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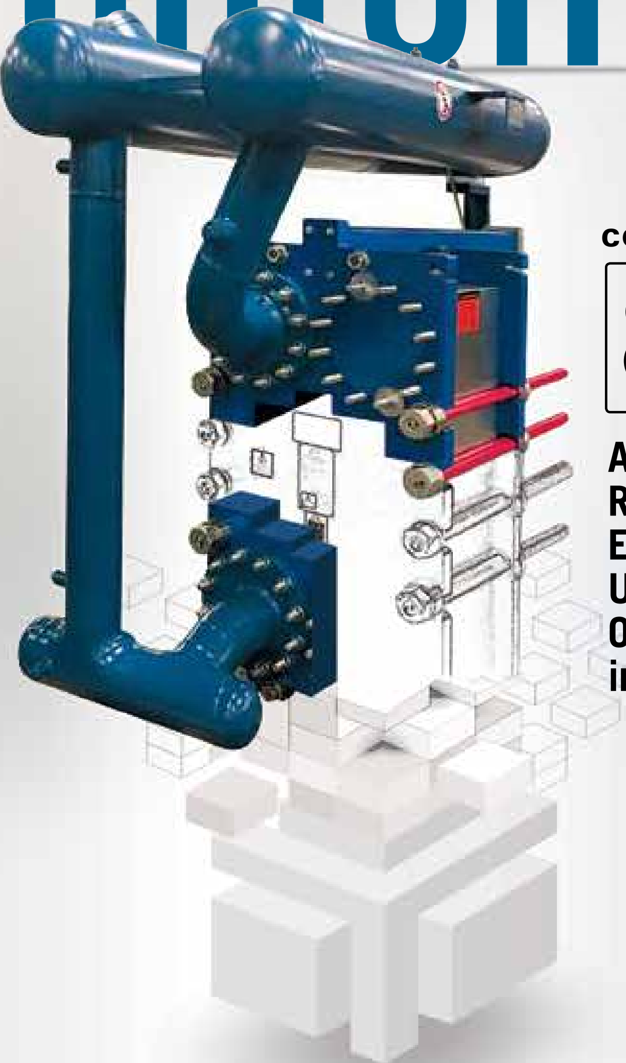

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president's MESSAGE

BY DAVE RULE

Once again, our industry is facing a major decision as to the preferred refrigerant that will provide appropriate performance and efficiency while considering the impact on the environment and public safety. This is a complicated question that must address the many diverse applications that are required for industrial and commercial refrigeration, many types of process cooling requirements ranging from manufacturing needs to pharmaceutical production and the general comfort cooling needs of public buildings to residential.

The one issue that everyone can agree on is that not just one refrigerant will address all of these application requirements. However, in considering the refrigerant that provides efficiency and performance while addressing the concerns of our environment, it is critical that the science and technology be addressed over the commercial marketing and arbitrary regulations that may exist.

This is our mission at IIAR to ensure that our industry, regulatory community and the general public have the facts and technology necessary to evaluate this important decision and select the best refrigerant for their system. Each refrigerant application must provide many years of safe and economic performance while ensuring that safe guards are in place concerning future environmental impact.

This issue of the Condenser features a cover story on secondary loop cooling and an article prepared by one of our members titled "The Catch 22 of R22 Replacements." Our secondary loop article is important since it addresses one of the "new – old" technologies that is being applied today to expand the opportunities to consider natural refrigerants. The feature article on refrigerants offers a comprehensive discussion concerning the recent history of our transition from the "Freon" refrigerants and the actual science behind refrigerant performance, economics and environmental impact. Both articles provide thoughtful reading and I encourage you to take the time to consider this information.

So, what is IIAR doing to address this important question? This really begins with the support of our membership and the efforts moving forward to ensure that the science and technology is available for our industry and the regulatory community to consider. Our efforts are also focused on the development of a sound education program through the Academy of Natural Refrigerants. Knowledge is the corner stone of our Advocacy program when it comes to making informed decisions on the refrigerant that will address our system needs in the future.

The regulatory community across the world is currently driving this refrigerant transition in their efforts to address the harmful effects of both Ozone Depletion and the more current issues of Global Warming. Here in the United States, we face a confusing regulatory environment where segments of the regulatory agencies support the use of natural refrigerants based on their positive environmental characteristics. While other sectors of the regulatory community make it increasingly difficult to use natural refrigerants due to arbitrary regulations.

Education will be a major part of our advocacy program moving forward and plays an important part in building the knowledge base in our membership and the regulatory community. Since the founding of the Academy of Natural Refrigerants, our voluntary committees and IIAR Staff have been working hard to develop a comprehensive certificate program to address safety standards and process safety management subjects to ensure that our engineers, PSM/RMP providers and regulatory community are well trained and have appropriate credentials to work in this industry.

I am pleased to report that the ANR courses are available through our online Learning Management System and the curriculum covers a broad number of important subjects. Virtually all of the IIAR standard courses are now available with IIAR-6 coming online within just a few weeks. The ANR safety courses now include basic PSM/RMP and Process Hazard Analysis, and Mechanical Integrity will be available in just a few months followed by PSM Engineering Calculations. The completion of these important certificate programs will provide individuals working in our industry with the opportunity to complete these courses with examination online and demonstrate their competence in the specific field of study.

IIAR is your organization and relies on your membership and support to complete this work. Your activity in this mission is critical to our success and the advocacy program to ensure our industry is well informed when considering the appropriate refrigerant for their system and the future impact that it may have on our environment. Education is the key to making these decisions and to ensuring that our industry is prepared to address the efficient design of our systems and the safety of our workers.

I look forward to working with all of our members to address these important issues and, if you are not a member, I encourage you to join today and to get involved with the IIAR mission.

chairman's MESSAGE

BRUCE NELSON

Hydrocarbons — A Natural Next Step For IIAR

Many hydrocarbons such as Propane, Propylene, and Iso-Butane, make great refrigerants. They are natural, have zero ODP, GWP less than 4, and are categorized as non-toxic. Compared to the HFC's and HFO's (also known as "F-Gases") they have:

- High COP
- High Latent Heat
- Low Liquid Density
- Low Cost
- Similar Working Pressures

The hydrocarbons are compatible with copper and with many low-cost components, such as hermetic and semi-hermetic compressors, expansion valves, and heat exchangers used in the HVAC and commercial refrigeration industries. Compatibility with standard compressor lubricants, desiccants, and elastomers is also excellent. The hydrocarbons are already in wide use – for cooking, heating, transportation, and power generation. Based on these characteristics the hydrocarbons are the only natural refrigerants that can match or beat the F-gases in commercial refrigeration systems on the basis of first cost and energy efficiency. Given the above, one must ask: "Why are we not making more use of the hydrocarbons as refrigerants?" The answer of course is flammability and the concern for safety. Safety standards do exist which allow for certain appliances having no more than 150g of a hydrocarbon refrigerant to be manufactured and installed. In fact, propane and iso-butane are increasingly being used in domestic refrigerators and in self-contained supermarket cases. The relatively small 150g charge limit has however restricted the use of hydrocarbons in larger systems where they make sense, such as in the high side of a supermarket cascade rack or in a packaged chiller.

Interest in the use of hydrocarbons and other natural refrigerants in commercial refrigeration applications has grown quickly driven by the imminent phase-out of the F-gases in an increasing number of states including; California, Massachusetts, New York, Connecticut, Maryland, New Jersey, and Washington State. Because of our expertise and ability to write ANSI-certified safety standards, the IIAR was approached by the North American Sustainable Refrigeration Council (NASRC) and others involved in the commercial supermarket refrigeration industry to consider developing the safety standards needed to allow the safe application of hydrocarbon refrigerants in larger commercial applications.

IIAR is uniquely qualified to develop the needed safety standards, facilitate their adoption by the model codes, advocate with local and national government agencies, and educate and develop competency with industry practitioners through the Academy of Natural Refrigerants. Hydrocarbons are a natural next step for IIAR!

A Task Force composed of IIAR Board members and industry experts was appointed by the IIAR Chairman, to examine these issues and return a recommendation to the Board regarding opportunities for IIAR. The recommendation was to proceed with development of a new hydrocarbon safety standard titled "Safety Standard For Closed Circuit Refrigeration Systems Utilizing Hydrocarbon Refrigerants."

I am pleased to report to you that work on this new safety standard is well underway – currently being taken up by members of the IIAR Standards Committee. The Hydrocarbon Standard Subcommittee is busy examining other existing North American and European standards, refining the scope and purpose for the new standard, and beginning to structure outline and content. If you have an interest in this topic, feel you can contribute to the development of the new standard, or just want to educate yourself on safe application of hydrocarbon refrigerants, I would encourage you to attend the IIAR Standards Committee meetings and get involved in committee activities.

Hydrocarbon refrigerants, applied safely, offer the prospect of extending the reach of natural refrigerants to many applications in the HVAC and commercial refrigeration markets currently dominated by the F-gas refrigerants. IIAR is uniquely qualified to develop the needed safety standards, facilitate their adoption by the model codes, advocate with local and national government agencies, and educate and develop competency with industry practitioners through the Academy of Natural Refrigerants. Hydrocarbons are a natural next step for IIAR!

Future Focus

AS SECONDARY REFRIGERANTS EVOLVE, END USERS SEE OPPORTUNITY IN NEW TECH

As refrigerants with high-global-warming potential are phased out, natural refrigerants are being considered for new applications, and the industry is seeing increased use of secondary refrigeration units that allow users to lower their ammonia charge.

Ken Mozek, refrigeration sales manager for Air Treatment Corp., said regulatory requirements are driving adoption of natural refrigerants, such as ammonia, and as a result, secondary refrigerant systems. “We’re seeing a high level of interest even in the commercial side of the business,” he said. “A lot of different innovative technologies are coming into play.”

James Hower, sales director, industrial refrigeration for Danfoss, said ammonia charge reduction has been a popular topic, and utilizing a secondary refrigeration fluid is a viable option to reduce charge while maintaining the robustness of a central system engine room.

Secondary circuits allow the charge of any primary refrigerant to be decreased significantly. “This means that potentially hazardous refrigerants can be used in a safe way in many applications,” said Björn Palm, head of division of applied thermodynamics and refrigeration, Department of Energy Technology at KTH, Royal Institute of Technology, in Stockholm, Sweden.

Bruce Nelson, president of Colmac Coil, said secondary use, whether it is chilled water, glycols, salt solutions or even volatile secondary refrigerants, such CO_2, allow users to manage and mitigate some of the safety issues, such as flammability, associated with the use of natural refrigerants.

“We can select secondary fluids that are foodsafe or benign that don’t have the safety ramification or risk,” Nelson said. “That allows us to really set people’s minds at ease and manage the risk profile. That makes fire marshals and environmental groups happy.”

Using secondary refrigerants with an ammonia chiller, for example, allows an end user to keep the ammonia well contained, well managed and well away from occupied spaces. “Secondary refrigerants allow us to begin to consider really reaching those other cooling applications we haven’t thought a lot about or discussed in a serious way up until this point,” Nelson said, referring to uses such as data-center cooling and pharmaceutical facilities.

What’s more, the use of secondary

refrigerant systems offers the prospect of the expanded use of natural refrigerants, Nelson said. “Ultimately it is about addressing climate change and reducing our carbon footprint. What we have all come to understand is that the use of natural refrigerants offers a way to reduce the direct emissions of greenhouse gasses because the natural refrigerants are by definition very environmentally friendly,” he said.

Use of secondary refrigerants also gives designers greater flexibility in secondary refrigerant piping design and material selection. “Depending on the fluid being used in the secondary loop, plastics, thin-wall tubing and other more cost-effective materials could be utilized,” Hower said. “Also, restrictions on routing of the piping and restrictions on equipment placement are reduced when using secondary refrigerants/fluids.”

REFRIGERATION OPTIONS

End users have several options they can consider with their refrigeration systems, and designers work with end users to determine what is the business case that needs to be achieved. “It isn’t a one-size-fits-all answer,” Nelson said. “The correct answer is it depends on the business case, the risk profile and what the customer really needs as a solution.”

Nelson added that in some cases, secondary refrigeration systems are the only way end users can accomplish what needs to be done. “In others, there is a choice between a secondary or a direct system,” he said.

Mozek said users have to consider their goals. “There are no silver bullets out there. There are pros and cons,” he said.

Jim Adler, department manager, refrigeration engineering at Hixson, said users have to analyze their systems and determine what they are trying to achieve.

