simplifying the delivery of the engineering design, assuring the deployment of industry standards and enabling greater consistency across multiple buildings. Unlike other controls that are "capable of" delivering specific criteria, Trane definitively states that our controls "will deliver" the promised performance. It's a big difference, and it provides added reassurance that engineers' solutions will provide energy efficiency, comfort and other benefits as promised.

Latest-generation unit controls arrive onsite with factory-programmed optimized sequences and prepped for app-based remote management. Advanced unit controllers allow for greater flexibility in set points, and capably manage complex equipment setups to deliver more advanced benefits for energy efficiency/sustainability, humidity management, zoned comfort and indoor air quality. Digital controls can produce multiple data points to serve detailed analytics. Intuitive user interfaces at

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the unit and on the mobile app allow building operators to detect declining performance easily and early to prevent downtime and correct cost inefficiencies. Built on open standard protocols, these controllers easily integrate with any non-proprietary building automation system.

Wireless zone sensors support open communication protocols through conformance with ASHRAE Standard 135 (BACnet/ZigBee®). Depending on the application, sensing may be required for temperature, humidity, occupancy and CO_2. **Air-Fi® Wireless sensors** feed into the BAS for easy management and control. Wire-free communication means sensors can be removed and relocated to serve future needs, without an electrician and without damaging walls.

Common System Configurations

Single-zone, two-speed system—This simple system is well-known to many industry professionals and building owners. It is comprised of a single rooftop unit with controller, and at least one zone temperature sensor or thermostat. The supply fan operates at either high or low speed, depending on cooling or heating requirements. Manifolded scroll compressors provide cooling, while heating is provided by a gas or electric heater. The unit may also be configured to reverse the refrigeration system to operate as a heat pump.

Single-zone VAV system—This unit's supply fan varies its speed to provide a variable volume of conditioned air to the zone. Manifolded or variable speed compressors provide cooling, while heating is provided by a gas or electric heater, or by reversing the refrigeration system to operate as a heat pump. This type of system is ideal for large open spaces such as auditoriums, warehouses and open retail.

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Changeover hybrid system—Comprised of a single rooftop unit with controller, two or more VAV terminal units (each with a controller and a zone temperature sensor) and a bypass damper. Manifolded scroll compressors provide cooling, while heating is provided by a staged gas or electric heater, or by reversing the refrigeration cycle to operate as a heat pump. The system control panel uses a voting strategy to determine whether the rooftop unit should deliver cool air down the duct or "changeover" to deliver warm air. A variable-speed fan varies the supply of cool air to the zones as the zone-level VAV dampers modulate (bypass damper is closed), and then operates at full speed in heating mode, thus requiring the bypass damper to bypass excess supply air to the return-air path. This highly diverse system is suitable for many applications and delivers greater energy efficiency than older changeover bypass systems that used a constant-speed supply fan.

Changeover VAV system—A single rooftop unit with controller, combined with two or more VAV terminal units, each with a controller and zone temperature sensor. Manifolded or variable-speed compressors provide cooling, while heating is provided by a modulating gas or electric heater. Again, the system control panel uses a voting strategy to determine whether the rooftop unit should deliver cool or warm air down the duct. As the zone-level VAV dampers modulate, the variable-speed fan varies the supply of air during both cooling and heating operation; therefore, a bypass damper is typically not needed.

Multiple-zone VAV system with terminal electric or hot water heat—In this configuration, one rooftop unit can serve several zones with independent temperature control in each one. It is capable of simultaneously providing heating to some zones and cooling to others. Most of the VAV terminal units are equipped with electric or hot-water heat.

