ENGINEERING
TOMORROW

# Design Changes to Reduce **Refrigerant Charge**

Soaring refrigerant prices, and uncertainties around future supply, have made reducing refrigerant charge an increasing priority for air conditioning manufacturers and cold room installers alike.

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**Optimizing refrigerant charge** has always been a key part of designing cooling systems and balancing their **efficiency, reliability, performance** and **cost**. But recently, that balance has shifted, and **refrigeration engineers** are once again looking at refrigerant as a key piece of the puzzle.

## There are two main reasons for this.

First, refrigerant prices are rapidly increasing in certain parts of the world. This is largely driven by dwindling supplies as traditional options are phased down under European F-Gas regulations, and other measures to limit the production of greenhouse gases under the Kyoto, Montreal, and Kigali protocols.

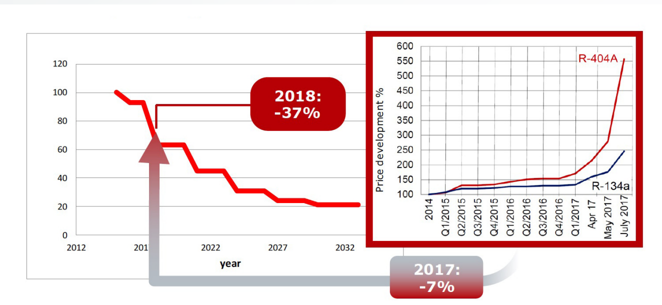


*Figure 1. Impact of phase down on refrigerants and prices.*

As a result, some refrigerants — such as R-404A — have risen in price by more than 500% in Europe since 2017.

Where once refrigerant may have been a relatively minor cost compared to a system's components, now the charge has a far larger impact on its overall production and installation price — making every saving valuable.

Second, the move to reduce Global Warming Potential (GWP) has resulted in growing use of flammable alternatives. In such cases, having less refrigerant charge materially increases the number of applications where a system can legally and safely be used.

So, in the current climate, reducing refrigerant charge is a key part of gaining competitive advantage – for manufacturers and installers alike – satisfying end users, and maintaining profitability.

## Ways to Reduce Refrigerant Charge

Potentially, reducing refrigerant charge can make systems safer, more flexible, and more competitive. It can be achieved in a number of different ways – many of which also bring an additional benefit to the system's full and part-load efficiency, or overall size.

We've identified these approaches engineers can take to reduce refrigerant charge without the need to compromise on safety, efficiency, or cost.

### 1. Reduce internal volume by reducing piping

Internal volume of course is an important factor for refrigerant charge, since there is a direct correlation between the two.

Because internal volume is dictated by the size and number of components, minimizing the length of piping or removing it altogether is vitally important. And the smaller diameter you can practically use, the better.

This is especially true in the liquid line. Each refrigerant has its own ratio of liquid to vapor density, but in all cases the liquid refrigerant density is significantly higher than vapor. So even though most of the volume in a system might be gas, the vast majority of its mass is in the liquid phase, which means each reduction in liquid volume has a disproportionately high impact on the overall charge amount.

A potential solution is to move some components closer to the condenser, or design reversible heat pump systems with bi-flow expansion valves, instead of bypassing it by adding parallel piping with check valves.

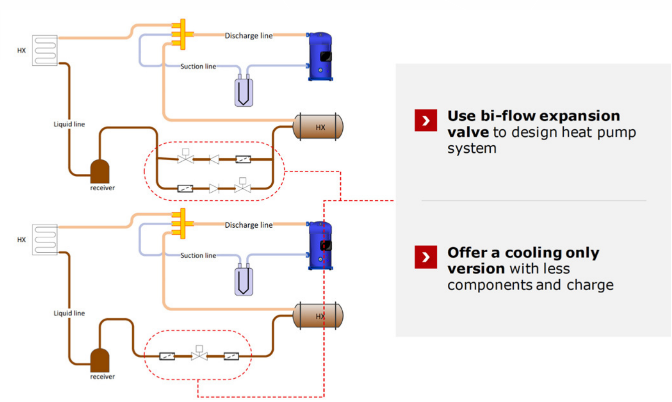


*Figure 2. Reducing internal volume.*

As long as refrigerant remains as a liquid before it reaches the expansion valve, and as long as the valve has sufficient capacity, reducing the diameter of the liquid line and the associated increase in pressure loss won't affect system performance.

