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100% Outside Air VRF Systems

Designing HVAC systems that offer superior IEQ and energy efficiency is not only possible, the technology is already available.

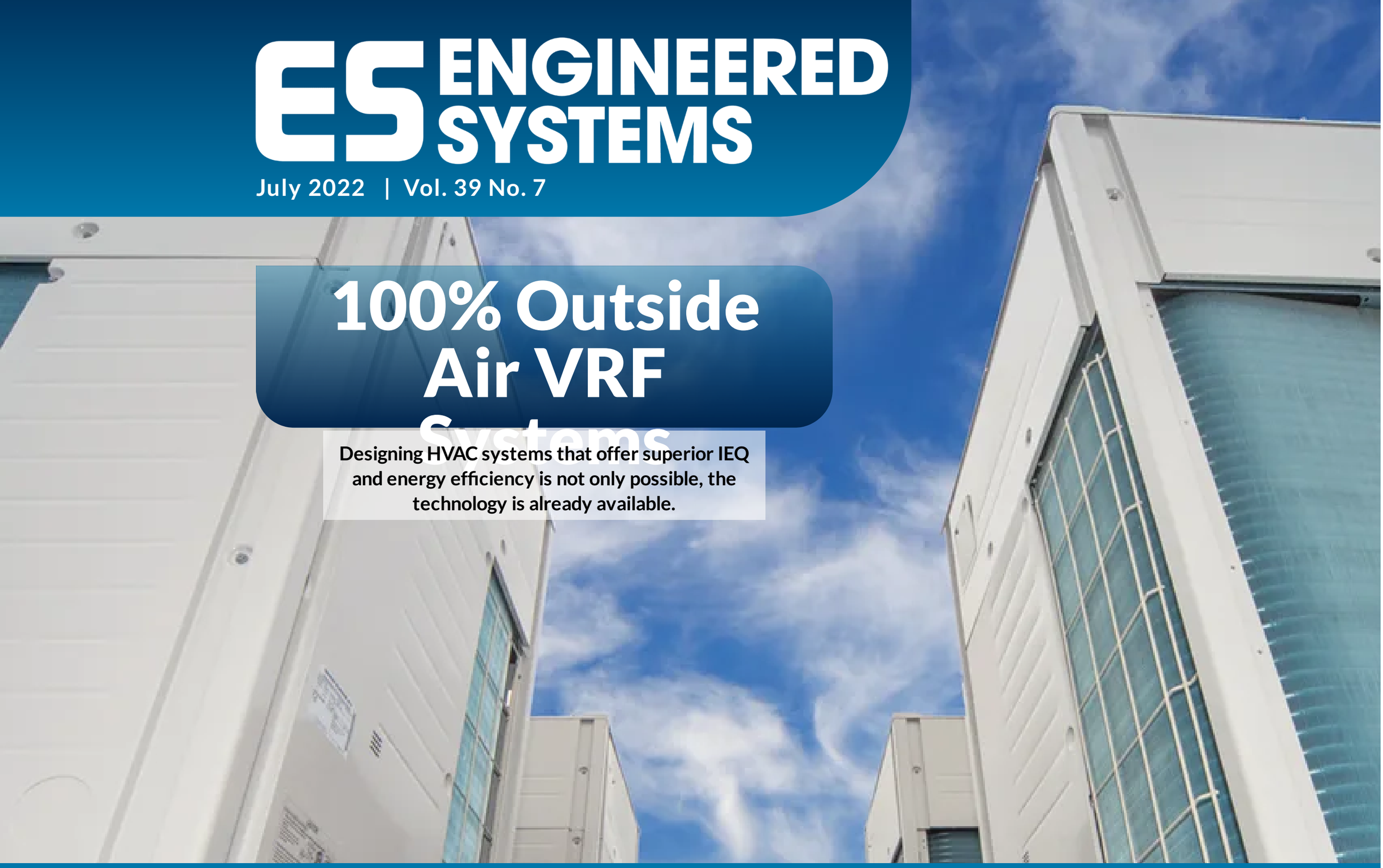

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Image courtesy of Daikin

100% Outside Air VRF Systems: A Sustainable, Hybrid Approach for Superior IEQ

Increasing the amount of outside air to the occupied space and increasing ventilation air change rates are effective solutions for reducing concentrations of contaminants and lit risk of infection.