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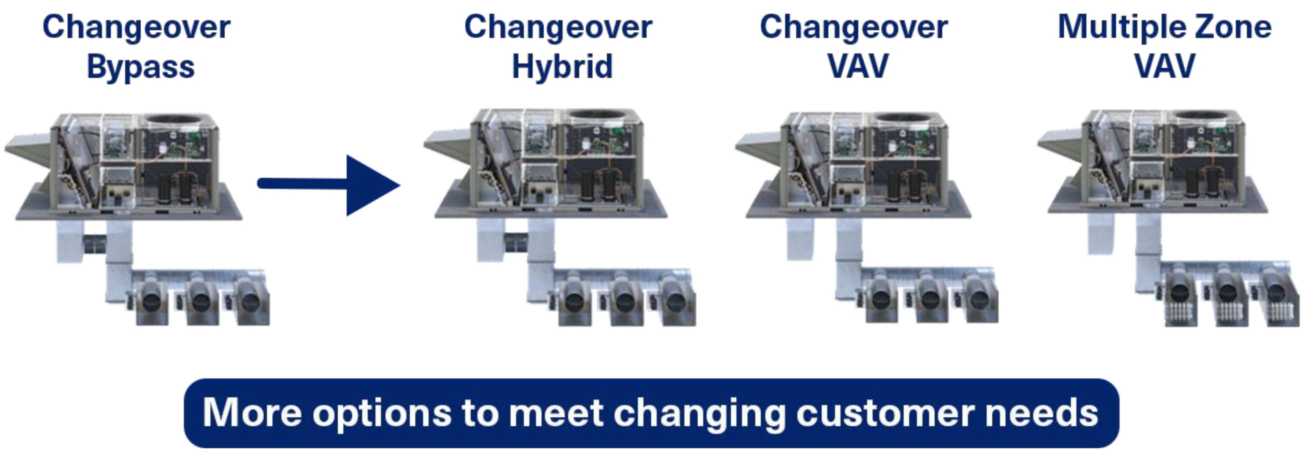
Multiple-zone package systems allow for more personalized comfort. Units with a reversing valve allow the electrified refrigeration system to provide cooling or heating. A knowledgeable system expert can tell you more, and help you weigh the pros and cons of each one for a particular application.



Controlling for operational excellence

Most providers' systems are "capable of" operational excellence. Trane takes the responsibility for making it happen and makes it easier for building owners to sustain the benefits over time. Complex systems require more complicated programming, and Trane brings this in-house to optimize performance using our library of documented engineered solutions. Most installations will require minor customization to achieve situational optimization, but the essential performance arrives readymade within Trane's **Symbio® unit controls** and **Tracer® building automation system**. Standardized, graphical interfaces provide user simplicity that helps reduce user errors that cause

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performance to decline over time. It's a more professional and risk-free approach than putting important programming in the hands of technicians with wide-ranging skillsets.

Create Trim/Respond - Requesting Member Attributes - Duct Static Pressure Setpoint Reset

Room 101 VAV 1-01	Default Duct Static Pressure Setpoint Reset Rules
Room 104 VAV 1-04	Default Duct Static Pressure Setpoint Reset Rules
Room 105 VAV 1-05	Default Duct Static Pressure Setpoint Reset Rules
Room 102 VAV 1-02	Default Duct Static Pressure Setpoint Reset Rules

Preview Ruleset Summary **Default Duct Static Pressure Setpoint Reset Rules**

Rule Summary

If Discharge Air Flow < 50% of Air Flow Setpoint Active for 0 Minutes
and if Air Flow Setpoint Active > 0.0 cfm for 0 Minutes
and if Air Valve Position Command > 95.0 % for 1 Minutes, generate 3 Requests.

ElseIf Discharge Air Flow < 70% of Air Flow Setpoint Active for 0 Minutes
and if Air Flow Setpoint Active > 0.0 cfm for 0 Minutes
and if Air Valve Position Command > 95.0 % for 1 Minutes, generate 2 Requests.

ElseWhile Air Valve Position Command > 95.0 %, generate 1 Requests until the Air Valve Position Command < 85.0 %.

Optimization: Understanding what it really means.

Optimization may be one of the most frequently stated benefits in our industry. But what does it really mean? Essentially, it is the act of making a system as effective as possible in delivering the benefits a customer wants.

Trane® Tracer systems have been developed to deliver ASHRAE Guideline 36 sequences and performance. Our pre-engineered trim-and-respond application includes the ASHRAE GL 36 defined rules, allowing flexibility to modify or expand the rules to meet any building or system need.