## 2. Improve heat transfer efficiency

A high proportion of your charge will be in the heat exchangers, so their design will have a significant impact on your system.

An efficient heat transfer process in modern plate and micro channel heat exchangers can have a positive impact on system design and can improve system efficiency.

A micro channel heat exchanger (MCHE) uses flat tubes with small channels that not only increase heat transfer efficiency, but also reduce the internal volume and refrigerant charge by up to 70% compared to fin and tube heat exchangers. In applications where MCHEs aren't a viable solution, fin and tube coils with smaller diameter tubes can be used.

Heat exchangers in refrigeration systems have a two-phase mixture of liquid and vapor refrigerant. In the evaporator and condensation processes, the amount of vapor changes from the inlet to the outlet of the heat exchanger. A smart heat exchanger design minimizes the volume taken up by liquid refrigerant and charge in the heat exchanger.

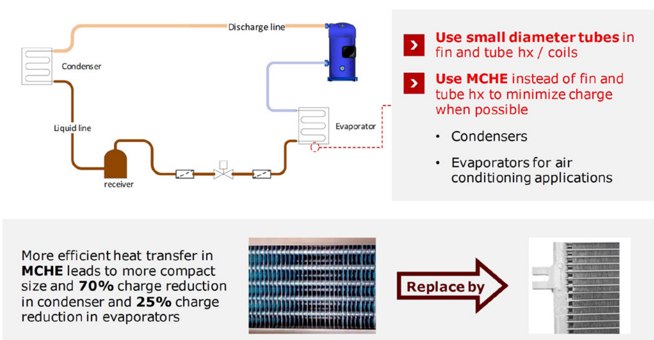


*Figure 3. Heat exchanger design and impact on refrigerant charge.*

An asymmetric plate heat exchanger design will reduce internal volume on the refrigerant side and the amount of refrigerant in the system — without an adverse impact on waterside pressure.

As a side benefit, this will result in improved heat transfer performance.

## 3. Consider system architecture

Traditional flooded evaporators require a large pool of refrigerant to work. In falling film evaporators however, refrigerant is sprayed on the tube bundle and only a small portion of the tubes are submerged in refrigerant, resulting in significant charge reductions.

In direct expansion (DX) systems, the refrigerant flows inside the tubes using flow boiling and condensation processes. DX systems will typically have less refrigerant charge than flooded systems, but will also be less efficient.

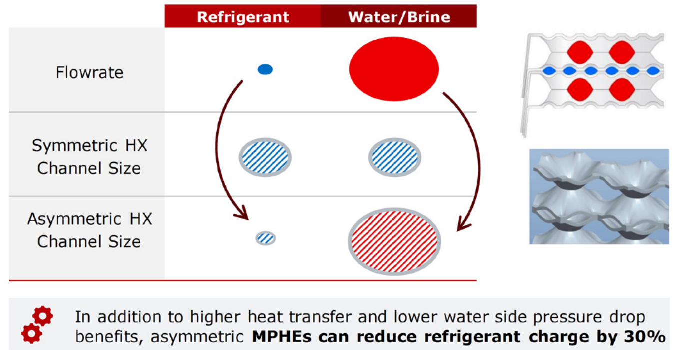


*Figure 4. MPHE design and impact on refrigerant charge.*

New DX heat exchanger technologies such as micro plate heat exchangers work with a very small temperature difference, and offer a similar performance to flooded and falling film systems.

In some applications though, it isn't feasible to have a packaged solution. The evaporator and condenser sections can only be connected by long refrigerant lines, and require a significant charge.

Alternatively, a water-cooled condenser and a brine loop can be used to carry the heat from the condenser to a remote cooler, which eliminates long refrigerant pipes and will significantly reduce system charge.

