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The State of **Refrigerants**

Refrigerant transitions are happening now, and these transitions will have a big impact on both equipment manufacturers and contractors.

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The transition began when **EPA**, through their **Significant New Alternatives Program (SNAP)**, banned manufacturers from selling many types of HFC refrigeration systems. Refrigerants like **404A** and **134a**, which have **high Global Warming Potentials (GWPs)**, were suddenly illegal in some new equipment.

You may have heard that the federal regulatory push for new refrigerants has, for now, slowed down. Contractors can be misled by this temporary pause in federal regulations. If you slow down your preparation to install and service these new systems, you could be playing catchup later — trying to catch up to your competition!

A Little Background

Beginning in 2016, EPA put rules into effect that banned the sale and installation of many types of commercial refrigeration systems — including supermarkets and commercial food service equipment — using high global warming refrigerants. That left low-GWP refrigerants like R-448A and R-449A and very low GWP refrigerants like CO_2 and R-290 for new installations.

The hiccup here was that, after litigation, EPA was told that it lacked the authority to tell manufacturers that had already moved from HCFCs to HFCs that they now had to move away from HFCs to very low global warming refrigerants. However, although EPA had to withdraw its rules, the die had been cast and most refrigeration equipment manufacturers have already moved on and are almost exclusively offering low-GWP options.

Meanwhile, the regulatory action has moved to the states. After President Trump announced that the US would withdraw from the Paris Climate Agreement, several states announced that 'we are still in' and that they would be controlling greenhouse gas emissions on a state level. They formed the US Climate Alliance, which now includes 25 governors representing over half of the US population.

California, as is usual with environmental regulations, is the furthest advanced, with several other states being just in the early stages of developing their regulations. In California, the former EPA SNAP rules on commercial refrigeration are currently in effect and restrictions on high-GWP refrigerants for air-conditioning systems are being drafted. HVACR equipment manufacturers are asking those states to work together for consistent regulations, but it is likely that the regulations will not all be identical. New York, New Jersey, Maryland and the State of Washington are all currently working on their individual regulations.

In the future, the industry will be dealing with different types of refrigerants than in the past. Most of the refrigerants that have lower global warming properties are also flammable, although some just slightly so. Others, such as propane (R-290), can be quite flammable. The chart below, taken from an ASHRAE standard, shows how refrigerants can be classified as toxic (B) or non-toxic (A) and non-flammable (1), lower flammability (2 and 2L) and higher flammability (3).

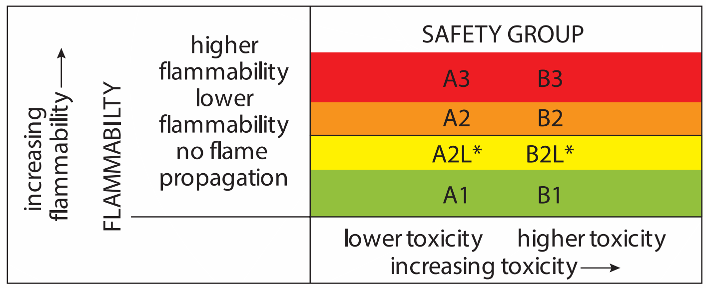

Figure 1: Refrigerant classification scheme.

The ASHRAE safety group classification is important to understand as each classification affects the implications of applying a given refrigerant to a system. When working with classifications of refrigerants that are flammable or toxic, safety is of the utmost concern.

There is a lot to consider; designers, installers and owners need to balance the safety and sustainability, the desired system performance, costs and the refrigerant properties.

The optimal point for design will also vary based on several factors such as the application, operating temperatures, regulations and standards. The various operating conditions will change based on regional use or on design use such as air conditioning, refrigeration or freezing. Another consideration is whether the system will be in occupied spaces or more isolated, such as a machine room.

Due to the various factors for consideration, it is easy to see that there will be no single refrigerant, but rather a patchwork of multiple refrigerants based on different applications.