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It's a bit of a balancing act, and there are almost always tradeoffs.

For example, running fans constantly to improve ventilation and indoor air quality often comes with a penalty to energy efficiency. Simply changing temperature settings to save energy and decarbonize is an obvious threat to occupant comfort. Optimized controls can operate the system to achieve multiple goals in prioritized, varying degrees.

- Schools may prioritize indoor air quality to improve test scores and attendance
- Restaurants may prioritize kitchen humidity management to maintain a comfortable work environment that helps to retain top talent
- Offices may want zone control that supports individualized employee comfort

Trane removes the need to begin each programming project from scratch. Our engineered solutions are updated often to reflect current standards, guidelines and security practices. Once installed, systems that are cloud-connected will remain up

Right-Sized System Control

Not every building requires the comprehensive capabilities of **Tracer® SC+ system controls**. For many buildings that use packaged rooftop systems, **Tracer Concierge®** provides scaled-down system management that's simple and effective—and perfect for buildings without a facility professional on staff. It's easy for contractors to install, set up and service, too.

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to date and secure through available continuous commissioning that restores the original settings and updates applications when new best practices are discovered, or different requirements come into play. Controls also enable the extended system monitoring that is a requirement for many building certifications, including WELL® and LEED®.

Raising energy efficiency through a systems approach.

Comprehensive system integration makes it much easier for operators to match system use to building occupancy and avoid using more energy than is necessary. Trane unit controls integrate easily with any building automation system into an overall energy management approach. That's critical to lowering a building's carbon impact. State-of-the-art building automation systems can reduce energy consumption in commercial buildings by up to 40%.[1]

Even as a standalone system, intelligent rooftop systems are delivering significant energy savings that have been documented in multiple studies. Our own modeling demonstrated 9% energy savings over ASHRAE 90.1 baselines, with 23% savings compared to a "typical building."[2]

A Pacific Northwest National Lab Study found 29% energy savings vs. poorly running/ unoptimized buildings.

Making your good work even better.

Rooftop systems will probably get even more complex as industry pressures increase. Right now, you can meet virtually any performance requirement by pairing packaged rooftop systems' features and options with pre-engineered controls. The end goal is to

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make it easier for you to deliver engineering excellence to serve any customer's needs. Engineered excellence without complexity. Trane gives you an easy path into the future with higher-performing intelligent rooftop systems.

[1] Project Drawdown, "**Building Automation Systems**," Web. Accessed May 2023.

[2] Pacific Northwest National Lab, "**Impacts of Commercial Building Controls on Energy savings and Peak Load Reductions**," Web. Accessed May 2023.

Exploring sustainable grocery refrigeration systems

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The grocery industry has seen an unprecedented demand for online shopping.

In recent years, the grocery industry has seen an unprecedented demand for online shopping. To meet the needs of consumers making the switch to online shopping, many retailers are choosing to expand their warehouses and for grocers that means expanding their refrigerated warehousing. As the footprint of refrigerated warehouse space and infrastructure grows it's important to understand how refrigerants align with corporate sustainability goals as well as how to plan for the evolving regulatory landscape.

With new and more stringent refrigerant regulations on the horizon, more clients are exploring alternative refrigeration systems as a means to holistically reduce annual greenhouse gas emissions. CO_2, a natural refrigerant with an ultra-low environmental impact, has been an intriguing alternative refrigerant for quite some time, but higher costs associated with the equipment, installation, and operation have prevented CO_2 from being widely adopted in the U.S. up until now. Fortunately, those previous barriers to CO_2 systems are being overcome as greater familiarity and economies of scale are bringing initial costs down while regulatory restrictions continue to increase on traditional refrigerants.

When looking specifically at grocery stores, 40% of energy consumption is tied to refrigeration systems. The average store can contain up to two miles of refrigerant piping which is equal to the length of 30 football fields. These pipes and the systems can leak at a rate of 25% each year.