## 4. Take advantage of new compressor technology

A system design engineer has few tools to meet ever-increasing efficiency requirements. One method can be to use a larger heat exchanger with a smaller temperature difference. But while this is a reliable way to increase system efficiency, it uses more refrigerant.

High efficiency compressors can improve efficiency not just in full-load situations or applications, but also in part-loads.

This is particularly true for variable speed compressors, and those which use an intermediate discharge valve to prevent over compression in part-load conditions. Using an oil-free centrifugal compressor with variable speed functionality can significantly increase compressor efficiency.

By taking advantage of new compressor technologies, it's possible to meet efficiency requirements without increasing charge.

Figure 5. Innovative and efficient oil-free and IDV compressor technology minimize refrigerant charge.

**5.** **Deploy smart control systems**

Taking better control of your system conditions can give an immediate refrigerant saving.

Using an electronic expansion valve (EEV) to replace a thermal expansion valve (TXV), results in better control of superheat and more effective use of heat exchangers, especially in part-load conditions.

For example, using variable speed fan control to control head pressure, instead of a mechanical valve to flood your heat exchanger, may mean you can eliminate or at least reduce the size of your receiver.

And a variable speed drive for the condenser fan motor means it can adapt to any condition and power consumption can be reduced. This is a far better way to increase part-load efficiency rather than using larger heat exchangers that use more refrigerant.


Figure 6. Better superheat control for lower refrigerant charge.

## Match the Solution to Your Requirementss

Clearly, there is no one right answer covering all applications. But as refrigerant prices continue to play an important role in system design decisions, and as safety continues to be an increasing concern for those using flammable refrigerants, it's likely that engineers will use a combination of methods, to improve cost, efficiency, and competitiveness.

If you're re-evaluating your system design with a view to reducing your refrigerant charge, or facing another challenge, your Danfoss engineer will be delighted to help you choose the most suitable option.

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*Mustafa Yanik is a global application expert A/C for Danfoss Cooling Segment.*

Visit refrigerants.danfoss.com to learn more.

# Product Description

Danfoss microchannel heat exchangers (MCHEs) use three main aluminum components: flat tubes, headers, and corrugated profile fin arrays. Brazed together, these aluminum components create a direct metallic bond, eliminating air gaps and improving heat conduction.

Compared to traditional round tube coils, Danfoss MCHEs' smaller, flat tubes reduce aerodynamic drag, creating a quieter, more energy efficiency system. The aluminum in a Danfoss MCHE is roughly the same amount used in just the fins of an equivalent round tube coil, reducing the coil's weight by 60%. And because Danfoss MCHEs are built entirely from aluminum alloy, the risk of galvanic corrosion is all but eliminated.

Danfoss MCHEs are about a third the depth of round tube coils, making them easier to fit into systems and, more importantly, requiring only 30% of the refrigerant needed in an equivalent round tube coil. With environmental regulations constantly changing and becoming stricter with every passing day, having a lower refrigerant change will make any system greener and better suited for future regulations.

Combining superior materials, a smart design, and improved energy efficiency, Danfoss MCHEs are a great choice for any refrigeration systems.