Which refrigerants are being considered for refrigeration applications? First, we need to consider some sub-categories of refrigeration applications. Supermarkets, condensing units and split systems and self-contained refrigerators and freezers all have very different capacities and footprints, thereby allowing us to apply different refrigerants to hit the optimum point for safety, system performance and cost.

Today we can already see rapid adoption of some of the lowest GWP refrigerants including the use of R-290 for smaller self-contained equipment. The condensing unit and split system market is not as clear cut. There has been a transition to R-407A/F and some locations are starting to work with R-448/R-449A and concerns remain prior to moving to flammable refrigerants for larger charge split systems. We can also see transitions in supermarkets to CO_2 and some trials with R290 with semi-plug ins.

Globally there is wider adoption of CO_2 as there are over 10,000 systems installed in supermarkets that are operating safely at higher trans-critical pressures.

Which refrigerants are being considered for air-conditioning applications? Sub-categories of air conditioning are unitary, commercial rooftops and commercial chillers which typically use scroll compressors with high density R-410A. Larger capacity commercial chillers using dynamic compressors such a screw or centrifugal use low density refrigerants such as R-134a, R-513a or R-123. As you can see from the chart, the primary refrigerants being evaluated as a replacement for R-410A are R-32, R-452B and R-454B.

Each refrigerant has some positive and negative effects on the system. Below is a side-by-side comparison of some of the design properties for R-410A and lower GWP substitutes.

Refrigerant properties

vs R410A	R32	R452B
Glide	☺ NA	☺ 1K
DLT	☹ +15K	☺ +2K
EER	☺ +1%	☹ -1%
Capacity	😐 +2%	☹ -2%
Operating map	😐 Similar to R410A	😐 Similar to R410A
Oil	Higher viscosity	Higher viscosity
Safety	😐 A2L	😐 A2L
GWP	😐 675	😐 680

Figure 2: Examples of performance comparisons with different refrigerants. Source: Danfoss test lab.

Refrigerants Require Holistic Evaluation

Aside from evaluating the refrigerant for flammability and toxicity classification, the refrigerant must be evaluated holistically as applied to an application to ensure proper system performance and reliability.

A significant amount of work is necessary to design and qualify both equipment and subcomponents that will use the newer refrigerants. The refrigerant properties (thermal capacity, operating pressures, density, discharge line temperature, glide, operating map, oil miscibility, saturation temperature-pressure relationship) need to be evaluated across the individual system sub components such as the compressor, heat exchangers, valves, piping and even controllers.

Pressure is one refrigerant characteristic that has been evaluated. For many years systems were designed for use with R-22 and or R-404A with a maximum working pressure of 500 psi.

To achieve a safe working system, equipment must withstand three to five times that maximum working pressure. In the 1990s, designers had to overcome the hurdle of increasing the working pressure to 650 psi to accommodate the higher working pressures of R-410A.

More recently, in the last decade designers have been working to build safe systems for the wider adoption of CO_2, which, when operating in the transcritical region, can operate at pressures upwards of 1800 psi.

Compression technology is a major consideration for refrigerant selection. It can take a year or more of development work to qualify a known compressor technology for a new refrigerant. The refrigerant properties will greatly dictate which compressors can be paired with specific refrigerants.

Compression and volume ratio, discharge temperatures and bearing loads are just some of the compressor design considerations. In air-conditioning applications, many scroll compressors are used with R-410A. To evaluate a lower GWP refrigerant, such as R-32, a complete change in design is necessary.

The high discharge temperatures might require the addition of liquid or vapor injection to keep the temperature within an acceptable level. R-32 has a higher density than that of R-410A, which allows a designer to reduce the piping sizes and charge to keep acceptable velocities.

Understanding the refrigerant density and pressure is critical to properly sizing pipe diameter. This is a critical aspect of system design with new refrigerants, as we can see a much higher percentage of failed compressors in systems where a refrigerant field retrofit has taken place due to lack of oil return and low suction velocities.