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Switching to low-impact, sustainable refrigerants like CO_2 will help reduce emissions by 108 gigatons globally. 108 gigatons is equivalent to the emissions from operating every home in the U.S. for 104 years or switching 4 trillion incandescent lamps to LED, or the amount of carbon sequestered by planting 1.7 trillion trees left alone to grow for 10+ years.

Regulations and GWP in Grocery Refrigeration

Most refrigerants currently used in commercial refrigeration systems are synthetic refrigerants made of either hydrofluorocarbons (HFCs) or blends with both HFCs and Hydrofluro-Olefins (HFOs). These synthetic refrigerants have come under increasing scrutiny because of their high Global Warming Potential (GWP). GWP is defined by the U.S. Environmental Protection Agency (EPA) as "a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2)". Basically, a higher GWP translates to a higher contribution to global warming and climate change. Most HFC and HFO blends suitable for refrigeration currently used have GWPs ranging from the low 1,000s to nearly 4,000. CO_2 has a GWP of 1.

For example, R407A, a widely used HFC, has a GWP of about 2,100, which means when released into the atmosphere, one pound would be 2,100 times more detrimental than one pound of CO2. Annual leak rates (the amount of refrigerant that leaks out of systems) can be up to 25% of the total refrigerant in the systems for a standard grocery chain. A 25% leakage rate for a grocery store refrigeration system with 1,200 pounds of refrigerant would therefore leak 300 pounds/year. In terms of GWP impact this R407A system would release the equivalent of 630,000 lbs. of CO_2 into the atmosphere (300 lbs. x 2,100 GWP). The impact of a comparable CO_2 based system would only be 300

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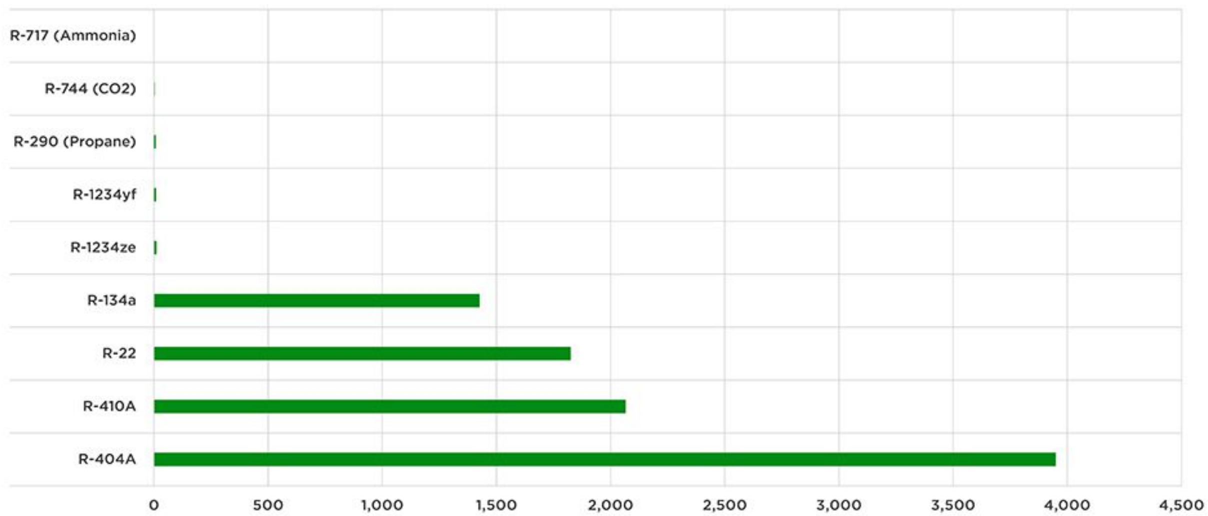
GWP OF SELECT REFRIGERANTS



pounds (300 x 1 = 300 lbs.) When we account for all the grocery stores and refrigeration systems around the world it starts to make sense how we could reduce overall CO_2 emissions by 108 gigatons.