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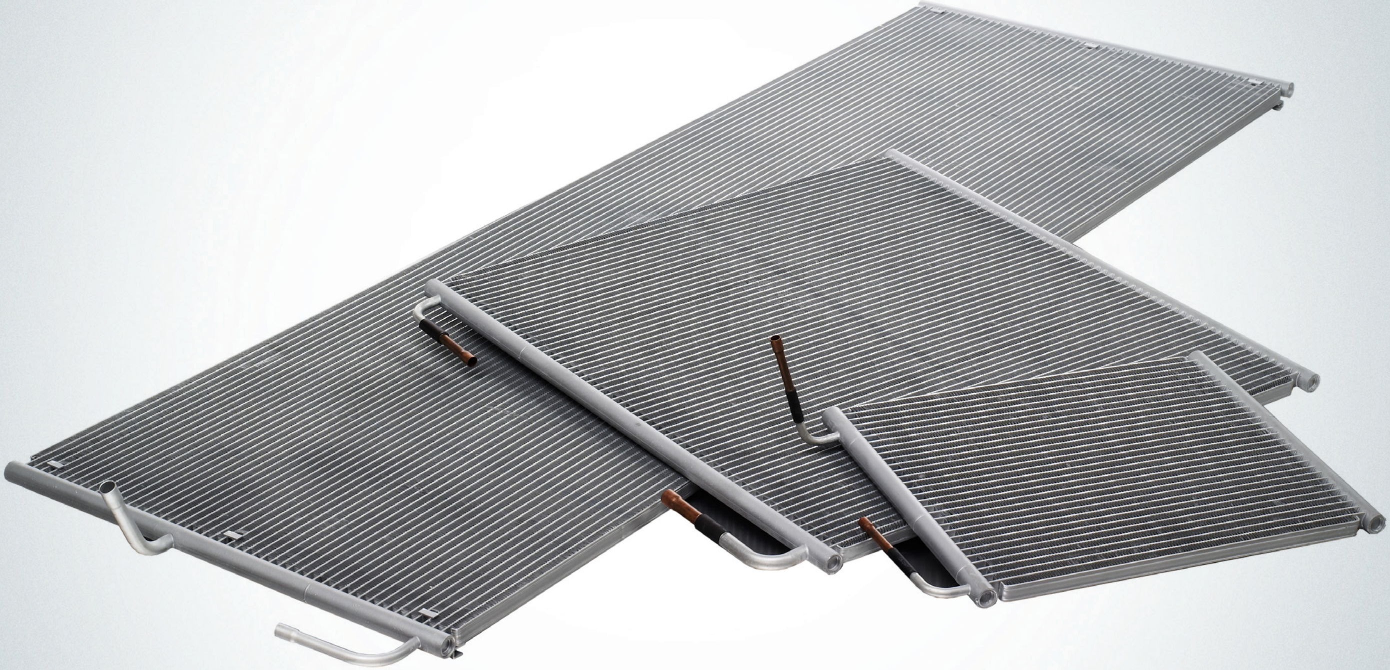

# Q&A with **John Sheff**,

## Director, Public & Industry Affairs for Danfoss

**John Sheff** is director, public & industry affairs for Danfoss. In this interview, Sheff discusses where we are with regulations today, how states are taking matters into their own hands, the need for education on A2L refrigerants and where the industry is headed.

### What is the current state of HFC regulations in the U.S.

Under the Obama Administration, SNAP Rule 20 and 21, which the EPA used to regulate ozone depleting substances under the Montreal Protocol, were interpreted to also regulate greenhouse gas emissions, so HFCs. The Trump Administration actually did not touch those rules. These were challenged in the courts by a couple of chemical manufacturers and were vacated by the federal courts. The courts basically said that under the Montreal Protocol, the EPA does not have the right to regulate greenhouse gas emissions. So those rules were thrown out. This administration still has the opportunity, however, to ratify the Kigali Amendment to the Montreal Protocol, which would put in place a phase-down of HFC refrigerants. But the administration has yet to take that up and it's unclear, even if they did, if Congress would ratify it. So there is no movement on the federal level for an overall overarching federal HFC program.

### How has this affected the states?

Because there is a lack of movement at the federal level, and because SNAP EPA, SNAP 20 and 21 were vacated by the courts, and the Kigali Amendment has yet to be ratified, all the action is in the states. California is leading the way, followed by some of the other states in the U.S. Climate Alliance — Maryland, Connecticut, Delaware, New Jersey, New York and a handful of others have said they're going to regulate HFC. Right now we are looking at what could be a fractured market for refrigerant regulation and the industry is trying to get a handle on that.

### What is the U.S. Climate Alliance?

The U.S. Climate Alliance is a bipartisan coalition of states and unincorporated self-governing territories in the United States that are committed to upholding the objectives of the 2015 Paris Agreement on climate change within their borders, even though the Trump Administration has withdrawn the U.S. from that agreement. It includes 24 states and Puerto Rico — that's 25 governors overall, roughly half the country or around 55 percent of the population and about 60 percent of the economic output of the country. And of those 24 states, a handful of them have said they're going to regulate HFCs in order to maintain their commitments to the Paris Climate Agreement.