Heat exchangers need to be evaluated based on the operating pressures, the density of refrigerant at operating conditions, the thermal capacity and if the refrigerant is zeotropic and has glide. If the refrigerant is flammable, such as R-290, considerations are made to reduce the internal volume as much as possible to meet charge restrictions.

For all components, a complete material compatibility evaluation is currently happening across the various refrigerants. There are 40+ replacement and lower GWP refrigerants. A list of all materials used, from steel, to copper, aluminum, to neoprene O-rings, polymer seals, gaskets and other plastics and coatings, needs to be tested for material compatibility.

If a new refrigerant is slightly flammable, the O-rings must be compatible to ensure there are no leaks or a product needs to be redesigned to eliminate the seals.

To read the complete paper on The State of Refrigerants, including tips on how contractors should prepare for these changes, please visit refrigerants.danfoss.com.

The limitations on **flammable refrigerants** do not exist solely for the safety of the end user. They also **protect the installer, and the manufacturer**.

Product Description

The Danfoss AB-QM™ pressure independent balancing and control valve (PICV) is an all-in-one balancing valve and differential pressure controller, providing 100 percent valve authority, accurate flow limitation and precise system control of hydronic systems. Available in a full range of sizes from ½-inch to 10-inches with a compact design able to handle any size application, the AB-QM™ is ideal for small spaces such as fan coil units and VAV boxes, as well as large buildings like offices, universities, hospitals, and buildings where accurate temperature control is critical, such as laboratories and research facilities.

Compared to traditional balancing valves, the Danfoss AB-QM™ PICV eliminates the need for Cv calculations and will save time on installation and commissioning.

The AB-QM™ pressure independent control valve helps to put an entire hydronic system into perfect balance by providing flows that match loads, even at partial loads, while minimizing maintenance and the horsepower required by the pump.

Danfoss **AB-QM**™ Pressure Independent Balancing and Control Valve

Case Study: A.K. Suter Elementary School

Engineering Tomorrow Solves Complex Energy, Comfort Problems

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Built in 1921, **A.K. Suter Elementary School in Pensacola, Florida** — like many older public schools in the state — used a retrofitted patchwork of packaged and split system air-conditioning equipment to keep students comfortable in a warm, humid climate.

In order to rejuvenate the almost 100-year-old school, Escambia County School District decided in 2011 to tear down the old school and rebuild it from scratch using new, high-efficiency HVAC technology. Today, the brand new A.K. Suter Elementary is by far the most energy-efficient of all ECSD schools — thanks in part to advanced HVAC technology, including Danfoss AB-QM™ valves and Danfoss Turbocor® oil-free centrifugal compressors.

"The new A.K. Suter Elementary School has a lot of features found in high-performance buildings," says Roger McGraw, P.E., mechanical engineer for ECSD Facility Planning. "The walls are constructed with insulating concrete forms (ICF) and a vapor barrier, so the building envelope is well insulated. The new HVAC system is state-of-the-art; two ultra-efficient variable-speed centrifugal chillers with Danfoss Turbocor® oil-free compressors ensure efficient chilled water production.

"The chilled water is supplied to several air-handling units (AHUs) and over 100 variable-air-volume (VAV) boxes each using Danfoss AB-QM™ pressure-independent balancing and control valves to optimize flow. This combination of technologies inside the ICF building envelope saves energy and handles our major comfort challenge — humidity."

Regional Humidity Dampens Learning Environment

Located in the Florida panhandle along the northern coast of the Gulf of Mexico, Pensacola has some of the highest humidity levels in the Sunshine State.

"Our summers are pretty extreme," says Jeremy Oksanen, the project's system designer and mechanical engineer with Premier Engineering Group. "We've got 'air you can wear' from April through October. The design conditions for the A.K. Suter project were 93.9F dry bulb and 77.7F wet bulb — and an 80F dew point at 85F dry bulb temperature. Translated into relative humidity (Rh), our mornings average 84 percent Rh and afternoons 64 percent. When humidity is at those levels and the dew point is high, everybody feels sticky, especially students."