There are several factors, such as the amount of cooling needed, the number of temperature zones required, the region’s seasonal temperatures, energy and water rates, and local authorities and codes, that dictate which refrigerants will work well in certain applications. “We try to ask enough questions to understand what is really important,” Mozek said, adding that for many users the goal is to optimize the rate of production while making their facilities safer.

Stina Forsberg, managing director of Temper Technology AB, based in Backa, Sweden, said it is important for the designer or end user to choose the right secondary fluid. “There is a wide range of heat transfer fluids and they are all different with different properties to consider,” she said. “This is something that is often forgotten.”

Nelson said, “Just as you’d select from a wide range of natural refrigerants for a primary system based on the application, you’d select the secondary based on energy efficiency targets, environmental concerns you may have and the temperatures you may be operating at.”

to do some pre-work to make sure that ammonia is out of the system before you ran hot water through it,” Adler said, adding that those systems typically use food-grade propylene glycols as the secondary refrigerant.

Food-grade propylene glycols are popular in cooling rooms, but if temperatures get too low, the fluid gets too thick, too hard to pump and the heat-transfer characteristics get worse, said Bob Czarnecki, chairman of IIAR’s Standards Committee. He noted that calcium chlorides or salt brines can be used for colder temps, but are highly corrosive.

In certain food-grade applications, such as dairies or beverage production facilities, ammonia doesn’t fit the cooling needs. In those applications, the equipment has to be cleaned with hot water.

When selecting a secondary refrigerant, end users should consider the end-of-life disposal of the secondary fluid as well as maintenance needs. Hower said some fluids require inhibitors to be maintained to prevent breakdown, corrosion and biological growth.

INDUSTRY-SPECIFIC APPLICATIONS

Fosberg said she is seeing secondary systems used in many different applications, including huge industrial applications. “This is mainly because the legislation regarding refrigerants and needing to have a lower refrigerant charge,” she said. “In Europe, the legislation is giving the industry no alternative. They need to move toward natural refrigerants and that is what they do.”

In certain food-grade applications, such as dairies or beverage production facilities, ammonia doesn’t fit the cooling needs, Adler said. In those applications, the equipment has to be cleaned with hot water.

“When you do that with ammonia, it would be a problem and would be popping pressure relief valves. You’d have

Forsberg noted that many products, including Temper’s, are treated with corrosion protection. She added that end users can check to see if a product has undergone corrosion testing and what type of corrosion protection the product has.

Hower said that traditionally, industrial secondary refrigerant systems were dominated by recirculated glycol, which has energy efficiency penalties and disadvantages when it comes to heat-exchanger equipment size.

Forsberg said there are a lot of alternatives to choose from today. “The industry has learned that heat transfer fluid or secondary refrigerant doesn’t have to be a glycol,” she said.

Temper Technology’s secondary refrigerant, also called a heat transfer fluid, is based on organic salts, potassium formate and potassium sulfates together with an advanced corrosion protection package. “From our point of view there is no life limit to this fluid because it is chemically stable. Glycols can chemically change and break down,” Forsberg said.

Hower said CO_2 recently has become a popular secondary refrigerant choice. It is a fluid that the industrial refrigeration industry is quite comfortable with, and it has largely removed many of the downsides of using a secondary refrigerant loop.

Hower said that due to differences in viscosity and the reduction in mass flow, which result from latent heat transfer versus sensible heat transfer, CO_2 volatile brine systems benefit from a reduced energy penalty compared to glycol-based systems. "This can approach a 20 to 30 percent improved energy efficiency for CO_2 volatile brines," he said. "Due to those same differences, heat transfer surfaces are greatly reduced resulting in smaller equipment sizes as compared to water-based heat transfer fluids."

With a CO_2 volatile-brine secondary system, thought must be given to the options available for defrosting low-temperature evaporator coils, Hower explained. Options could include electric, glycol and CO_2 hot gas via a gas generating system, so CO_2 compressors would not be required. "To increase energy efficiency when using glycol defrost, the heat for the glycol could be provided from the waste heat of the primary refrigeration system," he said.

The most popular secondary refrigerant is water, but water can't be used at near-freezing temperatures. "That limits your applications to space cooling," Czarnecki said.

Nelson said some of the latest interesting technologies today include salt solutions that allow users to operate at very low temperatures, lower than they would have considered in the past, even down to blast freezers. "Some new developments and technologies with potassium salts, silicone-based fluids, aqua ammonia or citric-based fluids are really extending the range of secondary systems," Nelson said.

New pump technologies are expanding end users' options. "A number of pump manufacturers are making variable-speed circulating pumps that have their own onboard intelligence and technology. It makes these pumps smart, in that they can regulate the speed and circulation rate depending on the target set-point they are watching," Nelson said.

That makes it possible to match the flow rates to the cooling load and dramatically reduce the pumping power required. "Between the fluids themselves and some of the pumping technologies, our industry is really in a good place and in a position to build these systems in a wide range of applications that minimize energy penalties," Nelson said.

Although secondary refrigerants have several benefits, these systems may come with a higher operating cost due to the additional pumps required and the electricity needed to run them.

END-USER CONSIDERATIONS

Although secondary refrigerants have several benefits, these systems may come with a higher operating cost due to the additional pumps required and the electricity needed to run them. "A lot of people in the industry don't do it because of their concerns with potential added cost," Czarnecki said.

Czarnecki added that new technology advancements now allow systems to utilize secondary fluids that have easier pumping, which enables designers to use smaller pumps with lower costs.

Servicing secondary refrigeration units is easier, Czarnecki said, because operators don't have to take time to get the ammonia out of the way. What's more, users don't have to install ammonia sensors throughout a facility. "There are intangibles, but it is often going to cost you more to put in and more to run a secondary refrigeration system," he said. "The advantage is that it is safer and easier to deal with."

PRIMARY REFRIGERANTS

As for the primary refrigerants, Palm said ammonia is already used in large-scale industrial plants and could possibly find a broader use in new applications in the future. He added that CO_2 is already used in supermarket refrigeration and in domestic hot water heat pumps in Japan.

With hydrocarbons, isobutane is already used in almost all domestic refrigerators sold in Europe and is common in other parts of the world Palm said. Propane and propylene are used in some heat pumps, AC equipment, and commercial refrigeration equipment. Regulations are being changed, allowing larger charges than before, so use can be expected to increase in the near future.

"Regardless of the primary refrigerant used, regular testing of secondary refrigerant/fluid should occur to detect contamination of the primary refrigerant into the secondary caused by a failure of the primary to the secondary heat exchanger," Hower said.

LOOKING AHEAD

Given the critical role secondary refrigeration can play in the industry, IIAR's board of directors has embraced the idea of expanding IIAR's scope of activity to include secondary refrigeration on a greater level. The association has formed a task force to examine what IIAR can do to expand its best-practice information, safety information and also educational opportunities within the Academy of Natural Refrigerants in regard to a secondary system. The task force will share information this March at the association's meeting in Orlando. Also, the meeting will feature an educational session devoted entirely to technical issues and topics surrounding secondary refrigeration, Nelson said.

He added that the ozone depletion potential of natural refrigerants is zero and the global warming potential of natural refrigerants is extremely low and in some cases zero. "It's really making the world a safer place," Nelson said.

Industry Research Leads to New Insight on Optimum Pipe Sizing

After extensive research and analysis, IIAR's Ammonia Refrigeration Foundation has released new information on the economics of piping selection and on the proper selection of ammonia wet suction risers, which can help end users prevent oversizing of piping and using more energy than is necessary.

The research and analysis projects resulted in new information that has been incorporated in the new IIAR Piping Handbook, as well as in three new software tools available with the purchase of the new handbook.

The results of two ARF-funded research projects have been used to improve the information found in the newly published IIAR Piping Handbook, said Bruce Nelson, president of Colmac Coil.

"The first study, 'Development of Void Fraction Correlation for Ammonia Two-phase Flow in Risers', conducted by Dr. John Thome, used pressure-drop data collected during an ASHRAE-ARF co-funded research project (RP-1327) conducted at the Danish Technological Institute – DTI," Nelson said. "This research project provided a new method for proper and accurate sizing of ammonia wet suction risers based on measured data."

Nelson said the second study, "Optimum Pipe Sizing" conducted by Robert Sterling, president of Sterling Andrews Engineering PLCC, examined, corrected and expanded the work on economic pipe sizing developed by Bill Richards for the original Piping Handbook.

"Chapter 1 in the IIAR Piping Handbook now reflects work done over many years by many people," said Gordon Struder, director of advanced engineering for EVAPCO and chairman of IIAR's piping committee.

Multiple studies and ongoing analysis lead to the findings. Struder said the work started as a research project funded by ASHRAE sponsored by the TC 10.03 refrigerant piping group. As part of that study, the Danish Technological Institute conducted testing and acquired data on a two-inch and four-inch wet vertical suction riser section. "The research project started more than seven years ago. IIAR continued the research with funding from the Ammonia Refrigeration Foundation," Struder explained.

ARF continued the study and used the information for the suction-riser sizing method developed by Thome.

Struder said this is the first time the IIAR Piping Handbook has covered two-phase ammonia upward flow in refrigerant piping. "From my perspective, this has really consolidated the industry knowledge that was out there and provides a very reliable method to calculate pressure drop regarding a wet vertical riser pipe. This has never been available before in the piping handbook," he said.

As part of the project, IIAR developed equations and created software that users can access to predict the appropriate pipe sizes for their system design, Struder said.

The second ARF-funded study on "Optimum Pipe Sizing", done by Sterling, also made an important contribution to the new Piping Handbook, not only in the form of the equations and explanations contained in Chapter 1, but also in the form of a new easy-to-use software program, Nelson said.

"The selection software was part of the end goal of the study, so that methods developed in the research could be applied quickly and easily by an informed user," Sterling said. "It is fairly simple, requiring a number of inputs like line type (suction, liquid, hot gas, etc.), energy rates, labor rates and insulation thicknesses, and, using industry data, calculates the optimum pipe size based on cost of ownership for a user-defined system life."

Sterling explained that using a computer to look at different options can quickly give a design team a lot more insight – from an overall standpoint -- on how sizing impacts what they're doing for a particular system. The software allows the designer to measure the cost of ownership, rather than just looking at pressure drop or velocity.

Sterling added that the study was important because the original method and sizes were developed at a time when it was impractical to do a detailed analysis of energy costs, material costs, and labor rates, utilization of the system, and system design life as they impact the cost of owning a particular section of pipe.

"It is obvious in hindsight, but nevertheless one of the important findings was that for a given peak load, for the same size and length of pipe in two different installations, cost of ownership can vary widely. The best pipe size isn't always straight forward," Sterling said.

"The energy impact when choosing a particular pipe section can vary widely with what you're doing with that pipe. A certain pipe designed for a certain peak load may be used a little or a lot, may be harder or easier to transport or install, etc.," he said.

Design benchmarks, rules of thumb and project costs can vary widely from firm to firm, and there is really no benchmark as to how to design a piping system, Sterling said.

The outputs are based on a 100-foot section of piping, Sterling explained. "It is up to the user/system designer to take that information, which is actually only a piece of the puzzle, and incorporate it into an overall project strategy that considers many other factors. The software can't design a system, it can only give a single piece of information, which according to the inputs is the present value of owning a particular section of piping," he said. In order to ensure that documentation of various scenarios is possible, it also includes a feature that prints a table of software inputs and outputs for any particular 'run.'"

"I can't speak for the Research Committee, but in my opinion, having a stake you can put in the ground and compare different options based on a range of factors that give a hard number as to what it may cost for an owner to buy this particular piping section and own it for the life of the system is important. There is always value in identifying things like energy penalties that are hidden when just looking at first cost and using an industry-available tool to flush out the information," Sterling said. "Even if the particular costs are not 100% accurate, comparing them among various designs can give an idea of what the best choice is, and that's important in my view."

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Curbing Confined Space Confusion

As code interpretations continue to change and improvements slowly morph into normal practice, when the time comes to tackle OSHA's confined space standard, where do you start?

SPACE EVALUATIONS:

The first phase of tackling OSHA 1910.146, is identifying if you have confined spaces. This is done by performing space evaluations. Typically the details of how we define the terms "limited" and "restricted" in regards to egress raise the biggest questions when performing these evaluations. For this we look to life safety codes and regulatory interpretations for defining restricted. Based on regulatory interpretations in your area, the question may become, "is the access to the space smaller than an exit door?"