## What is California doing to lead the charge?

California has adopted SNAP 20 and 21 with some provisions that go a little bit further. They're looking to limit refrigerants for air conditioning on GWP of 750 or lower by 2023, and commercial refrigeration of 150 GWP or lower on charges larger than 50 pounds. They're also looking at the 608 regulations, which regulate handling of refrigerant after they're installed. Basically, California has realized that they cannot achieve their climate goals by simply going after new equipment, so they're looking at how they can regulate existing equipment as well. The other states, New York, Washington, New Jersey, Maryland and some of the others, have not said they're going to go that far and are mainly looking at what was SNAP 20 and 21 on the federal level.

## What kind of regulations can we expect around new and alternative refrigerants?

As we work to get these low GWP, flammable or mildly flammable refrigerants into our building codes, that's going to be where the action takes place. Understanding how these refrigerants affect state and local building codes and how we can safely incorporate them into equipment, how we can safely incorporate them into buildings and then how can we safely work with them after they're installed. Regulations going forward are going to have to do with how we manage, how we incorporate these refrigerants into equipment, how they're going into buildings, and how they're managed once they're in buildings to make sure that the occupants are safe.

## What is the industry doing to educate users on A2L refrigerants?

The industry has put together the AHRI Safe Transition Task Force to really help states and local jurisdictions manage the transition into these refrigerants. But there needs to be training as well. Worldwide, there is a lot of experience with A2Ls in all these applications. So the task force is putting together rules and training materials that can be used for local installers and local contractors.

## What is the big concern for contractors now, regarding regulations?

Contractors need to be aware of what the regulations are, what the dates are for some of these states that are proposing HFC legislation and regulations, especially if their service areas span several states. They need to work with their distributors to be aware that some of these regulations are coming down and how to handle A2L safely. And again, A2Ls will be incorporated into the building codes and so there needs to be training on how they're installed and how they're safely managed.

# Where do we go from here?

We do believe that there needs to be a federal program and AHRI is working on that, as well as the Alliance for Responsible Atmospheric Policy, whether that's Kigali or it's a federal legislation that enables EPA to regulate HFCs. We do support such federal legislation if and when it comes about. AHRI is also actively involved with all of the states that I mentioned, working on these regulations to help them understand what is possible, what is feasible and what the industry can support. We understand the need to introduce A2Ls and to reduce emissions. And we just want to do it in a safe and responsible way and make sure that there's product available that meets these requirements.