By Don Hahne

News

FOR IMMEDIATE RELEASE

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ASHRAE Epidemic Task Force Releases Updated Airborne Transmission Guidance
Central guidance for preventing and mitigating the spread of SARS-CoV-2

ATLANTA (April 5, 2021) – The ASHRAE Epidemic Task Force released an updated, unsequenced statement on the airborne transmission of SARS-CoV-2 in buildings.

ASHRAE has released the following statement:

"Airborne transmission of SARS-CoV-2 is significant and should be controlled. Changes to building operations, including ventilation, heating, humidifying, and air conditioning systems, can reduce airborne transmission of SARS-CoV-2.

"It appears the April 2020 statement that said airborne transmission was "sufficiently low" that airborne precautions should be taken, lit that Grolle, Tellier, Bahnfleth, Jimenez, Marr, Miller, Peccia, Prather, Stetzenbach and the World Health Organization (WHO) contended that transmission of SARS-CoV2 was by droplet and fomite transmission, and not airborne. Subsequently, both have changed their tune to acknowledge airborne transmission.

FIGURE 1. A newsletter issued by ASHRAE on April 5, 2021.
Image courtesy of ASHRAE

On April 5, 2021, ASHRAE's Epidemic Task Force released an updated letter on airborne transmission guidance for SARS-CoV-2. The letter stated, "Airborne transmission of SARS-CoV-2 is significant and should be controlled. Changes to building operations, including the operation of HVAC systems, can reduce airborne exposures."

On May 7, 2021, the U.S. Centers for Disease Control and Prevention (CDC) posted the following update on SARS-CoV-2 transmission: "SARS-CoV-2 is transmitted by exposure to infectious respiratory fluids." The same posting goes on to state, "Infectious exposures to respiratory fluids carrying SARS-CoV-2 occur in three primary ways: deposition, touching, and inhalation of air carrying very small droplets and aerosol particles that contain infectious virus."

The CDC website went on to say that factors increasing the risk of SARS-CoV-2 infection are "… increased exhalation, prolonged exposure, and enclosed spaces with inadequate ventilation."

Since inadequate ventilation has been linked to aerosolized transmission of the virus within buildings, the following statements have been made by leading national authorities:

ASHRAE Epidemic Task Force:
- "…Evaluate recirculation or increase outside air fraction from design levels up to 100%" and
- "Increase outdoor air ventilation and open outdoor air dampers to 100% *as indoor and outdoor air conditions permit.*"

CDC:
- "When indoors, ventilation mitigation strategies can help reduce viral particle concentration;" and
- "…Open outdoor air damper beyond minimum settings to reduce or eliminate HVAC air recirculation."

U.S. Environmental Protection Agency (EPA):
- "Ensuring proper ventilation with outside air can help reduce the concentration of airborne contaminants, including viruses, indoors."

Increasing the amount of outside air to the occupied space and increasing ventilation air change rates (ACR) are effective solutions for reducing concentrations of contaminants and the risk of infection.

However, increasing a building's outdoor air, especially if heat recovery is not an option, requires more energy. Global public awareness regarding carbon's impact on climate has resulted in numerous environmental initiatives to reduce energy usage and its respective carbon footprint. The AIA has advocated for net-zero building designs since the inception of its 2030 Commitment. The 2030 Commitment home page states, "The built environment creates a staggering 40% of the world's (CO$_2$) emissions, architects, engineers, and owners play a key role. Consequently, the 2030 Commitment goes on to state, "We must all commit to net-zero emissions by 2030." The Carbon Leadership Forum's MEP 2040 Challenge posts on its home page, "All systems engineers shall advocate for and achieve net-zero carbon in their projects — operational carbon by 2030 and embodied carbon by 2040."

ASHRAE has, for years, embraced the nation's growing national imperative to increase building energy efficiency by continuing to develop and expand Standard 90.1's performance requirements. The *ASHRAE Journal* publishes articles regularly on HVAC designs to optimize system performance, e.g., the September 2021 issue included the article, "How Building Decarbonization Can Transform HVAC." The article leads with the following comment, "Buildings in the U.S. account for 40% of carbon emissions." The article goes on to express, "Many of the U.S.'s largest corporations, including Apple, Microsoft, Kohl's, Walmart, and Bank of America, have made commitments to achieve carbon neutrality or to get their electricity from carbon-free sources, namely solar and wind energy. An all-electric building coupled with a renewable or carbon-free source of electricity is considered to be decarbonized in its operation." In fact, in July 2021, the U.S. Department of Energy (DOE) announced it has "reviewed ANSI/ASHRAE/IES Standard 90.1-2019, 'Energy Standard for Buildings, Except Low-Rise Residential Buildings,' and determined the updated edition would improve energy efficiency in commercial buildings subject to DOE's review."