Once you've determined a space is a confined space, the next step is to determine if the confined space is permit required. Could the inside configuration trap an entrant, could it have a hazardous atmosphere, engulfment hazard, or other hazards like moving parts, chemicals, fall, or dust? If you've answered yes to any of those questions, the space is considered permit required. Some examples of permit required confined spaces might include condensers without full size exit doors, air makeup units and duct work, spiral freezers (this could be based on the employee's location within the freezer), and chillers.

TO ENTER, OR NOT TO ENTER?

If you've found that you have permit required confined spaces, your facility has two options: To enter, or not to enter. If you determine spaces will not be entered, awareness training and signage is adequate. If you determine your employees or hired contractors will need to enter at least one of the spaces, additional steps are required — the first of those being the completion of confined space assessments.

CONFINED SPACE ASSESSMENTS:

As an employer you are required to notify your employees and contractors of space hazards and elimination/control measures for those hazards. This is done through an assessment of the space. The objective of an assessment is to identify potential problems and how to fix them. Subjects such as identification of space hazards, hazard elimination and control measures, entry protocols, and rescue are all considered assessment staples.

HOW MUCH TRAINING?

If you've determined only contractors will enter spaces on your site, those that hire and manage contractors will need additional training. Training should include how to understand if the contractor has adequate training themselves and is performing a safe entry with the correct entry and rescue equipment. If however, you've decided your employees will enter confined spaces, their training should cover the duties of entrants, attendants, supervisors, your permit, non-entry rescue, the equipment your team will use, and a means to verify participants are competent.

RESCUE: INTERNAL VS. EXTERNAL

Before sending an entrant into a space, you are required to have a way to remove them from the space should they have an emergency. This can be accomplished by having a trained confined space rescue team on site, using a fire department, or hiring a standby confined space rescue company.

Internal teams require annual refresher rescue training. Typically rescue training is added on to the confined space entrant/attendant/supervisor training and done all at once. If your site identified potential respiratory hazards within spaces your team will enter, you may also want to evaluate training your team on SCBAs. On site teams are helpful if your location is going to routinely enter spaces, enter a limited variety of spaces, or is in an area where the fire department's rescue team cannot perform a rescue in a timely manner due to distance from your location or being on another call. When considering what would be timely, a good rule of thumb is that rescuers should be in the space treating the victim within 6 minutes of the emergency notification.

If you determine spaces will not be entered, awareness training and signage is adequate. If you determine your employees or hired contractors will need to enter at least one of the spaces, additional steps are required — the first of those being the completion of confined space assessments.

Using external support may be helpful if confined spaces are rarely entered or if there is a space that presents a unique or challenging rescue for which a professional team might be better suited. External support may also be helpful if there is a written agreement with a fire department that has a dedicated confined space rescue team near the facility.

SPACE RECLASSIFICATION:

When discussing reclassification, it's important to understand reclassification cannot apply to every space. To determine if a permit required confined space can be reclassified, first evaluate if the permit space poses no actual or potential atmospheric hazard. The key word is "potential". For example, consider a new, temporary, or transferred employee performing LOTO or double block and bleed procedures. The potential for error may be increased

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with employees less familiar with the equipment performing these tasks. If chemicals will be added or if welding is taking place, this could create an atmospheric hazard. Next, consider if all other hazards within the space are eliminated without entry into the space. Here, the key word is eliminated, and not controlled. For this, think of fall hazards, freely rotating ribbons/augers, internal configuration, and engulfment hazards.

The remaining steps include justification for the reclassification by using the pre-entry portion of the permit. With part of the permit completed, why reclassify? Many entries take place on weekends and off-shifts when crews are smaller, and overtime becomes a factor. The main advantage to reclassification, is not needing a rescue team assigned and ready, or an attendant present. But it's also important to consider how anyone would know if the entrant has a medical event in the space. Who calls for help if there is no attendant, and who performs the rescue if there is no rescue team identified and ready?

COMMON PROBLEMS:

When applying confined space concepts in the field, challenges often occur. Training can be either one of your greatest successes as a team or one of the greatest pitfalls. Most simply put, training should cover what the team will be expected to do in the field, with the main goal being to improve the safety of your team and drive down risk. Regardless of if the training is done internally or externally, if the training fails to cover what the team is expected to do on the job, retraining will be required.

Another potential snag awaiting you is equipment. A common practice is to buy equipment and perform assessments later. This can result in gear that doesn't work correctly for your spaces, or doesn't hold up in your environments. Also common, is not inspecting the confined space gear. This can result in expired gas meters, meters calibrated with expired calibration gas, broken winches, empty SCBA bottles, or pins missing on tripod or davit systems when they're pulled for an entry.

Lastly is the ever-present danger of complacency. A large percentage of injuries tie back to non-routine tasks, and a large percentage of tasks completed within confined spaces tend to be non-routine tasks. This could present itself in the form of complacency with alarming meters, the hazards within the space, or tenured yet untrained employees performing confined space duties as the entrant, attendant, rescuer, or acting as the permit's authorizing supervisor for an entry.

SMOOTH SAILING:

Although there can be grave risks when not approached correctly, confined space entries are successfully completed all across the country each week without a glitch. When the right processes, procedures, and permits are coupled with well executed training and a respect of the space hazards, teams can perform entries- and even rescues- like a well-oiled machine, helping to keep your location up and running without missing a beat.

Jen Allen is the Vice Present for Allen Safety LLC, which specializes in confined space rescue training, HAZMAT training, customized safety audits and PSM compliance audits.

AMMONIA REFRIGERATION FOUNDATION

news

Education Committee Reports Scholarship Program Growth

Your Foundation's scholarship program has been steadily growing since it was launched in 2016, helping address the industry's growing need for specifically trained engineers.

Mark Stencel, chairman of IIAR's Education Committee, said that in 2016, the program had three applicants. The next year, it was seven. Then it grew to 10. In 2019, there were 26 applicants. "The geographic [location] of these applicants extended form the U.S. to Canada, Latin America, and even some from Africa," Stencel said.

The scholarships sponsored by the IIAR/ARF Founders Scholarship program are awarded each year to junior and senior level students with an interest in perusing an engineering or related technical degree.

In a renewed effort to focus on education, In 2017, the Ammonia Refrigeration Foundation (ARF) voted to increase the value of the scholarship program, Stencel said. A student participating in the scholarship both junior and senior year will receive up to $13,000 in scholarship grants as well as an all-expenses paid trip to IIAR's Annual Natural Refrigeration Conference & Expo.

"[Through this scholarship] we are able to attract very talented, high-caliber individuals to the industry and expose them to natural refrigeration while providing them a vehicle through the conference for multiple career opportunities, Stencel said.

The value gained from this scholarship is tremendous. Bob Port, IIAR Scholarship Subcommittee chair, viewed by many as the driving force behind the scholarship program, said that the conference visit is particularly beneficial.

"Every year, the kids are the same way – they're just blown away by coming to the conference," Port said. "The amount of attention they get, the people that they get to work with… they have more people asking them for resumes than they know what to do with."

Stencel agreed there are many benefits of the scholarship both to the individual students participating and the industry as a whole. "I believe the scholarship program has the direct benefit of attracting recipients to the natural refrigeration industry," he said, "but there's an indirect benefit of getting the word out in the consciousness of engineering students wherever the program is publicized about the tremendous opportunities there are in natural refrigeration."

Port added that scholarships such as the ARF program are critical for the viability of natural refrigeration. "The importance is huge. We're kind of a small niche of a much bigger industry . . . but we're critical. A lot of people won't eat if we don't exist," he said. "We struggle to get new people brought into the industry."

Port explained that as lynchpins of the ammonia refrigeration industry's leadership age and retire, they need to be able to pass on their institutional knowledge to younger, up-and-coming talent. "You don't see as much young blood coming in behind you," he said. "We really need to start getting more younger people into the industry and excited about it."

Interested applicants must meet specific requirements and they are vetted using a number of criteria. First, the scholarship is open to juniors and seniors attending a four-year accredited engineering college. These students must be pursuing a course emphasis in thermal fluid science or related disciplines, and they must have completed 45 semester credit hours while maintaining a minimum 3.0 grade point average. Students are required to submit an application form along with their transcript and a letter or letters of recommendation.

"The scholarship has gained traction, but as the industry, the foundation and the opportunities grow, the hope is that the scholarship grows as well," Stencel said. "[The hope is] to have more applicants and more participants and it becomes a real vehicle to bring talented young people into our industry."

More information on the scholarship is available online at iiar.org.

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Newest Certificate Program for the Academy of Natural Refrigerants:

- Performing an Effective PHA
- IIAR 6
- Basic Ammonia Design

Due to be released – IIAR Standards and Publications:

- IIAR 9: Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) for Closed-Circuit Ammonia Refrigeration Systems
- IIAR 2: Standards for Safe Design of Closed-Circuit Ammonia Refrigeration Systems
- The Piping Handbook
- IIAR 6: Standard for Inspection, Testing, and Maintenance of Closed-Circuit Ammonia Refrigeration Systems

IIAR Discounts – IIAR members receive discounts on industry publications, conference registration, and IIAR Academy of Natural Refrigerants certificate courses.

Selecting the Right Compressors

For a refrigeration system to run at optimal energy efficiency, it's important to carefully select the right type of compressors need to be selected, and the correct cooling method employed.

There are three primary types of refrigeration compressors – rotary screw, reciprocating, and rotary vane. Understanding how they work is critical in running an operation in the most effective way possible, said Tony Lundell, the director of standards and safety at IIAR.

First, we'll take a look at the three types of compressors – how they're are applied, configured and cooled – and then well explore common mistakes that are made in the industry regarding energy efficiencies using these different setups.

There are two main types of rotary screw compressors – single and twin. One of the main benefits of these compressors is their versatility. They can be used in nearly any refrigeration application, Lundell explained. They can accommodate compression ratios of up to 20:1 with ammonia and can be installed in a variety of configurations.

Twin-screw compressors have male and female rotors that draw refrigerant vapor in where it is compressed in the space between the two as they turn. The vapor is pushed through the compressor where it is pushed through a discharge port, Lundell said. These increase pressure and temperature significantly and very successfully. Single screw compressors are work similarly, but with only one turning element.

These compressors both use oil, which can be cooled in one of four ways.

1) Liquid-injection cooling involves injecting high-pressure liquid refrigerant into the compressor where it flashes to a low-pressure temperature within the space between the rotors. That evaporation cools the oil in the system. This is a fairly low-cost option, but it comes with associated inefficiencies Lundell said.

However, recent advancements in motorized expansion valves allow plants to lower their discharge pressure further than when using thermal expansion valves for liquid injection, Mike Reiner, director of engineering at GEA Systems North America, said.

2) Thermosyphon cooling is another option. This is considered a passive method of cooling compressor oil. Thermosyphon cooling uses a heat exchanger, typically a shell-and-tube or a plate-and-shell heat exchanger mounted on the side of the compressor. High-pressure liquid ammonia is piped from an overhead pilot vessel into one side of the exchanger, and the heated oil passes through the other side, where it is cooled. Proper installation and refrigerant piping design is crucial for the thermosyphon system to properly function, Reiner said.

There are three main advantages to using this method of cooling, Lundell explained. First, there is no capacity power penalty associated with it. Second, there's no artificial lower limit to discharge pressure. Third, the heat rejected from the oil is routed directly to the condenser, providing energy savings especially in booster compressors and two-stage systems.

3) Water or glycol cooling is similar to thermosyphon cooling in that a heat exchanger is mounted to the side of the compressor unit, but water or glycol rather than ammonia is pumped through. This method makes the heat taken from the oil more readily available and useable. There is no limit to the discharge pressure of these systems, Reiner said. Another advantage of using water or glycol oil coolers is that the rejected heat can be used in other areas of the facility, such as for under-floor heating or preheating water.

4) Direct contact cooling between the refrigerant and oil is a relatively new method but works well with certain systems. A layer of liquid refrigerant is maintained on top of the oil within a separator, which boils off and constantly cools the oil. While this method is promising, Reiner said few if any manufactures are current use this cooling method.

Reciprocating compressors are widely used in high- or low-temperature environments. These systems can accommodate 8:1 compression ratios with ammonia and can be installed as boosters, high-stage, high-suction and single-stage compressors. Typically, they aren't as large as screw compressors, Lundell said.