The state of Florida requires between 68F and 78F dry bulb setpoints for all student areas, in addition to some form of humidity control. But, the setpoint for indoor humidity is not defined. The U.S. Occupational Safety and Health Administration, however, recommends indoor air be maintained within 20 to 60 percent Rh, equivalent to a dew point of 24F to 60F.

"In the old school, we had split-system heat pumps and some packaged rooftop units," McGraw says. "However, they were all very old, so we did not have that much control. Due to the humidity, the equipment was in all-cooling mode all the time. That's one reason the energy bills were high."

To measure annual school energy consumption, McGraw uses the metric of millions of BTUs (MBTU) per square foot. Older schools like A.K. Suter typically use more than 85,000 BTUs per square foot per year and higher — an amount McGraw hoped to cut in half with the new HVAC system in the new school.

The second biggest problem McGraw hoped to solve was zoning.

"Zoning is critical for comfort," he says. "When you try to create separate zones for different areas, it seems somebody, somewhere, is uncomfortable most of the time. As a result, doing zoning right was a requirement for the new system design."

VAV System with Independent Hydronic Control Loops

"We put a lot of thought into how to design a system that combines efficiency and comfort," says Oksanen. "To deliver conditioned air to classrooms, this design is based on using single-duct VAV boxes."

As the name implies, a VAV box is a sheet metal box equipped with an actuator that opens or closes a damper to increase or reduce the supply of air. Each single-duct VAV box used for this project is ducted to an air handler that contains a cooling coil with a 51F to 53F setpoint — cold enough for sufficient water vapor to condense on the coil for dehumidification, and then a reheat coil at the VAV box with a variable setpoint to raise the air temperature to avoid overcooling. The supply air temperature is reset upwards based on humidity levels and valve position to reduce reheat.

Just as fan dampers ensure proper air flow, valves are critical to control fluid flow.

The overall system employs supply air fans in AHUs to deliver conditioned air through ductwork connected to the VAV boxes. Then, return air fans circulate the air back to the AHUs.

The cooling coils and reheat coils in the VAV boxes are connected to a four-pipe, variable primary hydronic system. Variable-speed pumps drive the chilled or hot water through the chiller or boiler loop to supply the coils inside the VAV boxes or AHUs. One pair of pipes circulates chilled water to coiling coils; another pair circulates hot water to reheat coils.

"It can be a challenge to balance and control water flow in a four-pipe system supplying numerous VAV boxes, especially in a variable primary system where your conditions are constantly changing," says Oksanen. He points out that if the system is unbalanced, VAV boxes on some circuits will receive more water than required. In effect, those circuits "steal" flow from other circuits.

The first circuits are in overflow, which creates underflow in other circuits. The underflow VAV boxes do not get sufficient chilled or hot water to meet the cooling and heating requirements.

Pushing pumps to the maximum is one way to solve the underflow problem. However, this simply increases pressure to increase total flow, which increases pump energy consumption and stresses pumps and valves. Another tactic is to adjust supply water temperatures to meet the requirements of the VAV boxes in the underflow circuits, but that also wastes energy.

Solving Hydronic Circuit Balancing

Standard manual control valves cannot solve the overflow/underflow balance problem.

"When you have variable primary systems, we can never depend on manual balancing valves," McGraw observes. "That's because the system rarely operates in the same conditions to allow manually balancing the system."

"Instead, we like using Danfoss AB-QM™ pressure-independent control valves. They replace the typical two-way balancing valve and control valve pair that usually get installed on the return flow side of VAV cooling and heating coils. For this project, every VAV box and AHU gets an AB-QM™ valve, totaling about 130 valves. The valves ensure flows are balanced in the entire operating range of the system."