The DOE's Standard 90.1 statement also expresses the following building efficiency directive: "Upon publication of this affirmative determination, each state is required to review the provisions of the commercial building code regarding energy efficiency and, as necessary, update their codes to meet or exceed Standard 90.1-2019."

Public and governmental pressure is growing to increase building efficiency and to convert energy consumption from fossil fuels to renewable resources. These carbon neutrality initiatives, at first glance, appear to be at odds with ASHRAE's HVAC recommendations for reducing the risk of infection. HVAC system and product strategies need to be evaluated and adopted to achieve both sustainable and superior indoor environmental quality (IEQ).

The purpose of this article is to evaluate the use of 100% outside air (OSA) high efficiency heat pump technology in hot, dry climate zones, i.e., the Southwestern desert, and to understand if such a system could impact meet the objectives of both national initiatives outlined above. High efficiency heat pumps, or variable refrigerant volume (VRV)* systems, are all-electric solutions for heating and cooling a building that have been used in the Sonoran desert for a number of years. However, these systems are frequently laid out with untempered outdoor air ducted directly to fan coil plenums and/or ceiling and wall cassettes. Unfortunately, in extreme climate zones, such an approach is not conducive for optimizing VRV performance. Elevated mean air conditions result at fan coil evaporator coils and cassettes, resulting in higher peak loads and greater electricity demand. Block loads. Condensers are oversized and efficiency compromised when operating at part load. This article will examine performance data generated from three variable refrigerant volume (VRV) system configurations. One is a traditional VRV design with a conventional, unpressurized outdoor air approach, and two other VRV system layouts will apply dedicated, 100% outside air (DOAS) units – one supplying OSA at a conventional dew point and the other at low dew point.

FIGURE 2. Weaver's Needle
Image courtesy of Don Hahne

FIGURE 3. A floor plan complete with load calculations at the Southwest MOB.
Image and load calculations courtesy of SmithGroup

Analysis: Design and Intent

Daikin's 2-pipe heat recovery design was chosen for the VRV layout. A heat recovery system uses branch selector boxes with thermal expansion valves to direct refrigerant flow for simultaneous cooling and heating from a common condenser. The first cost of 3-pipe systems, unlike 2-pipe heat pump configurations, requires branch selector boxes and extra refrigerant lines resulting in approximately a 15%-20% first-cost premium compared to the first-cost design of a VRV heat pump design.

FIGURE 4 (Right): A Daikin 2-pipe heat pump.
FIGURE 5 (Left): A Daikin 3-pipe heat recovery unit.
Image courtesy of Daikin

The electrical room used VRV cassettes mounted directly in the space without outside air connections. Three design concepts were assigned, each with the same room air condition: 75° DB/50% RH.

Variable-Refrigerant Systems Design Options:
- Design No. 1. VRV system mixing unpressurized outside at 95° DB/79° WB summer and 38° winter with return air at fan coil return at plenums.
- Design No. 2. VRV system designed parallel to 100% DOAS with enthalpy wheel supplying 55.13° dew point LAT.
- Design No. 3. VRV system designed parallel to 100% DOAS with enthalpy wheel supplying 48.8° dew point LAT.
- **100% Outside Air (DOAS) Performance:**
  - Daikin Rebel DOAS units with enthalpy wheels, DX coils served by variable speed scroll compressors, and hot gas reheat provided for designs Nos. 2 and 3.
  - Designs No. 2:
    - Cooling Coil: Leaving Air Conditions (LAT)
    - 55° DB/53° WB LAT
  - Hot Gas Reheat Coil:
    - 70° DB/59.58° WB or 53.13° DP LAT (heating, part-load cooling)
    - 55° DB/ 53.89° WB or 53.13° DP LAT (100% cooling) VRV credit taken.
    - DOAS is dynamically reset supply air dew point and temperature based on humidity and temperature for enhanced efficiency.
    - VRV system fan coils to maintain room temperature set point for cooling and heating modes.
  - Designs No. 3:
    - Cooling Coil: Leaving Air Conditions (LAT)
    - 52° DB/50.2° WB or 48.8° DP LAT
  - Hot Gas Reheat Coil:
    - 70° DB/57.42° WB or 48.8° DP LAT (heating, part-load cooling) VRV credit taken.
    - 55° DB/50.2° WB or 48.8° DP LAT (100% cooling) VRV credit taken.
    - DOAS is dynamically reset supply air temperature for enhanced efficiency.
    - VRV system fan coils to maintain room temperature set point for cooling and heating modes.