Reciprocating compressors use pistons – similar to a car engine – to

There are two main types of rotary screw compressors – single and twin. One of the main benefits of these compressors is their versatility. They can be used in nearly any refrigeration application, Lundell explained. They can accommodate compression ratios of up to 20:1 with ammonia and can be installed in a variety of configurations.

compress refrigerant vapor within a cylinder. Most compressors have two to 16 cylinders. The pistons are driven by a crankshaft powered directly by an electric motor or indirectly using belts. An inlet valve is opened and low-pressure, low-temperature refrigerant vapor is drawn into the cylinder. The piston lowers, the valve is closed, and the piston rises to compress the vapor. During the compression process, heat is generated and must then be dissipated, Reiner said.

Typically, reciprocating compressors are cooled by water which is circulated through the heads and cylinder jackets, again, like an automobile engine. Some also have external oil coolers using water-cooled heat exchangers. Depending on location, water from natural sources can be circulated through the system at little to no cost in terms of energy expenditure and revenue. Some reciprocating compressors are air cooled, like old-fashioned Volkswagen engines or most motorcycles, and require no additional cooling, Riner said.

Finally, rotary-vane compressors are rarely used in new installations, but they remain abundant in older facilities. They are mostly used as booster compressors in low-temperature applications. They can accommodate a compression ratio of 5:1 with ammonia, according to Lundell.

Inside a rotary-vane compressor, there is an offset shaft with flat blades radiating from it. As the compressor turns, these blades thrust outwards and press on the vapor. They are fairly efficient, and they can move a tremendous flow of refrigerant without producing a lot of heat, Lundell said.

Rotary-vane compressors are cooled through liquid injection similar to screw compressors, or distilled oil or water can be pumped through the system's jackets to take the heat away from the vanes.

While great many various combinations of compressors and cooling methods can be employed for any number of tasks, selecting the right combination and setting it up correctly is critical in ensuring the system runs as efficiently as possible.

Often multiple compressors are needed to keep a large load at a certain temperature. At a minimum, at least one compressor should have a variable frequency drive (VFD) installed. This way, the compressors without a VFD can remain working in a fully loaded condition and the VFD compressor can adjust to trim the load, Rainer said. This will save money, save energy and reduce maintenance costs.

Another problem some facilities run into is that when a facility's production increases, the number of condensers doesn't grow with it, Lundell said. Instead, engineers adjust the temperatures of the equipment, running at lower suction pressures and higher discharge pressures to keep up with increased demands on the equipment. This requires more energy and burns equipment out.

Finally, some facilities set condenser head pressures and never adjust them based on atmospheric conditions, leading to tremendous costs and inefficacies during times of temperature and humidity fluctuations. Lundell said that a wet-bulb approach can solve this issue, adjusting the pressure in the condenser and saving both money and energy.

Shipping Bay: Safety & Reduced Energy Usage Overlap (a Win-Win)

from the technical **DEPARTMENT**

TONY LUNDELL, CIRO, PMP, IIAR DIRECTOR OF STANDARDS AND SAFETY

While working as the utilities and facilities manager, to bring on a new major expansion at a large food manufacturing facility, "Safety Always" was part of the culture. The new expansion called for growing from a facility with eight lines of existing production to an immediate addition of sixteen production lines - and targeted to expand to thirty-two lines of production within two more years.

As with most companies, the challenge to continually sustain and search for new ways to reduce energy usage through operations, maintenance, and projects continued to escalate as a business priority.

While the many utilities projects were implemented, one memorable challenge that improved safety results and reduced energy costs pertained to an approach implemented at the plant shipping bay. The utilities staff teamed up with the shipping department staff to address the following problem.

The shipping bay temperature was operated at 0°F and was located between a -20°F freezer taking up a full long wall. Four doors and thirty-one dock doors for truck access were located on two of the other walls. The remaining wall had office windows on each side of an entrance door. The other side of the thirty-one dock doors, where trucks backed up against cushioned seals and dock locks, was directly outdoors and exposed to seasonal ambient temperature. Although the winter months were definitely more favorable for reduced outdoor infiltration and ambient heat-load issues, the hot and humid summer conditions presented the greater peak energy usage challenges that needed to be addressed.

To address these issues a shipping department employee was assigned on each shift to keep watch over the dock doors and to address any findings that would improve housekeeping, prevent unsafe conditions, and reduce energy usage.

The dock manager would monitor shipping door attendants, and ensure trucks were backed up and sealed as well as possible before opening the dock doors. They would also make sure the dock door was closed after filling the trucks and before the truck departed the docking station. This cut down on massive air infiltration. There were a couple of shipping door attendants on duty that handled the truck and dock door sequencing from the backup, loading, and the departure.

While working as the utilities and facilities manager, helping bring on a new expansion to the business at a food manufacturing facility, "Safety Always" was part of the culture.

Housekeeping items were implemented to reduce and prevent potential unsafe conditions such as slips, trips, and falls. This included dock area cleaned of any wood pallet pieces, plastic wrap, cardboard, water, ice, or other types of debris. The removal of these items permitted the dock doors to close and tightly seal, thus reducing energy usage.

Addressing fixed building and equipment issues can offer significant methods to address both safety and energy.

1) Tighten, repair, or replace any existing door seals that are torn and/or not sealing well.

2) Install dock-level seals on the sides and below the lifting plate to prevent infiltration.

3) Replace upper door-cable pulley wheels with larger wheels to reduce time the doors take to open and close and reduce infiltration.

4) Repair or replace dock door panels that are damaged to ensure proper insulation thickness.

5) Tighten door rails and door wheel anchor plates and lubricate with low temperature grease to reduce friction loss and energy usage.

Addressing these issues offered significant benefits:

We were able to defrost the dock evaporator less frequently, due to lower frost/ice buildup from air infiltration.

We turned one evaporator into a reheat unit using a hot gas coil that allowed all the evaporators to dehumidify without lowering the dock bay temperature.

Overall, the dock bay area was much cleaner, potential hazards of slips, trips, falls were eliminated, the energy usage was reduced significantly. A few simple changes at the loading dock can improve both safety and efficiency.

IIAR Extends Safety, Education to Global Partners

IIAR continues to be active internationally, participating in and sponsoring conferences and natural refrigeration education in India, Mexico, Chile, Argentina and Colombia, with the goal to share IIAR's message to important global stakeholders.

In several venues, IIAR is helping to promote the use of natural refrigerants and to develop training to familiarize regulatory bodies with industry safety standard practices.

IIAR is planning to have a strong presence at the REFCOLD show in India on November 21, 22 and 23, said Yesenia Rector, IIAR's International Director.

She said five or six of IIAR's U.S. company members will have a place in a special IIAR pavilion at REFCOLD. The institute's presence is important because India's refrigeration industry is on pace to grow more than 40 percent by next year.

"India is very promising," Rector said. "The need for industrial refrigeration – in particular, ammonia refrigeration – is huge in this county."

In August, IIAR was active in several Latin American countries, hosting an August event in Mexico, helping develop a university program in Chile, hosting a conference in Argentina, and participating in a conference in Colombia.

The early-August event in Guadalajara, Mexico, was aimed at helping end-users, as well as Mexico's regulatory bodies, become more familiar with IIAR and resources the institute offers, Rector said.

Some of the topics discussed were the regulation of synthetic refrigerants in Latin America, comparisons of ammonia and carbon dioxide systems, and best practices regarding the safe operations of these systems.

Included in the event was a "a practical workshop for ammonia refrigeration – for its use and safety," Rector said. The workshop had presentations about safety release valve protection and ammonia detection.

"We wanted to do something similar to what we're doing in the United States annual expo, Rector said.

Earlier this year in Chile, the University of Santiago began offering a degree in refrigeration engineering using curriculum based largely on IIAR materials. The first students are preparing to graduate, and instructors along with local authorities and IIAR leadership are working to adapt the curriculum to the lessons learned from the inaugural class.

"They're ready to start working on

IIAR Extends Safety, Education to Global Partners

version 2.0," Rector said, adding that the next class will convene in the spring of 2020.

IIAR was active in an August conference in Buenos Aires, Argentina. Similar to the event in Mexico, the purpose was to educate end-users and inform regulatory bodies about the work IIAR has done, and how we can assist them in developing safety standards for their country.

The Buenos Aires event had a slightly different focus from the Mexico conference. Rector said, explaining that it covered more basic refrigeration concepts.

"About 60 to 70 percent of the attendees were end-users," Rector said. "They have specifically requested basic information about the operation of ammonia refrigeration systems."

This request is significant because Argentina's government has been hesitant to promote the ammonia refrigeration industry, and Rector said she hoped the event could help clear up some misconceptions about the industry.

"There's a lot of push back, a lot of fear," Rector said. "Authorities don't understand how this industry can flourish – so we're spreading the word… the key is education."

In late August, IIAR has partnered with the Asociación Colombiana De Acondicionamiento Del Aire Y De La Refrigeración, or ACAIRE. While that association's function has mostly focused on air conditioning, Rector said ACAIRE agreed to host IIAR at their annual expo August 28-30 in Barranquilla to get the word out about the ammonia refrigeration industry.

IIAR had a booth at the ACAIRE Expo, and the intent was "to expose more people to the nature of ammonia refrigeration," Rector said. While this might sound fairly commonplace, the mission is critical.

While there are many ammonia refrigeration systems established in Colombia, the operators and engineers of these systems do not have the resources they need to maintain them correctly, Rector said. This is due in part to ammonia's reputation in that country as a chemical used in the production of narcotics, she explained.

"No one wants to say, ' I have an industrial refrigeration system that runs on ammonia'," Rector said. "These systems are operating out there, and the end-users and operators don't seek the help they may need because they are afraid to admit [they're using ammonia.]"

Rector hopes IIAR's partnership with ACAIRE can legitimize the use of ammonia in Colombia and help clear its name.

> "There's a lot of push back, a lot of fear. Authorities don't understand how this industry can flourish — so we're spreading the word… the key is education."
>
> **Yesenia Rector, IIAR's International Director**

The Catch 22 of R22 Replacements

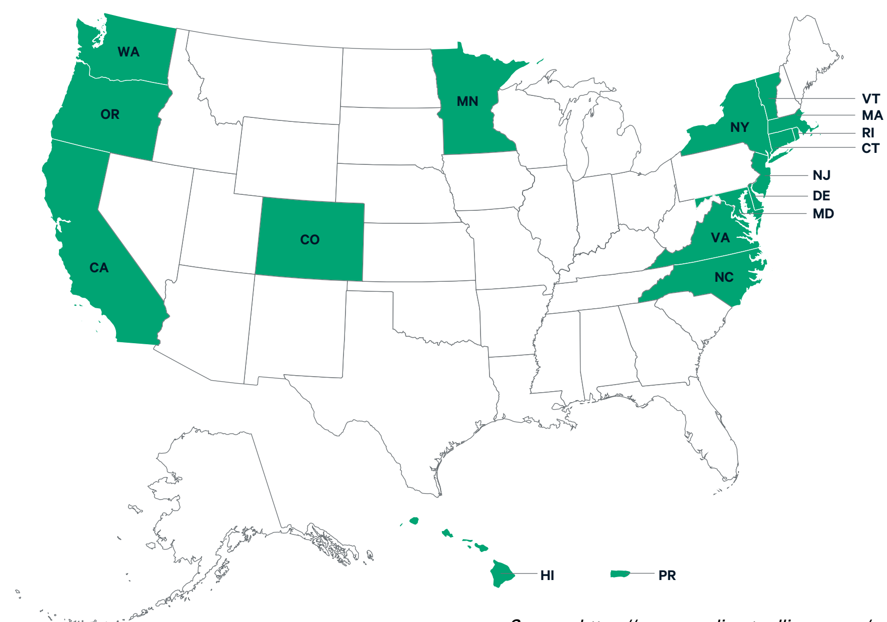
FREON AND BEYOND

If you've recently googled "it's almost 2020 and I still have R22" then hopefully this article grants you some timely insights. The world of refrigerants has become much more complex since you could refer to your refrigerant as "Freon" and not make an embarrassing social blunder because you were actually using a halogenated hydrocarbon and not a fluorinated hydrocarbon mixed with an unsaturated fluorinated alkene. While Freon® is simply a brand name which covers several legacy refrigerants (including R22) it continues to be the "kleenex" of the synthetic category despite there being many more brands to choose from which are wildly different in terms of application and performance.