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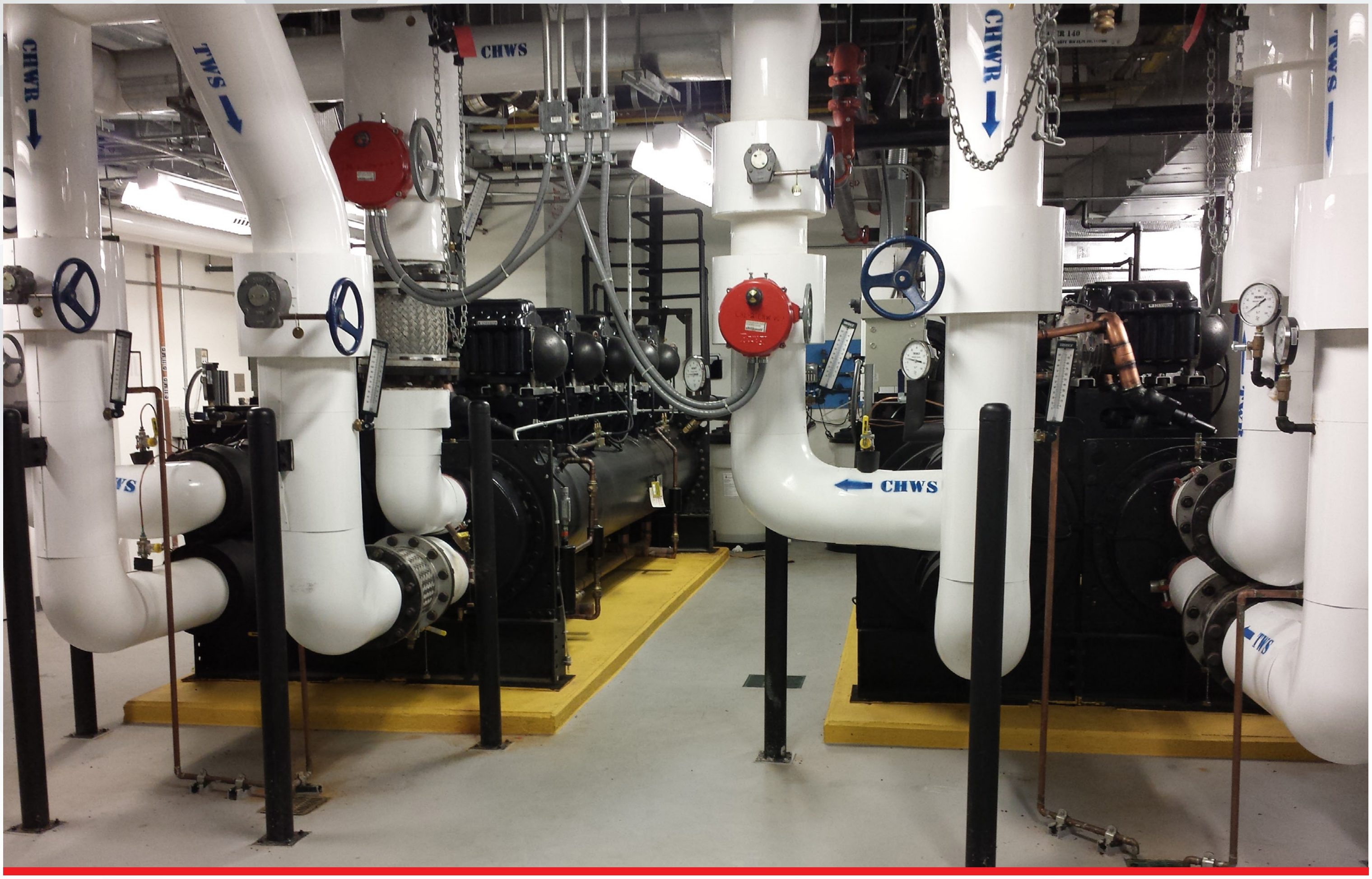


**Case Study:** University of North Carolina Wilmington

# Engineering Tomorrow Saves Energy in All Conditions

Danfoss Turbocor Compressors Handle Humidity from Amazon-Rainforest Highs to Seattle Lows in One Application



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Located just 100 yards from the Atlantic Intercoastal Waterway and 500 yards from the Atlantic Ocean itself, the **University of North Carolina Wilmington (UNCW)** takes marine science seriously. UNCW CREST Research Park includes three world-class marine laboratories, including the MARBIONC Building — a new 69,000-square-foot interdisciplinary research facility for marine biotechnology.

A silver LEED-certified facility, the MARBIONC Building provides labs for lease to commercial enterprises that require reliable, energy-efficient 24/7/365 cooling for laboratories. That's why Steve Sharpe, energy manager for UNCW, selected Smardt chillers using Danfoss Turbocor® compressors to handle humidity that ranges from Amazon-rainforest highs to Seattle lows.

"Summers can get pretty swampy on the North Carolina coast," Sharpe says. "We have to deal with high latent loads for cooling. But it's a mid-Atlantic region, so we experience climate variations throughout the year."

"Consequently, we decided to build a chiller plant that could take advantage of that wide range of operating conditions and still run reliably. If we lose cooling, we can lose research. As it turned out, Smardt centrifugal chillers with Danfoss Turbocor magnetic-bearing variable speed compressors could handle that range of conditions with 100 percent reliability."