The modeled VRV system applied Daikin's older Series P condenser technology (Daikin's new condenser series, Emerica, was not rated, as performance curves are still being generated. Evidence shows Emerica condensers are 30% more efficient than the Series IV model.) Since building room layouts and peak loads were identical for each of the three designs, fan coil sizing and layouts were also identical. Condenser capacity and sizing did change per design as space latent loads varied, resulting from the supply of OSA at moderate or depressed dew points for design numbers 2 and 3. The latent load for design no. 3 increased in the cooling mode as the supplying depressed 48.8° dew point. Both systems took advantage of another layer of efficiency when in full cooling. When all fan coils are in cooling mode, the DOAS hot gas reheat coil will auto reset discharge air temperature to a cooling minimum value, allowing for the VRV component to take an energy credit for designs 2 and 3.

100% OSA: Conceptual Advantages

Applying DOAS unit to operating parallel to a VRV system allows for enhanced space humidity control while ensuring the correct amount of OSA is supplied directly to the space. Buildings challenged by inadequate humidity control often experience this due to inadequate supply air dew point temperature. Be aware, a room design set point of 75° DB/50% RH has, in Phoenix, at 1,500 feet in elevation, a 55.13° dew point. Supply air delivered at 55° DB/54° WB has a dew point of 53.32°. Consequently to control space humidity at 50% RH with a dew point dependent of 1.83° will require more air. When outside air is supplied with a higher dew point depression, 48.8° for example, in design no. 3, VRV fan coil humidity control improves significantly. The DOAS hot gas reheat coil will modulate to maintain the room set point quantitative practice for medical office buildings. Increased VRV efficiency also results from the lower part load condition at the VRV fan coils. Entering air will be very close to the room space condition, allowing for reduced coil loads. DOAS compressors can be disabled when the outside air condition is 70°DB/48.8° dew point or lower, depending on the type of building and usage. "Free" cooling annualized hours in Phoenix can double in comparison to those hours usually calculated from conventional, mixed-air, package rooftops in our dry climate region.

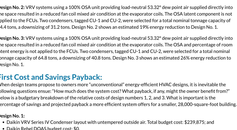

FIGURE 6. A Daikin 100% OSA + VRV layout.
Image courtesy of Daikin

Design	Fan Coil Qty	Condenser Qty	Condenser Capacity	Condenser Sizing	Cooling Coil Entering Air Temp	Cooling Coil Leaving Air Temp	Cooling Coil Leaving Air Dew Point	Hot Gas Reheat Coil Leaving Air Temp	Hot Gas Reheat Coil Leaving Air Dew Point	Total Cooling Capacity	Total Heating Capacity
No. 1	20	1	20	100%	75°F	54.5°F	53.13°F	N/A	N/A	19.5	20.0
		1	8	40%							
		1	12	60%							
Total	20	2	20	100%							
No. 2	20	1	20	100%	75°F	55°F	53.13°F	70°F	59.58°F	19.5	20.0
		1	8	40%							
		1	12	60%							
Total	20	2	20	100%							
No. 3	20	1	20	100%	75°F	52°F	50.2°F	70°F	57.42°F	19.5	20.0
		1	8	40%							
		1	12	60%							
Total	20	2	20	100%							

FIGURE 7. An EXCEL performance comparison chart.
Image courtesy of Vertiv.

Comparative Energy Review:

Figure 7 reviews the energy savings related to condenser sizing. The energy modeling results illustrated below outline data for each design option.

Design No. 1: A VRV system using unpempered outside air with return air VRV fan coils required 105.6 nominal tons of condenser capacity to meet the building's total peak load, which was 3.92 tons greater than the total system peak load. Three condensers, tagged CU-1, CU-2, and CU-3, were selected for a total nominal tonnage capacity of 105.5 tons.

Design No. 2: VRV systems using a 100% OSA unit providing load neutral 53.32° dew point air supplied directly into the space resulted in a reduced fan coil mixed air condition at the evaporator coils. The OSA latent component is not applied to the FCUs. Two condensers, tagged CU-1 and CU-2, were selected for a total nominal tonnage capacity of 74.4 tons, a downsizing of 31.2 tons. Design No. 2 shows an estimated 29% energy reduction to Design No. 1.