Federal and State Regulations

To reduce the GWP impact of refrigerant leaks, the EPA issued regulations restricting the use of certain HFC refrigerants in 2015. The EPA regulations have been argued back and forth in the courts but a federal court decision in April of 2020 upheld the regulation prohibiting switching from ozone-depleting substances to HFCs that have a high GWP. This ruling was an important step in limiting the planet-warming impact of HFCs and speeding up the adoption of existing, safer alternatives.

States have also passed legislation limiting the use of high GWP refrigerants. For ex-

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ample, in California, laws were enacted to prohibit the use of high GWP refrigerants R404a and R507a in new supermarket refrigeration systems starting in 2019. Furthermore, they require new, non-residential refrigeration equipment containing more than 50 lbs. of refrigerant to use refrigerants with a GWP of 150 or less. For other states, this type of legislation is still in the proposal and feedback phase, but California's laws serve to indicate the type of restrictions that we can anticipate for high and even moderate GWP refrigerants in the coming years. The proposed GWP limit of 150 in California is particularly noteworthy because there are currently no commercially available options for non-toxic, non-flammable refrigerants with GWPs below 150. The chart below shows the different refrigerant options in use or development in relation to their relative pressure and GWP.

Legacy = HFC (high GWP) refrigerants
1 = Natural (low GWP) refrigerants. Note CO2 is the only non-toxic, non-flammable option
2 = More recent HFO blend (intermediate GWP) refrigerants
3 = Newer (lower GWP) refrigerants, not yet in commercial use

Clean Air Act: Section 608

In addition to the aforementioned regulations on high GWP refrigerants, the EPA's Clean Air Act (CAA) Section 608: Regulatory Requirements for Stationary Refrigeration and Air Conditioning limits the allowable refrigerant leak rate on systems with more than 50 lbs. of refrigerant to 20% annually on commercial refrigeration and 30% annually for industrial process refrigeration. The CAA also specifies leak repair requirements and establishes guidelines for refrigerant reclamation, sales restrictions, technician certification, service practices, appliance disposal, equipment recycling,

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and recordkeeping. This rule was modified on February 26, 2020 so that some of these requirements, such as the leak repair requirements and associated recordkeeping and reporting provisions will only apply to ozone depleting refrigerants as of April 10, 2020. Nevertheless, these requirements are a bellwether for what can be expected at a state level in the coming years. The California Air Resources Board (CARB) already has a refrigerant management program which requires facilities with refrigeration systems containing more than 50 lbs. of a high GWP refrigerant to conduct and report periodic leak inspections, promptly repair leaks, and keep service records on site.

AIM Act

The Consolidated Appropriations Act of 2021 included the AIM Act. This act directs the EPA to phase down both the production and the consumption of HFCs in the United States by 85% over the course of the next 15 years. An HFC phasedown at the global level is expected to avoid up to 0.5° Celsius of global warming by 2100. At a national level, this is the most impactful legislation when it comes to HFC phasedown and regulation.

CO_2 Systems in Grocery Refrigeration

Transcritical CO_2 systems use CO_2 (R744) as the sole refrigerant and are so named because at 87.8°F CO_2 reaches its critical point (the point at which a substance's liquid and vapor phase boundaries converge and liquid and vapor become indistinguishable from each other) and above this temperature the high pressure side of the system operates supercritically or transcritically without condensing from a vapor to a liquid. Other CO_2 refrigeration systems, such as CO_2 cascade or CO_2 liquid overfeed systems avoid the inefficiencies associated with operating transcritically but at the expense of using CO_2 in conjunction with another (often high GWP) refrigerant and of incurring

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the associated costs and inefficiencies of adding additional heat exchangers and associated equipment. For the purposes of this discussion we will focus on transcritical CO_2 systems.