## Optimizing an All-Variable-Speed Chiller Plant

Sharpe aimed to build the chilled water plant to exceed ASHRAE Standard 90.1-2013, Energy Standard for Buildings Except Low-Rise Residential Buildings. By using this standard as a baseline and following other ASHRAE recommendations, such as chiller plant optimization, Sharpe knew he could reduce the chilled water plant energy consumption by nearly 40 percent.

ASHRAE Standard 90.1-2013 requires selecting chillers optimized for part-load conditions as gauged by the Integrated Part Load Value (IPLV) metric. IPLV measures chiller efficiency over a range of operating conditions — precisely the situation Sharpe was facing.

"Our climate extremes are 97.5°F (36°C) dry bulb and 88.3°F (31°C) wet bulb temperatures," Sharpe says. "These conditions are very taxing on a system. The MARBIONC Building uses nearly 100 percent outside air. So, when you have high wet bulb temperatures, you have to ring the moisture out of the outside air being supplied inside. Outdoors, the high humidity hampers evaporation, making it tough for cooling towers to reject heat into the atmosphere."

"Fortunately, in actual day-to-day operation, less than 150 hours a year occur at the highest dry bulb and wet bulb temperatures," adds Sharpe. "This offers a lot of potential to save energy at all the hours spent at lower operating conditions."

While considering technologies to optimize the chiller plant, Sharpe talked to John Blakeney, branch manager at Thermal Resource Sales (TRS) for the Wilmington, North Carolina area.

"We help facilities manage energy and resources with their process and production initiatives," says Blakeney. "In this case, the project was a laboratory requiring the use of nearly 100 percent outside air. Given the variability of ambient conditions and the load, an all variable-speed chiller plant was the best option."

Based on ASHRAE recommendations at that time, the most efficient type of plant would be a single, primary-flow, fully variable-volume chiller plant. In this design, variable-speed pumps circulate chilled water to cooling coils in air handlers that provide space cooling.

Along with variable-speed pumps, variable-speed chillers are employed because they can track the variable thermal load very closely, saving energy for the remaining 8,610 hours operating below peak load.

Blakeney explains, "In conventional chilled water plants, chillers are the main energy consumer, drawing a large amount of electricity to meet the cooling demand. Then, pumps distribute chilled water at the specified flow rate, wasting energy by running at constant flow speed."

In an optimized variable primary flow (VPF) system; the volume of chilled water flowing through the chilled-water loop and the chiller's evaporator can vary. Outside, condenser water flow from the chiller to the cooling tower can also vary. Furthermore, water temperature can change, too. Consequently, the chiller must contend with chilled water flow rates, entering condenser water temperatures (ECWT) and chilled water supply temperatures

(CHWST) that vary considerably from static set points used in conventional chiller plants.

"All these varying temperatures and flow rates mean the optimized chilled water plant will need to employ a lot of technology using variable-speed drives (VSDs)," Blakeney says. "That includes variable-speed condenser pumps, variable-speed cooling tower pumps and fans, and, of course, a variable-speed centrifugal chiller capable of operating reliably at part-load conditions."

## Boosting Efficiency with Magnetic Bearing Chillers

To take maximum advantage of all the hours below full load, Sharpe selected two 750-ton Smardt WA240 water-cooled variable -speed chillers. Each chiller uses five Danfoss Turbocor TT400 oil-free magnetic-bearing centrifugal compressors, individually rated at 150 tons nominal.

"Variable-speed multi-compressor chiller technology provides outstanding annual building efficiency in a climate like ours," Sharpe says. "The key is to use multiple compressors that can throttle back or 'turn down' capacity to match the reduced load. At low loads, multiple compressors also mean the chiller can shut down compressors to keep them running in their efficiency sweet spot. At the same time the compressor is handling lower loads, it may also have to deal with lower lift."

Sharpe explains that when ECWT can be lowered, the compressor work and energy use is also lowered. For example, every 1F drop in ECWT below the full-load design point can increase chiller efficiency by 1 to 2 percent. Lowering ECWT is possible when building loads are lower, for example, on weekends when the building has fewer occupants. It can also occur when outdoor conditions are cooler.