Design No. 3: VRV systems using a 100% OSA unit providing load-neutral 53.32° dew point air supplied directly into the space resulted in a reduced fan coil mixed air condition at the evaporator coils. The OSA and percentage of room latent energy is not applied to the FCUs. Two condensers, tagged CU-1 and CU-2, were selected for a total nominal tonnage capacity of 64.8 tons, a downsizing of 40.8 tons. Design No. 3 shows an estimated 34% energy reduction to Design No. 1.

First Cost and Savings Payback:

When design teams propose to owners more "unconventional" energy-efficient HVAC designs, it is inevitable the following questions ensue: "How much does the system cost? What payback, if any, might the owner benefit from?" Below is a budgetary breakdown of the relative costs of design numbers 1, 2, and 3. What is important is the percentage of savings and projected payback a more efficient system offers for a similar, 20,000-square-foot building.

Design No. 1:
- Daikin VRV Series IV Condenser layout with untempered outside air. Total budget cost: $229,875; and
- Daikin Rebel DOAS budget cost: $0.

  - Total system equipment cost: $229,875.

Design No. 2:
- Daikin VRV Series IV Condenser layout with unpempered outside air. Total budget cost: $184,090; and
- Daikin Rebel DOAS budget cost: $73,055.

  - Total system equipment cost: $257,145;
  - Total Premium: $17,270; and
  - Projected payback: five to 10 years** (based on $0.16/kWh power).

***Payback would vary between local utility rates, climate zone, regional market values, contractor installation costs, etc.*

Design No. 3:
- Daikin VRV Series IV Condenser layout with unpempered outside air. Total budget cost: $173,051; and
- Daikin Rebel DOAS budget cost: $93,280.

  - Total system equipment cost: $266,331;
  - Total premium: $26,456; and
  - Projected payback: six to 13 years** (based on $0.16/kWh power).

***Payback would vary between local utility rates, climate zone, regional market values, contractor installation costs, etc.*

When analyzing pricing, the values above are for the VRV and DOAS equipment only. Installation, controls, ductwork, copper piping, and wiring are not included. However, one should keep in mind that complex lifecycle costs compared to standard package rooftop units have not been taken into account. Variable refrigerant systems are more robust than standard rooftop DX units. When compared to high-quality, premium grade DX solutions, a reduction in electrical load infrastructure could be available as well as the potential for architectural savings. VRV systems are more resilient and are made to last years.

Arguably the most important point. Creating an environment with superior IAQ while reducing contaminant concentrations are two compelling reasons why 100% OSA VRV systems, especially with depressed dew points, should be considered for design solutions.

Concluding Remarks

This article will consider the feasibility of existential pressures influencing future HVAC designs. However, paying higher energy costs to create environments that reduce the risk of pathogenic infection will not be a longtime conclusion. Designing for HVAC systems that offer superior IEQ and more energy efficiency is not only possible, the technology is already available. 100% OSA variable-refrigerant systems supplying low dew point supply air offer one such compelling design strategy.

This hybrid VRV concept aligns with the AIA's 2030 Commitment and the Carbon Leadership Forum in meeting its carbon neutrality targets by providing an all-electric HVAC solution that can be powered by renewable energy sources. Future analysis should be considered to arrive at tighter performance results more closely aligned with building types and a range of other geographical regions. More research should be conducted to determine what optimal room ACH rates more effectively reduce airborne contaminant concentrations. Regardless, a 100% outside air VRV system is one compelling option for creating more efficient buildings and healthier environments conducive to maintaining personal health and well being while reducing the impact of our carbon legacy on future generations.

**VRV refers to Daikin's name brand of Variable Refrigerant Volume. Daikin introduced the variable-refrigerant concept in 1982.*

Don Hahne
Don Hahne has a bachelor's degree from University College London and a master's degree from Boston University. He has been in the HVAC industry for 39 years, beginning in 1983 working as an estimator for Norman S. Wright Co. SW., in Arizona, where he transitioned into outside sales. In 2000, he joined Specialty Products as an outside salesman before moving into engineering sales in 2008, where he became ASP's proponent and educator on high-performance HVAC system solutions. In 2019, he joined Daikin North America's Applied Group as a sales representative. Hahne currently holds the position of director of high-performance HVAC solutions, serving as an educator for sustainable HVAC system concepts, products, and applications. In 2020, and the height of the COVID Pandemic, he became a regular resource for HVAC solutions for cooling healthier more risk-free environments. Contact him at dahn@varisolutions.com.