CO_2 Advantages

Because CO_2 is the baseline when measuring GWP, its GWP is 1 and the use of CO_2 refrigeration will allow retailers to future-proof their refrigeration systems against any upcoming refrigerant regulation changes at both the state and national level. Installation costs have been decreasing as installers have become more comfortable with CO_2 systems. Some installers are even reporting lower installation costs compared to systems with synthetic refrigerants due to the smaller pipe sizes used on CO_2 systems. Bill Zornes with Key Mechanical states that his company has seen installation costs that are approximately 10–12% less than traditional refrigerant systems with similar design styles. Key Mechanical has completed the installation of CO_2 systems and Bill doesn't foresee a big learning curve for those installers who are less familiar: "I believe there is a small learning curve on the service side, but once technicians understand the system has the same components and operates in the same manner as we have all known it to be, it's quickly overcome. [On the] installation side, I see no real learning curves providing you are using best industry practices."

Equipment costs are also coming down as more systems are installed throughout the United States. Hill Phoenix, a refrigeration system manufacturer based near Atlanta, GA, has installed more than 800 Transcritical CO_2 systems in North America and more than 12,000 systems in the world under the brand Advansor. In 2020 Derek Gosselin, with Hill Phoenix, stated that the equipment costs vary based on design choices and location and that there still is a cost premium of 15–25% for CO_2 systems vs. systems

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using synthetic refrigerants but that the costs are coming down. He notes that it is best to compare total installed cost, including equipment, refrigerant management, and installation. According to Derek, the total installed cost of a CO_2 system can be as little as 5–10% higher compared to equivalently sized systems using synthetic refrigerants. In addition to the environmental considerations, the lower cost of the CO_2 itself is another point in its favor. CO_2 is generally about $4/lb. whereas most traditional refrigerants range from $34–100/lb.

Transcritical CO_2 Challenges

The efficiency of every refrigeration system decreases as the saturated condensing temperature increases, but the deterioration in efficiency is more dramatic for transcritical CO_2 systems. Transcritical CO_2 systems can achieve equal or better efficiency than synthetic refrigerant systems at condensing temperatures at or below about 60–65°F, but as the ambient and condensing temperatures rise, the synthetic refrigeration systems become increasingly more efficient compared to transcritical CO_2 systems. Thus, any comparison of the annual energy usage between the two systems will be heavily dependent on the location and climate chosen as the basis of the comparison. Chart 2 below gives the results of a study Henderson Engineers performed in 2016 to compare the annual energy usage between a transcritical CO_2 system (R744) and systems using synthetic refrigerants R407A and R448A.

The conclusion of this analysis was that energy usage differences were minor in cooler climates but significant in warmer locations. When comparing the overall climate impact of a refrigeration system, the increased energy usage needs to be considered based on the carbon intensity of the electricity sourced from the regional grid. Even in the most unfavorable weather conditions (e.g. warm and wet areas such as Austin, TX),