Things get more complex if you consider that the regulatory landscape has many R22 users retrofitting refrigerants before their system expires. This means compatibility of the new refrigerant with the old system is critical. What's more is that while accounting for differences in capacity, efficiency, oil compatibility, operating pressures and temperatures, amongst several other factors, one must also attempt to predict the lifespan of the new gas. As R22, or more specifically, HCFCs (hydrochlorofluorocarbons), are phased out to protect the ozone, the HFC (hydrofluorocarbon) refrigerants available to replace them are now considered "super pollutants" contributing to the greenhouse effect. In 2016, the same mechanism used to phase out chlorine-containing refrigerants (eg R22) was revised to also regulate HFCs due to their global warming potential (GWP). The revision to the Montreal Protocol is the Kigali Amendment, which came into force on January 1, 2019. Although not all have chosen to ratify it yet, the signatories of the Kigali Amendment include 197 parties--which makes it truly a global resolution (there are only 195 countries in the world). In the United States, due to the current administration's delay of Kigali ratification, more than half of the country (24 governors representing 55 percent of the US population and an $11.7 trillion economy) has joined what is called the US Climate Alliance which pledges to uphold the Paris Climate Agreement. This means agreement to reduce GHG (greenhouse gas) emissions--partly by passing legislation to phase down HFC refrigerants like California and Washington have already done, and several other states are in the process of doing.

As January 1, 2020, the conclusion date of the US R22 phase out, is now only months away, many are hustling to understand their next move. Those who have already replaced their ozone-depleting R22 with an HFC are now anxiously watching the patchwork of GHG legislation develop, while many who delayed their R22 conversions actually still have the luxury of considering ways to leap-frog HFCs to a more permanent or "future-proof" solution. It is therefore important to understand what refrigerant options are available and how they may perform based on their most fundamental characteristics.

Current U.S. Climate Alliance States



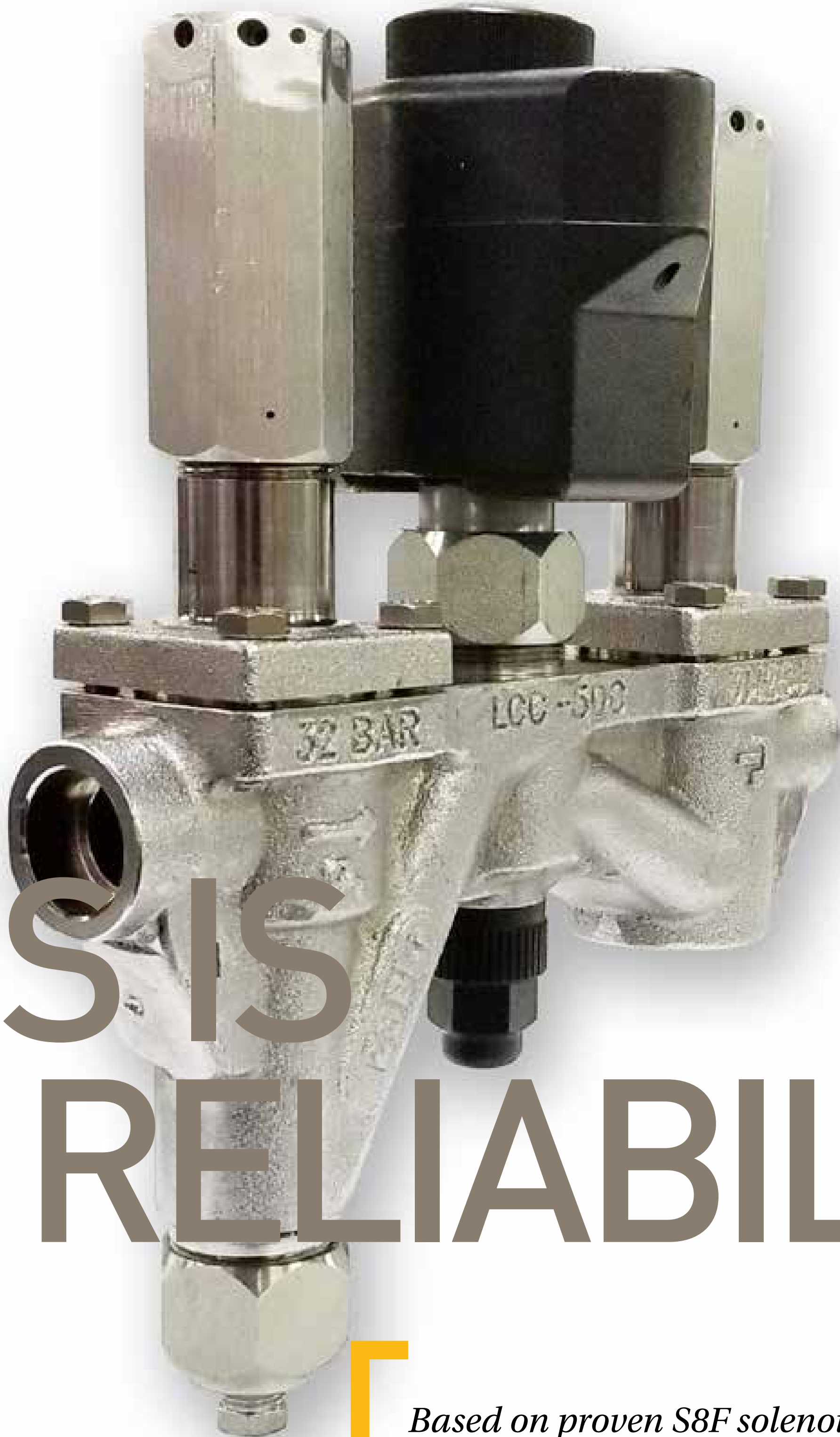
Source: https://www.usclimatealliance.org/

REFRIGERANT PROPERTIES

High critical temperature, high latent heat, low pressure ratio, and high refrigerating capacity per compressor displacement make for a good refrigerant that in turn make the refrigeration system both efficient and cost effective; however, not a single refrigerant wins in every category. Ammonia (R717) comes the closest as it has the best critical temperature and latent heat while having good capacity and low pressure ratio--which points to the reason ammonia has enjoyed great success over the past century and is still growing into new markets today. However, not every application is suited for ammonia, which is why R22 had been used primarily where ammonia had not.

CRITICAL TEMPERATURE OF VARIOUS REFRIGERANTS

Today there are still a large number of R22 systems, many of which are nearing their end of life. Even the newer systems cannot revert to ammonia, but neither could they easily switch to carbon dioxide (CO_2), propane, and probably most of the synthetics on the market. The latter is primarily due to one of the most important characteristics of a refrigerant: how much cooling it can produce given a certain amount of compressor displacement--referred to here as volumetric capacity (VC). For the purposes of this article, a "high" VC is with respect to the refrigerant, leading to a "low" compressor



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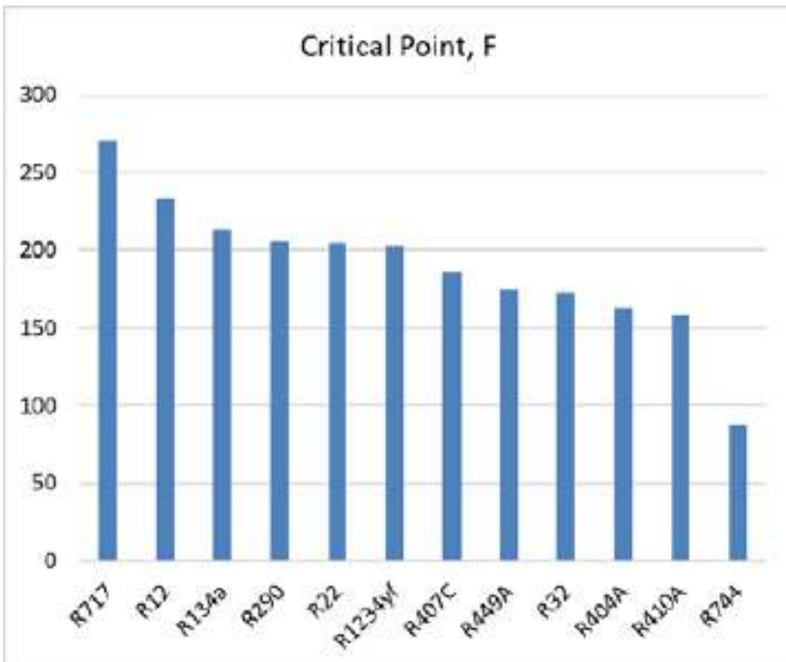
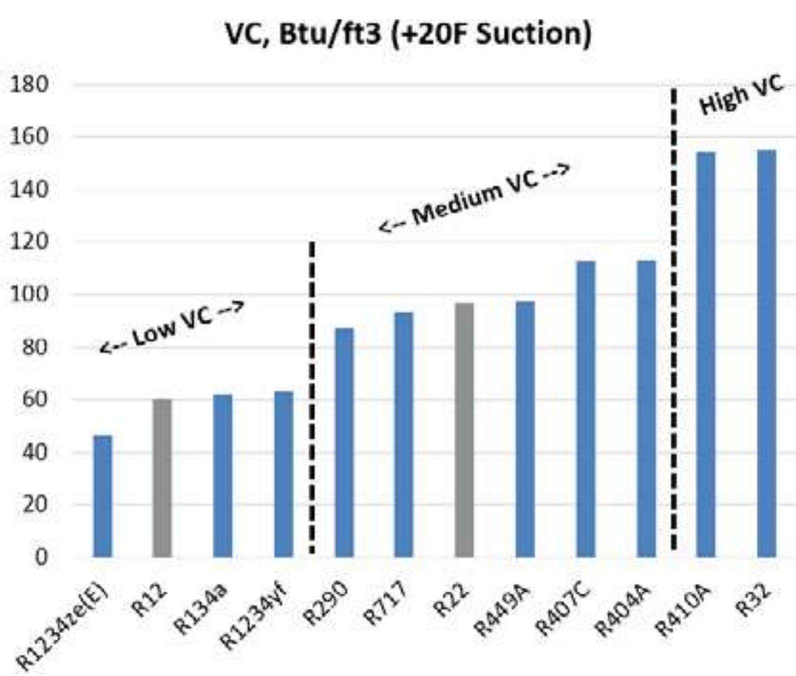
Critical Temperature of Various Refrigerants



Volumetric Capacity of Various Refrigerants



displacement requirement—and is a good thing. Broadly, refrigerants can be categorized into low, medium, and high VC groups, determined primarily by the latent heat and vapor density. Ammonia has a latent heat approximately 6 times that of other refrigerants, but a low vapor density counteracts much of this and yields a VC similar to that of R22. With CO_2 the opposite is true in that an extremely high vapor density paired with an already good enthalpy gives it more than three times the VC of R32. This means CO_2 compressors will be relatively small, however, they will need to overcome more than four times the pressure lift of an R32 system and more than seven times that of an ammonia system.

VOLUMETRIC CAPACITY OF VARIOUS REFRIGERANTS

The important thing to understand is that low VC refrigerants tend to operate at lower pressures and require larger system components (compressors, piping, valves, etc) while high VC refrigerants will run at higher pressures and can deliver capacity with smaller components. This introduces the first challenge when retrofitting synthetic refrigerants in existing systems: swapping a higher VC refrigerant for a lower VC refrigerant, generally, will result in a considerably undersized system. Conversely, swapping from a lower to higher VC refrigerant may compromise design pressures, scorch oil, and in most cases lead to system failure. It's important then to know the VC of your refrigerant so you don't waste time considering alternatives that don't stand a chance inside your system.

Without going too far back, we can better understand the available refrigerants by looking at the refrigerants they're meant to replace. R12 is a good place to start because it contrasts well to R22 which has twice the VC and operating pressure. Since both R12 and R22 have been phased out due to their ODP (Ozone Depletion Potential) we can track the lineage of their replacement gases to where we are today.

R12 REPLACEMENTS – "LOW VC"

R134a was the first chlorine free (ODP = 0) HFC refrigerant tested comprehensively[1] and since it's properties match closely to that of R12, it served as a good replacement and has been widely used in many medium temperature and air-conditioning applications to this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day. R134a has a relatively low GWP value (circa 1300-1400 in contrasts to more than 10,000 for R12) and so has dodged some of the early US regulations on HFC refrigerants. However, the use of R134a has been limited due to the expense of building large systems with low VC refrigerants and due to restricted application in low temperatures. It has however found favorable applications with large capacity centrifugal compressors.