Often, when load decreases, so does a factor known as "lift," which is the difference between the refrigerant pressure in the condenser and the refrigerant pressure in the evaporator. Lift is affected by weather, but will be dictated by the tower water temperatures, as that will play a factor in the condensing pressure of the refrigerant. Thus, it's important to have a compressor that is able to handle varying conditions.

Additional problems occur in non-magnetic-bearing chillers that require oil for lubrication. Proper pressure differentials must be maintained between the condenser and evaporator. Otherwise, oil will not flow out of the condenser, and the machine will trip off due to low oil pressure.

Danfoss Turbocor TT400 compressors do not have oil circulation problems because they use magnetic bearings that require no lubrication. The rotor shaft levitates in a magnetic field without the friction produced by physical contact bearings. Furthermore, there is no oil to foul evaporator tubes.

Sharpe also notes the Smardt chiller has outstanding stability across a very wide operating range.

"Danfoss Turbocor TT400 compressors have a very large operating envelope where the stall and surge lines are very far apart," he says." That means a single compressor can turn down capacity to handle very low loads and flow."

## Variable Frequency Drives Propel Energy Savings

Along with employing a true variable-speed, variable-flow chiller, another tactic that boosts system efficiency is minimizing the energy used by the cooling tower.

"You save energy whenever you can reduce cooling-tower fan speed and flow down to the point that ambient conditions make it possible to reach your minimum condenser water temperature," says Matt Squires, branch manager of Engineered Control Solutions, Wilmington, North Carolina, office.

Squires worked with Blakeney in specifying and installing the controls and the Danfoss VLT HVAC FC 102 drive that modulates the cooling tower fans.

"This installation uses a Tower Tech forced-updraft, counter-flow cooling tower, which is very compatible with Smardt chillers," Squires says. "With a maximum capacity of 2,000 gallons per minute, this cooling tower works well with variable heat load applications. In this case, we applied one 100-horsepower Danfoss VLT FC 102 drive to operate ten 10-horsepower direct-drive fan motors. This configuration makes the most of the heat exchanger surface area. It delivers some of the best efficiencies you can get."

The configuration saves energy by using the Danfoss VLT drive to slow fan motor RPMs. The physics of reducing fan RPMs can cut electricity consumption exponentially. For example, reducing speed by 20 percent results in nearly 50 percent energy savings.

## Brute Force Optimization

To optimize all the variables of the chiller plant, Sharpe called upon Blakeney for a solution.

"We specialize in providing a Central Plant Energy Control System (CPECS) that enables dramatic operating cost savings and improved chiller plant performance," says Caleb Jones, a project engineer for Kiltech (a Smardt Company). "The system uses continual feedback loops and advanced control algorithms to provide real time and predictive data processing. It's the opposite of 'set and forget' until you have a problem."

The Kiltech CPECS uses a model-based analysis method to most efficiently operate the plant. CPECS analyzes the actual load and outside air conditions at regular intervals, and uses equipment models to predict the most efficient operating point of the chiller plant. It then controls the plant to meet this operating point.

At the same time, it runs a model of an ASHRAE 90.1 plant. It compares the models against each other at all possible scenarios to determine the savings realized over the ASHRAE 90.1 baseline.

"CPECS is predicated on a brute force optimization method," says Jones. "It models everything. It knows the performance curves and power consumption of each component in the plant. It creates thousands of scenarios. Then, it picks the lowest kW per ton from all those models."

For the MARBIONC Building, the CPECS is continuously running the model so that the plant can operate efficiently across all operating conditions.

"The difference between an ASHRAE-compliant plant and the Smardt chiller plant is pretty amazing," says Sharpe.

The CPECS report from August 2016 to 2017 shows the plant ran 6,687 hours using 1,123,373 kWh for an average annual plant efficiency of 0.576 kW/ton. A baseline ASHRAE Standard 90.1 plant modeled on those same hours would have had an efficiency of 1.034 kW/ton, consuming an extra 929,529 kWh and costing an additional $67,855.