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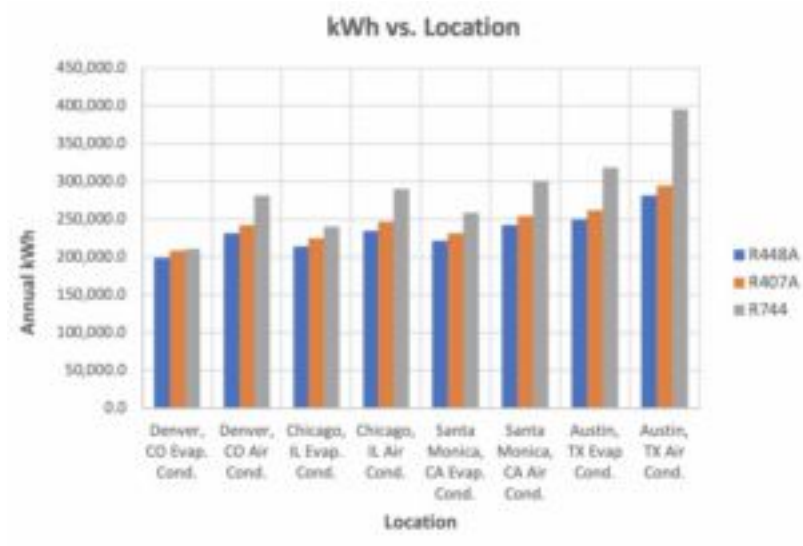
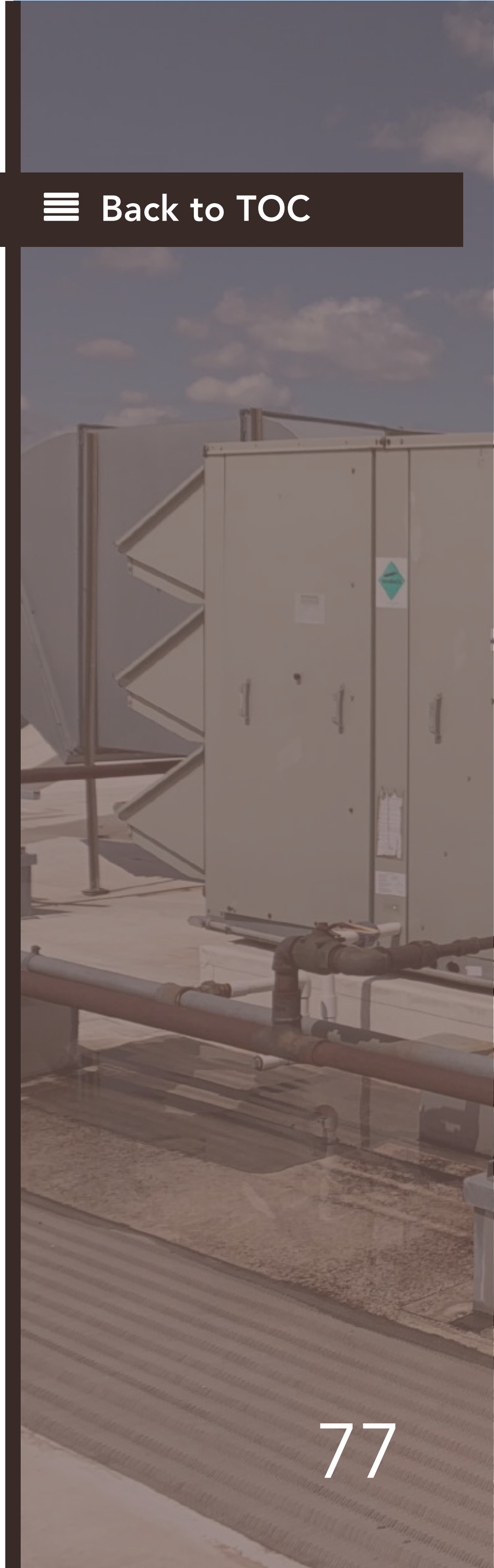
CO_2 systems could have a lower life-cycle carbon footprint when factoring in the additional energy use, especially over time as renewable energy sources continue to come online.



Mitigating CO_2 Challenges

Limits to compressor operating windows preclude operating CO_2 compressors below a condensing temperature of about 55°F but advances in technology that allow lowering the minimum condensing temperature would make the advantages of a CO_2 system more pronounced in lower ambient temperatures. Other technologies, such as the use of a separate flash gas compressor, would increase the efficiency of the CO_2 system and should be considered. Other energy-saving technologies, such as parallel compression, ejectors and various low-superheat options are more commonplace for transcritical CO_2 systems. Overall, there is reason to think that proper equipment selection and continuing technological advances will make CO_2 competitive with synthetic refrigerant systems in cool to moderate climates. And in warmer and more humid climates where transcritical CO_2 systems should be expected to use more energy than an equivalent synthetic refrigeration system, other factors such as government regulations and the desire to use natural refrigerants may dictate the use of CO_2 refrigeration systems despite any energy penalties associated with the system.



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Conclusion

The changing regulatory landscape is requiring our industry to look at alternatives to the traditional synthetic refrigeration systems. Sustainable refrigerant design will be a crucial component in grocery stores as they try to reduce their carbon footprint. Transcritical CO_2 is not without its challenges, particularly in warmer climates such as those in the southern half of the continental U.S., but increasing contractor familiarity, decreasing manufacturing costs, and continuing technological advances are making CO_2 refrigeration systems more viable than ever before.

Dustin Padget
Dustin Padget, *Refrigeration Technical Director.*

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