Even though the GWP of R134a is the lowest of all non-flammable HFCs, it hasn't proven to be low enough for permanent use. In Europe, R134a was immediately disqualified when they required the GWP of all mobile air conditioning refrigerants to fall below 150. Europe's F-gas phase down regulations as well as the Kigali amendment are phasing down R134a along with many other HFCs for refrigeration and air-conditioning applications as well. So the future for low VC synthetic refrigerants has hinged on the use of a different family of refrigerants, known as "HFOs" or hydrofluoroolefins.

Perhaps the most well-known and widely used HFO is R1234yf which has similar properties to R134a but with a GWP of 4. HFO's achieve a very low GWP by being relatively unstable and breaking down quickly in the atmosphere. Long-term stability within a refrigeration system has also been a concern; however, this issue was apparently resolved through testing prior to its induction into wide-scale mobile air-conditioning (MAC) in Europe. R1234yf might have been a slam-dunk R134a replacement if it weren't for its most annoying characteristic--flammability. Although it is being used in MAC, lingering safety concerns and controversial experiences of R1234yf-induced crash fires (Daimler-Mercedes)[2] have led to further development and use of CO_2 systems for MAC.

One way to get around the flammability issue with HFOs is to mix in some R134a. With enough concentration of fluorine (complements of the R134a) the flammability can be reduced to a level where "non-flammable" status can again be achieved. However, this of course comes at the cost of increased GWP and so can be viewed as a self-defeating tactic, and certainly can't be a permanent solution. R513A has therefore been established as yet another stepping stone. Of course, as R134a undergoes a future phase down, refrigerant blends that rely on R134a will also be affected. In other words, if the Montreal Protocol is regulating R134a, by association, R513A is also regulated by it.

In time, HFOs will find their natural boundaries, as did R134a due to cost and performance concerns. For example, it's not likely that HFOs will find wide use in cold storage or blast freezing applications as a result of their relatively high boiling points. Colder evaporating temperatures will cause systems to operate in a vacuum--drawing air and moisture into the system when there are leaks. Unlike with ammonia, even small amounts of moisture in HFO or HFC systems will degrade oil, form acids, contribute to motor burnout on semi-hermetic compressors, and likely freeze up expansion valves. Refrigerant price is another deterrent. The process of HFO manufacturing requires complex chemical reactions which are inherently expensive leading to prices around $35/lb in bulk, and $135/lb in smaller quantities.[3] Ironically or not, a limited supply of reclaimed R12 is still available in the US to service existing systems, and it is approximately the same price as R1234yf. This suggests that HFO use in large systems may also be limited.

It is still early days for HFO refrigerants. Beyond ozone depletion and global warming, there are certain environmental issues yet to be fully understood. HFO refrigerants break down and oxidate quickly into the atmosphere as previously mentioned, however, when they do so, they turn into trifluoroacetyl fluoride and formaldehyde, but then settle out as carbon dioxide, hydrofluoric acid, and trifluoroacetic acid--also known as "TFA"[4]. Researchers surprisingly don't seem to care so much about the hydrofluoric acid as it eventually neutralizes, but TFA is known as a "durable" acid which contaminates bodies of water as it returns to the ground via rainfall. The increase of TFA in fresh water sources as a result of wider HFO use poses a real concern that has not been entirely resolved. Just like there

Montreal Protocol Kigali Amendment: Annex F lists HFCs which are now "Controlled Substances"

"Annex F: Controlled substances

Group		100-year Global Warming Potential
Group I		
CHF_2CHF_2	HFC-134	1,100
CH_2FCF_3	HFC-134a	1,430
CH_2FCHF_2	HFC-143	353
$CHF_2CH_2CF_3$	HFC-245fa	1,030
$CF_3CH_2CF_2CH_3$	HFC-365mfc	794
CF_3CHFCF_3	HFC-227ea	3,220
$CH_2FCF_2CF_3$	HFC-236cb	1,340
CHF_2CHFCF_3	HFC-236ea	1,370
$CF_3CH_2CF_3$	HFC-236fa	9,810
$CH_2FCF_2CHF_2$	HFC-245ca	693
$CF_3CHFCHFCF_2CF_3$	HFC-43-10mee	1,640
CH_2F_2	HFC-32	675
CHF_2CF_3	HFC-125	3,500
CH_3CF_3	HFC-143a	4,470
CH_3F	HFC-41	92
CH_2FCH_2F	HFC-152	53
CH_3CHF_2	HFC-152a	124
CH_3CH_2F	HFC-161	12
Group II		
[CHF3	HFC-23	14,800]"

are natural sources of CO_2 emissions, there are also natural sources of TFA emissions; however, there is a limit to TFA concentration in drinking water, and some countries are already paying close attention to the additional contribution from HFOs.

In review, we've now looked at the implications of moving from R12 to R1234yf while making pit stops at R134a and R513A, picking up flammability along the way, and ending with a refrigerant that may contaminate drinking water and costs as much as the limited remaining supply of reclaimed R12. On the bright side, R1234yf eliminates ODP while minimizing GWP and is not expected to be more than 5% less efficient than R134a.

R22 REPLACEMENTS – "HIGH VC"

Shifting now to R22 replacements in the medium to high VC category, we can again follow the development of replacement refrigerants—which introduces some additional complication along the way. As it turns out, R22 is a good refrigerant, which in many ways behaves more like propane and ammonia than it does like much of its synthetic kind. R22 is also a pure refrigerant like propane and ammonia in contrast to its replacements, which are all blended mixtures. The early batches of HFC blends like R507a and R404A developed to replace R22 used R143a primarily mixed with R125 which were chlorine-free refrigerants and so had an ODP of 0. R143a and R125 also have similar boiling points and so these early blends were able to avoid significant temperature glide . However, with the high GWP value of R143a (4800) these early blends were regrettably not developed with GHG in mind—resulting in a consequential increase in refrigerant GWP in the first major shift away from R22.

The use of R404A and R507A has already been abandoned in Europe due to the EU's F-gas regulations; and even in the US, these refrigerants were federally banned from use in new supermarkets for several years due to their high GWP. Further state level activity in the US is also prioritizing these refrigerants for delisting and phase down in many mainstream applications. In foresight of all this activity, a second iteration of R22 replacement HFCs were developed. While the first iteration managed to avoid substantial temperature glide, the second iteration has certainly not. Of course, to reduce GWP, the R143a had to be replaced with something else, and R32 was the logical candidate with a GWP of only 677. But refrigerant blending is never that easy; and there always seems to be a tradeoff. R32 is a flammable refrigerant (hence why it had not been used as a stand-alone refrigerant) but in weak enough concentration, the blended gas remains nonflammable. However, R32 also has a very low boiling point (-62F) as compared to R134a (-15F) which results in a large temperature glide for the final blend. R407F is one example from the 407-series refrigerant blends used as an R22 replacement, which experiences an evaporating temperature increase of more than 10 degrees (F) and a condensing temperature reduction of almost as much.

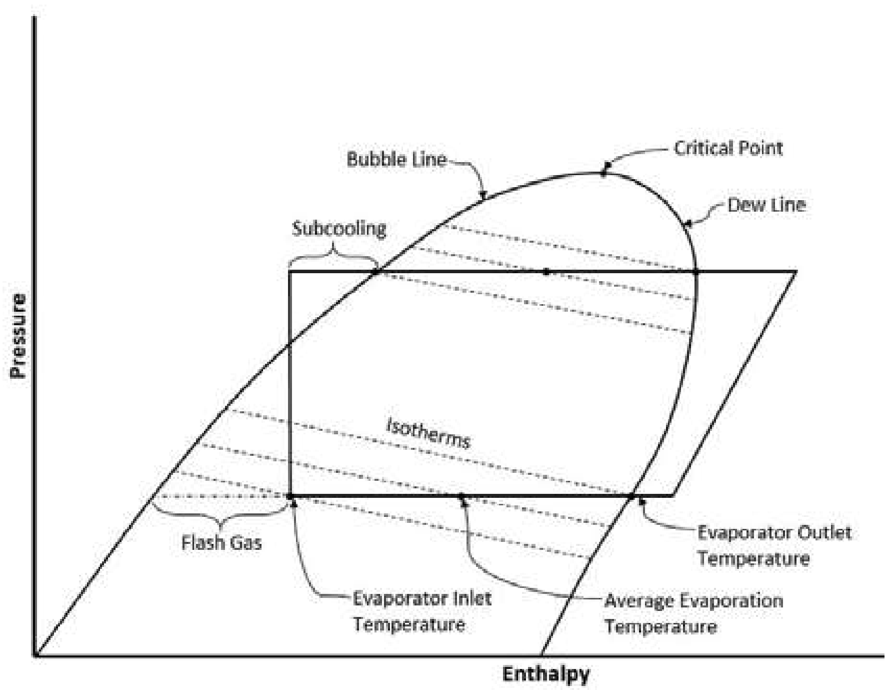
TEMPERATURE GLIDE

The debate around temperature glide has intensified since the R32 blends first came to market, and this is not surprising because of the multifaceted complications that arise because of it. Heat exchanger design and performance, system application, commissioning, and service practices are some examples of issues requiring consideration. Another is fractionation--which refers to the separation of the various refrigerants in the mixture during evaporation, condensation, or whenever liquid and vapor coexist at a constant temperature--like in a refrigerant cylinder. This means cylinders must be charged in full to maintain refrigerant composition and performance within systems. This also means that refrigerant leaks become especially concerning if they occur in evaporators or condensers since the overall refrigerant composition can become skewed and lead to unpredictable system operation, potential degradation in capacity and efficiency, and perhaps require a full evacuation and re-charging of the refrigerant to restore performance. While this result of fractionation is a valid concern, actual experiences with evaporator and condenser leaks have been mixed and many users continue to top off refrigerant charges without validating the remaining refrigerant composition. This of course doesn't mean that composition isn't affected since slow efficiency losses may be hard to detect and capacity losses may not cause problems except on the hottest day of the year. Another issue with fractionation is incompatibility with certain applications. Flooded evaporator systems for example are often desirable as they offer efficiency advantages over dry expansion systems while often offering higher reliability and simpler controls. However, flooded systems are problematic for high-glide refrigerants as they would yield a different refrigerant composition in the evaporator as opposed to the rest of the system, and neither composition would match the actual desired blend.

Temperature glide also complicates system design and energy comparisons. AHRI (Air-Conditioning, Heating, & Refrigeration Institute) standard 540 requires that compressors rated for use with zeotropes (refrigerants with glide) must reference saturated dew point temperatures when representing condensing and evaporating pressures. Compressor selections are therefore often based on dew point--which is the warmest temperature during phase change. However, if dew point temperatures are also used to select heat exchangers, this will lead to oversized evaporators and undersized condensers when UA values are used which were based on the use of pure refrigerants. This is actually a major problem as there is a lack of heat exchanger rating information from manufacturers accounting for the effects of temperature glide. In fact, the common performance-rating standard for evaporator air coolers (AHRI 420) excludes refrigerants with a temperature glide exceeding 2F. A large retailer in the US undersized dozens of condensers when they initially switched to R407F because they referenced compressor condensing temperatures (at the dew point) and used the UA metric they had always used which did not account for temperature glide. Because the glide of R407F is so large, several sites received condensers which were approximately 40% too small.

Dealing with temperature glide in evaporators is even trickier than in condensers. Averaging the bubble and dew temperatures at the evaporating pressure will unfortunately not give the average evaporating temperature. Because flash gas is produced during expansion, some of the temperature glide gets "used up" at the expansion valve, so the refrigerant entering the evaporator will actually be warmer than the bubble point temperature. Moreover, as flash gas percentage is also dependent on the amount of subcooling up stream of the expansion device, estimating your average evaporating temperature requires multiple calculation steps. This is not an insurmountable problem for designers, but it certainly complicates things for the commissioning and service technicians who often move from different refrigerants, with and without glide, in a single working day. Requiring software to accomplish what they are used to doing with a pocket PT chart while working on a roof in the rain makes this complication more than an annoyance.

Pressure-Enthalpy chart for Zeotropic Refrigerants



Caleb Nelson is a licensed professional engineer with 15 years of experience specializing in refrigeration engineering, consulting, and manufacturing. Caleb has been involved in the design of various types of systems including synthetic refrigerants, CO_2, ammonia, and propane. In Caleb's current role as vice president of business development for Azane, Inc., his primary focus is in the application of low-charge ammonia technology for cold storage, industrial process, and various other applications.