To balance the system, Danfoss AB-QM™ valves incorporate an integrated differential pressure controller that enables stable control with 100 percent "authority" — a term that means the AB-QM™ valve has complete control of the pressure drop in the system. As a result, at partial loads, there is no overflow because the AB-QM™ valve will always limit the flow to exactly meet requirements. From a system design standpoint, installing AB-QM™ valves divides the entire system into completely independent control loops.

Segmenting the hydronic distribution piping into independent loops or "modules" ensures the design flow — which, in this case, is typically six gallons per minute (GPM) — is available at all the VAV terminal units at design temperature setpoints. Thus, the AB-QM™ valve is the key that unlocks the three requirements for optimal system balancing by: 1) supplying design flow to all terminal units at design conditions; 2) minimizing variation in the differential pressure (pressure drop) across the control valve; and 3) ensuring the water flow is compatible with system components and interfaces.

McGraw also appreciates how the Danfoss AB-QM™ valve is easy to work with. "I like keeping each VAV box within the engineer's design setpoint," he says. "If a new piece of equipment is added and I need to change the flow because folks are a little bit uncomfortable, the AB-QM™ valve makes it easy. All I have to do is change the dial to either a 10, 15, or 20 percent increase in the flow and it happens. I don't have to hook up a computer. I don't have to change out the cartridges in the valve components. I just take the valve head actuator off and dial it in. In a couple minutes, the AB-QM™ actuator re-learns everything. It's simple compared to a manual balancing valve or auto-flow valves with cartridges."

Variable-Speed, Oil-Free Centrifugal Chillers

To generate chilled water at the 44F setpoint, two water-cooled centrifugal chillers are employed, each using two Danfoss Turbocor® TT400 variable-speed, magnetic-bearing compressors. Each pair of compressors deliver 250 tons of nominal cooling capacity per chiller.

Together, the two chillers provide what is known as "N+1 redundancy," meaning that one chiller is available as a standby or backup — as well as being available to provide additional capacity in the event of school expansion.

In day-to-day operation, the chillers take advantage of the Danfoss Turbocor® compressor's extraordinarily high efficiency at part-load conditions.

"Part-load efficiency is really important in this application," says McGraw. "The ICF building envelope is very effective, so ambient conditions outdoors have little effect on the cooling load.

"McGraw calculates that the lead chiller runs at 60 percent capacity 85 percent of the time, and below 20 percent capacity nearly a third of the time. It goes above 80 percent capacity only 3.3 percent of the total operating hours.

That's where the maximum benefits of Danfoss Turbocor® magnetic-bearing variable-speed technology are realized.

"A constant-speed centrifugal chiller is spinning the centrifugal impeller at maximum RPM regardless of outdoor conditions," says Oksanen. "When full cooling capacity isn't required, mechanical throttling vanes or valves can be used to reduce the chiller's capacity. However, the motor is still running at full RPMs, which wastes energy."

With Danfoss Turbocor® compressors, the shaft/impeller speed is reduced and — in combination with the inlet guide vane assembly — capacity can be "turned down" to match the cooling load required. To reduce speed quickly and reliably, the Danfoss Turbocor® compressor uses a synchronous permanent-magnet brushless motor.

Each motor is integrated with a variable frequency drive (VFD) that controls the voltage and amperage. VFD technology makes it easy to change speed by reducing the frequency of the current supplied to the motor. The drive varies frequency between 300 and 800 Hz, which provides a compressor-speed range from 9,000 to 29,000 RPMs without using a gear set.

Efficiency is further enhanced by the oil-free magnetic bearings, which eliminate the friction associated with using traditional contact bearings. In a Danfoss Turbocor® compressor, the rotor is levitated in a magnetic field rather than riding on bearings coated with a film of oil.

The absence of oil lubrication eliminates the efficiency losses that can occur when oil fouls a chiller's heat exchanger tubes. Tube fouling decreases heat transfer. One study shows that as little as 3.5 percent oil content in a refrigerant charge can reduce efficiency as much as eight percent.

To read the complete A.K. Suter Elementary School Case Study, please visit refrigerants.danfoss.com.