PRESSURE-ENTHALPY CHART FOR ZEOTROPIC REFRIGERANTS

One critical disadvantage of temperature glide is the COP penalty it inflicts by demanding lower suction pressures. This is already well known to those who appreciate the difference between flooded systems and dry expansion systems--the latter of which require larger evaporator approach temperatures in order to generate superheat at the evaporator outlet for expansion valve control. This penalty is exacerbated by glide since even more temperature approach is needed to allow for the gliding temperature increase in addition to superheat. Some may attempt to minimize this loss by controlling to fewer degrees of superheat, but this increases the risk of liquid returning to the compressor.

Chillers operating with high flow rates and low fluid TD's (such as ice rinks) are especially vulnerable to ef-

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ficiency penalties with high temperature glide refrigerants. This is because fluid temperatures do not return to the evaporator warm enough to promote full evaporation or drive sufficient superheat at normal evaporator approaches. In retrofit cases where this has not been accounted for, systems have suffered from what's now known as "low-TD syndrome" where an expansion valve does not sense sufficient superheat and incorrectly responds by limiting refrigerant feed to the evaporator. This reaction by the expansion valve would normally be appropriate since a loss of superheat would typically indicate excessive refrigerant feed. When superheat does not increase as a result of reducing feed, the expansion valve control continues to limit the evaporator feed until the system effectively shuts itself down. In all cases, lowering the evaporator temperature is required to fix the problem—but at the expense of system capacity and efficiency. A refrigerant with 11 degrees (F) of evaporator glide (e.g. R407F, a.k.a. Performax® LT) in a dry expansion evaporator would penalize compressor COP by 10% in comparison to a pure refrigerant operating in a flooded evaporator.

As undesirable as temperature glide may be, it appears to be a permanent fixture, at least when it comes to non-flammable synthetic (fluorinated hydrocarbon) options for replacing R22 and the other high VC refrigerants like R404A and R507A. This is because all the available "Low GWP" pure refrigerants with a higher VC are flammable and must be mixed with non-flammable low GWP refrigerants--and all of those have very different boiling points! Also interesting is that there aren't many suitable ingredients available for mixing high VC blends for a low GWP. Primarily, there's R32, R125, R1234yf, R1234ze(E), R152a, and R134a, and in the correct percentages, the furthest GWP can be suppressed while remaining non-flammable is approximately 1300--which is clearly not a long-term solution. In fact, there are no low GWP (<500) halogenated refrigerants with a VC similar to R22—blended or pure—flammable or not. Refrigerant manufacturers will likely continue to look for creative ways to come up with new low-GWP options, such as mixing CO_2 or propane with synthetic blends; however, doing so produces prohibitive levels of temperature glide (in excess of 20 degrees F) in most systems. In light of this, it can be concluded that there are no comparable replacements for R22 suitable for long-term use--except for natural refrigerants.

NATURAL REFRIGERANTS

Meanwhile, many of the barriers preventing a broader use of natural refrigerants (likely the same ones that instigated the first generation of halocarbons) have been overcome in the past decade, first in Europe and now in the US. For ammonia, safety concerns have been addressed through massive charge reduction in packaged systems, which also allows for easier and broader application. Limiting the risk of ammonia leaks to the outdoors and reducing the charge below 500 lbs. has significantly improved its acceptance--even encouraging several supermarket chains to use it. The many benefits of ammonia are still best exploited by medium-to-large industrial applications, and because of its high critical temperature, it's an efficient solution in all climate zones.

Cascade systems have allowed early applications with CO_2 (on the low side at manageable pressures) while technology advanced to make high-pressure, transcritical systems feasible. Transcritical CO_2 may become the system of choice in the US for retailers in cooler climates—as it has in Europe, Canada, and other parts of the world. Because of carbon dioxide's low critical temperature, however, efficiency improvements have been gained with multiple stages of compression, ejectors, external subcooling, low pressure receiver overfeed arrangements, and specialized controls. Further energy benefits are available where there is sufficient heating demand which can be reclaimed from the refrigeration system. Heat reclaim can be especially beneficial for CO_2 systems where it helps to improve performance above the critical point. Industrially, transcritical operating pressures have restricted the use of large compressors limiting it to commercial and light-industrial applications. Although development of larger compressors is ongoing, it is likely that ammonia (or where strategic, ammonia-CO_2 cascade) will retain much of its market share as the incumbent and more efficient solution for large industrial applications.

The future of hydrocarbons is also looking brighter as the charge restrictions due to flammability concerns are relaxing. In May this year, the IEC (International Electrotechnical Commission) approved an increase from 150 grams of refrigerant per system to 500 grams. This is an indication that a similar increase in the US is now likely inevitable. Even at 150 grams, hydrocarbons such as propane have seen good market growth in smaller self-contained applications as it offers comparable performance to R22. An allowance for larger charges will no doubt be a catalyst for broader use, and perhaps could support retail applications where warm climates may prohibit the use of CO_2.

CONCLUSION

If you're still using R22, you're hopefully aware that its production and importation to the US ceases in a few months. However, understanding how Europe and certain industries in the US have transitioned away from R22 is helpful, especially if their hard-learned lessons can be avoided. Attempting to eliminate R22 leaks and betting on the limited supply of reclaimed refrigerant is not a long-term winning strategy—especially if everyone were to attempt it. However, is it productive to employ HFCs like R507A or R404A if it means eliminating OPD by doubling GWP? Switching to a lower GWP HFC at the expense of temperature glide and efficiency may buy time, but adds complication and running costs. At the end of the day, HFC regulation is an inevitable global trend which is gaining momentum every day—despite political pendulums. This makes it hard to ignore that there are favorable natural refrigerant options covering the spectrum from small soda machines to large industrial warehouses--especially since "freon" looks less and less favorable as it is forced to look less like R22.

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IIAR Webinar Series Addresses Safe Work Practices

The International Institute of Ammonia Refrigeration has researched and gathered information from several members over the past year to develop a series of seven "Permit to Work: Safe Work Practices" webinars to help members of the industry stay safe and remain OSHA compliant.

The General Duty Clauses from the Occupational Safety and Health Administration and Environmental Protection Administration each require that employers provide employment and a place of work which are free from recognized hazards. Before an employer permits work to occur, they need to rely on their established procedures and other safe work practices.

Each of the seven webinar was developed to capture the needed content for a particular procedure or practice. The webinars were about one hour long, and participants in the live presentations were able to ask questions during Q&A sessions at the end of each webinar and were given the opportunity to earn a Professional Development Hour (PDH) or a Continuing Education Unit (CEU) to be applied for sustaining certification.

Following are brief overviews of each webinar, along with the date it originally debuted. All of these webinars are available to members on IIAR's website.

LINE OPENING PROCEDURE:

This webinar covered work involving any system that can open to the atmosphere which might be hazardous – meaning any system involving extreme temperatures, systems under extremely high or extremely low pressures, or a system that uses toxic, combustible or corrosive materials. This webinar will help viewers develop comprehensive procedures to protect employees from an injury that may be caused by the unexpended release of materials, or exposure to the extreme environments contained therein.

Presented Sept. 26 , 2018

CONFINED SPACE ENTRY:

For the purposes of this webinar, a confined space is considered to be one large enough that an employee can enter to perform assigned work but that has limited or restricted means for entry and exit and is not designed for continuous occupancy. Obviously, these spaces present dangers that regular work areas would not, so it's important to have comprehensive guidelines for how and when an employee can and should enter one of these areas.

Presented Jan. 23

WORKING AT HEIGHT:

This webinar covers work in any place where, if precautions are not taken, a person could become injured from a fall. The work could be above ground or floor level where a person could fall from an edge, through an opening, or through a fragile surface. It also includes work at ground or floor level where a person could fall into an opening in the floor or a hole in the ground from excavation or erosion. The mechanics of a slip and fall accident and the four types of falls – "Trip and Fall," "Stump and Fall," "Step and Fall" and "Slip and Fall" were each covered during the webinar.

Presented March 27

GROUND DISTURBANCE:

This webinar covered best practices for work that compacts or disturbs the ground. Compacting, excavating, digging and pile driving were each reviewed, but as a rule of thumb, disturbing the ground without knowing what lies beneath result in damage to components, costly repairs, injuries and even death. The "811 Call Center" for notifying appropriate utility companies where applicable, and the color code for marking buried utility lines, were covered in the webinar.

Presented May 22nd

HOT WORK PERMITS:

This webinar discussed work involving electric welding, gas welding, cutting, brazing and other flame- or spark-producing operations. Fire protection and fire prevention were classified as being so important, due to unfortunate historical events, that Hot Work Permits, as a Safe Work Practice, actually became one of the elements for both Occupational Safety and Health Administration's Process Safety Management Standard and the Environmental Protection Agency's Risk Management Plan Rule. IIAR also has a recorded webinar "Hot Work Permits for Ammonia Refrigeration Systems" that members can review.

Presented July 17th

LOCKOUT/TAGOUT PROCEDURE:

This webinar will address the practices and procedures necessary to disable machinery or equipment, thereby preventing the release of hazardous energy while employees perform servicing and maintenance activities. Employees servicing or maintaining machines or equipment may be exposed to serious physical harm or death if hazardous energy is not properly controlled or eliminated. Affixing appropriate lockout or tagout devices to energy-isolating devices and by deenergizing machines and equipment is how this is generally done.

Coming soon.

ELECTRICAL/ARC FLASH:

This webinar will cover how to keep workers safe around electrically energized equipment. Arc flashes are unwanted energy releases in the form of plasma in which the air is the conductor. At worst, these arcs can cause massive explosions, devastating everything in their paths and creating deadly shrapnel. This webinar will discuss compliance with OSHA standards including: Developing a safety program with defined responsibilities, calculating the degree of an Arc Flash hazard, appropriate personal protective equipment for workers and how to train employees on the hazards of arc flashes.

Coming soon

IIAR is committed to providing awareness and education to address safety refrigeration industry across the board. The association welcomes input from members and industry practicing experts for the development or improvement of previously presented materials that would benefit the refrigeration industry.

If you believe any additional "Safe Work Practice" should be explored, please contact Tony Lundell at the IIAR Headquarters. His email is tony_lundell@iiar.org.

Health Savings Accounts: Are They Just What the Doctor Ordered?

Are health insurance premiums taking too big of a bite out of your budget? Do you wish you had better control over how you spend your health-care dollars? If so, you may be interested in an alternative to traditional health insurance called a health savings account (HSA).

HOW DOES THIS HEALTH-CARE OPTION WORK?

An HSA is a tax-advantaged account that's paired with a high-deductible health plan (HDHP). Let's look at how an HSA works with an HDHP to enable you to cover your current health-care costs and also save for your future needs.

Before opening an HSA, you must first enroll in an HDHP, either on your own or through your employer. An HDHP is "catastrophic" health coverage that pays benefits only after you've satisfied a high annual deductible. (Some preventative care, such as routine physicals, may be covered without being subject to the deductible). For 2019, the annual deductible for an HSA-qualified HDHP must be at least $1,350 for individual coverage and $2,700 for family coverage. However, your deductible may be higher, depending on the plan.

Once you've satisfied your deductible, the HDHP will provide comprehensive coverage for your medical expenses (though you may continue to owe co-payments or coinsurance costs until you reach your plan's annual out-of-pocket limit). A qualifying HDHP must limit annual out-of-pocket expenses (including the deductible) to no more than $6,750 for individual coverage and $13,500 for family coverage for 2019. Once this limit is reached, the HDHP will cover 100% of your costs, as outlined in your policy.

Because you're shouldering a greater portion of your health-care costs, you'll usually pay a much lower premium for an HDHP than for traditional health insurance, allowing you to contribute the premium dollars you're saving to your HSA. Your employer may also contribute to your HSA, or pay part of your HDHP premium. Then, when you need medical care, you can withdraw HSA funds to cover your expenses, or opt to pay your costs out-of-pocket if you want to save your account funds.

An HSA can be a powerful savings tool. Because there's no "use it or lose it" provision, funds roll over from year to year. And the account is yours, so you can keep it even if you change employers or lose your job. If your health expenses are relatively low, you may be able to build up a significant balance in your HSA over time. You can even let your money grow until retirement, when your health expenses are likely to be substantial. However, HSAs aren't foolproof. If you have relatively high health expenses (especially within the first year or two of opening your account, before you've built up a balance), you could deplete your HSA or even face a shortfall.

HOW CAN AN HSA HELP YOU SAVE ON TAXES?

HSAs offer several valuable tax benefits:

- You may be able to make pretax contributions via payroll deduction through your employer, reducing your current income tax.
- If you make contributions on your own using after-tax dollars, they're deductible from your federal income tax (and perhaps from your state income tax) whether you itemize or not. You can also deduct contributions made on your behalf by family members.
- Contributions to your HSA, and any interest or earnings, grow tax deferred.
- Contributions and any earnings you withdraw will be tax free if they're used to pay qualified medical expenses.

Consult a tax professional if you have questions about the tax advantages offered by an HSA.

CAN ANYONE OPEN AN HSA?

Any individual with qualifying HDHP coverage can open an HSA. However, you won't be eligible to open an HSA if you're already covered by another health plan (although some specialized health plans are exempt from this provision). You're also out of luck if you're 65 and enrolled in Medicare or if you can be claimed as a dependent on someone else's tax return.

HOW MUCH CAN YOU CONTRIBUTE TO AN HSA?

For 2019, you can contribute up to $3,500 for individual coverage and $7,000 for family coverage. This annual limit applies to all contributions, whether they're made by you, your employer, or your family members. You can make contributions up to April 15th of the following year (i.e., you can make 2018 contributions up to April 15, 2019). If you're 55 or older, you may also be eligible to make "catch-up contributions" to your HSA, but you can't contribute anything once you reach age 65 and enroll in Medicare.

CAN YOU INVEST YOUR HSA FUNDS?

HSAs typically offer several savings and investment options. These may include interest-earning savings, checking, and money market accounts, or investments such as stocks, bonds, and mutual funds that offer the potential to earn higher returns but carry more risk (including the risk of loss of principal). Make sure that you carefully consider the investment objectives, risks, charges, and expenses associated with each option before investing. A financial professional can help you decide which savings or investment options are appropriate.

HOW CAN YOU USE YOUR HSA FUNDS?

You can use your HSA funds for many types of health-care expenses, including prescription drugs, eyeglasses, deductibles, and co-payments. Although you can't use funds to pay regular health insurance premiums, you can withdraw money to pay for specialized types of insurance such as long-term care insurance. IRS Publication 502 contains a list of allowable expenses.

There's no rule against using your HSA funds for expenses that aren't health-care related, but watch out--you'll pay a 20% penalty if you withdraw money and use it for nonqualified expenses, and you'll owe income taxes as well. Once you reach age 65, however, this penalty no longer applies, though you'll owe income taxes on any money you withdraw that isn't used for qualified medical expenses.

Questions to consider

- How much will you save on your health insurance premium by enrolling in an HDHP? If you're currently paying a high premium for individual health insurance (perhaps because you're self-employed), your savings will be greater than if you currently have group coverage and your employer is paying a substantial portion of the premium.
- What will your annual out-of-pocket costs be under the HDHP you're considering? Estimate these based on your current health expenses. The lower your costs, the easier it may be to accumulate HSA funds.
- How much can you afford to contribute to your HSA every year? Contributing as much as you can on a regular basis is key to building up a cushion against future expenses.
- Will your employer contribute to your HSA? Employer contributions can help offset the increased financial risk that you're assuming by enrolling in an HDHP rather than traditional employer-sponsored health insurance.
- Are you willing to take on more responsibility for your own health care? For example, to achieve the maximum cost savings, you may need to research costs and negotiate fees with health providers when paying out-of-pocket.
- How does the coverage provided by the HDHP compare with your current health plan? Don't sacrifice coverage to save money. Read all plan materials to make sure you understand benefits, exclusions, and all costs.
- What tax savings might you expect? Tax savings will be greatest for individuals in higher income tax brackets. Ask your tax advisor or financial professional for help in determining how HSA contributions will impact your taxes.

The IIAR and ARF reserve investment funds are currently managed by Stifel Financial Services under the investment policy established by their respective board of directors. Members of IIAR may use the services of Stifel for personal and business investments and take advantage of the reduced rate structure offered with IIAR membership. For additional wealth planning assistance, contact your Stifel representative: Jeff Howard or Jim Lenaghan at (251) 340-5044.

Stifel does not provide legal or tax advice. You should consult with your legal and tax advisors regarding your particular situation.

Knowing Without Looking?

BY KEM RUSSELL

I Recently, I was working with the main refrigeration operator at a facility when he stated something that I felt was not a good idea. Since I would be working with this person and company for some time over the foreseeable future I didn't respond to his statement, but started thinking if this is how many others feel.

This refrigeration system was computer controlled and had data and graphics to indicate operating conditions. In my conversation with the operator he said that he very rarely goes out to the refrigerated rooms, but scans the information on the HMI (Human Machine Interface) a few times a day. If parameters appear to be within acceptable ranges, he saw no reason to get out of the control room.

This facility has been operating for many years in an acceptable manner. However, I believe that staying in the control room or only remotely monitoring conditions in a system is not the best way to operate or inspect a system. Being able to do this does show how well most properly designed and constructed systems can function for years with very little human input, but this is not what is best.

Control systems for refrigeration systems have made amazing changes and improvements over many decades. The information now available to operators, and the presentation of that information, can greatly help a knowledgeable and trained refrigeration operator fine-tune a system for efficient and safe operation. Decisions can be made to keep the system running at its best, to not only make operational adjustments, but also to schedule maintenance when minor effort is required.

Computer control systems for industrial refrigeration facilities started showing up in the early 1980's. Many of these systems were PLC (Program Logic Controllers) based – systems from Allen Bradley, Sq. D, Siemens, etc. All have very reliable hardware, which had proven performance in industrial manufacturing fields. The challenge now was development of control logic for the industrial refrigeration system. This was a rocky road in many cases since knowledge of what control should happen in an industrial refrigeration system was not understood by programmers. Although refrigeration systems seem similar, they have unique aspects for proper operation, which must be appropriately considered in the control logic.

The early versions of control were ladder logic, which basically simulated the ladder-logic control drawings produced to wire the system and build the appropriate control panels. As control changed from relays, timers, steppers, etc. to programmed logic, the PLC slowly advanced to not only do the control, but also do it better and faster.

Also, in the early 80's, computers started to be available and these began to be applied to refrigeration control systems. The programming in BASIC (some), C and C++ (most) was a long trial-and-error process. The graphics on the early systems were, you might say, primitive -- but this would change. These computer-controlled systems opened up a world for more intuitive operator input as well as informative graphical display of system operational conditions. With the improvements of the computer systems there was more reliable hardware, faster and larger RAM and data storage, and overall faster processing speed, all of which led to greater strides forward for refrigeration system control, if it all worked properly.

Through the 80's and into the 90's I spent many, many days at refrigeration facilities, along with a programmer, in the development and fine tuning of refrigeration control systems. I would watch the data being presented by the computer, and also the actual operation of the refrigeration system. The programmers I worked with were amazing at development of the code to operate a system.

However, I can honestly say that I never, at any project, found the operation of the system to not require some changes/modifications/etc. The programmers wrote the code to do what they thought was appropriate, but they didn't have sufficient understanding of just what should be happening out in the real world.

The programmers were the "software", and I was the "hardware". On projects I would go out through the refrigeration system watching and listening. Most times things don't happen really fast in a refrigeration system, so this watching and listening took more than a casual glance. I would do the observation than go back and talk with the programmer as well as see what the control system was doing. Usually, this was not a onetime process but took checking and re-checking to get the actions of the control system within acceptable performance ranges in the field. This checking in the field did not end even after the computer control systems were performing well.

Here is just one example: At a large distribution center, with multiple operating temperatures, I visited the facility a few months after the facility had been commissioned. I spent more than an hour watching the operation of the computer control system and the graphic information, which included display capability of a large amount of historical data. In viewing the data of the freezer storage, something just seemed "off" to me. The large -10°F freezer and separate -20°F ice cream storage had both been holding temperatures within acceptable ranges, but the temperature split on many of the penthouse evaporators just didn't appear to me to be in the right range.

I asked the refrigeration operator if he had looked at the coils in those

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penthouses. He hadn't, for two reasons. One, the temperatures were okay. Two, it was a long walk from the control room through the facility, up the stairs to the roof and across the roof to the penthouses. Well, I said, since I am a visitor here why don't you go with me and we'll take a look. About 10 minutes later we stepped inside one of the penthouses.

There were four large evaporators in each of two freezer penthouses. The air-return side of the coils showed a pretty thick frost and ice buildup along the edges between fan sections and all long the pans. I suggested that he turn off one of the units so we could also visually check the air-discharge side of the units. These units had ductwork that directed the air from the coil, down 90 degrees through the penthouse grating to horizontal ductwork within the room. Each fan section had a fairly easily accessible panel opening to access the fan motors and to see the discharge side of the coil.

Upon opening the access panel and looking inside, I turned to the operator and said I think we have a problem. There was a large buildup of what I call "hoar" frost over a large portion of the discharge-air side of the coil, which extended several inches toward the fan. The operator looked in there and said, "Oh man!" (Well, he might have used other words). We checked several other coils and found a similar condition, including the units in the ice cream penthouse.

The solution was: One, do some immediate unit cleaning. Two, to make adjustments to the defrost sequence and timing, which eventually corrected the hoar-frosting problem. Fortunately, this problem was caught before it became a serious mess. This problem could have been discovered much earlier, but the operator had put all of his understanding of what was happening in the system to what he was observing at the HMI.

Lesson learned: Do not rely only on the information you see in your control system. This can be a very useful tool, but should be combined with regular, actual system observations by a refrigeration operator who is knowledgeable and trained in the operation of his system. Putting all your eggs in one basket will eventually end up with some cracked eggs.

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EPA Continues Compliance Focus on Ammonia Facilities

iiar government RELATIONS

BY LOWELL RANDEL, IIAR GOVERNMENT RELATIONS DIRECTOR

Compliance and safety in ammonia facilities continues to be a high priority for the Environmental Protection Agency (EPA). In 2016, EPA announced a series of National Enforcement Initiatives focused on improving safety in a variety of high hazard industries. Among these initiatives was an effort entitled "Reducing Accidental Releases at Industrial and Chemical Facilities". EPA has placed specific emphasis on ammonia facilities as a part of the initiative, which has subsequently been renamed a National Compliance Initiative (NCI). The initial NCI was scheduled to run through fiscal years 2017 – 2019. EPA has recently announced that the NCI on chemical facilities will continue for fiscal years 2020-2023.

The goal of the NCI is "to reduce the risk to human health and the environment by decreasing the likelihood of chemical accidents. A successful initiative would reduce communities' risk by having regulated facilities and industry associations work to: improve safety; increase compliance with RMP and GDC requirements; and promote coordination and communication with state and local responders and communities."

The International Institute of Ammonia Refrigeration (IIAR) has been actively engaged with EPA regarding the NCI since it was initiated and will continue to do so throughout the life of the initiative.

MINIMUM KEY SAFETY MEASURES

One of the major components of the NCI was the establishment of a list of minimum key safety measures for inspection of ammonia refrigeration systems. These are measures that EPA has determined should be in place, regardless of an ammonia refrigeration system's age or size. IIAR provided input to EPA during the development process to help shift focus away from some items that were not applicable to ammonia refrigeration systems.

This is not intended to be a complete list of important safety measures but rather a subset of easily verifiable items that could help facilities prevent ammonia releases and prepare for any releases that do occur. It is important to note that the list does not replace the obligation to comply with EPA's Risk Management Program.

One of the major components of the NCI was the establishment of a list of minimum key safety measures for inspection of ammonia refrigeration systems. These are measures that EPA has determined should be in place, regardless of an ammonia refrigeration system's age or size. IIAR provided input to EPA during the development process to help shift focus away from some items that were not applicable to ammonia refrigeration systems.

Below is a summary of the key safety measures on which EPA inspectors will be focusing when inspecting ammonia facilities:

IDENTIFYING HAZARDS

- Hazard Addressed: Releases or safety deficiencies that stem from a failure to identify hazards in design/operation of system
  - ❍ Facility has completed a process hazard analysis or review.

OPERATING ACTIVITIES:

- Hazard Addressed: High risk of release from operating or maintenance activity
  - ❍ System has self-closing/quick closing valves on oil pots.
  - ❍ Facility has written procedures for maintenance and operation activities.
  - ❍ Only authorized persons have access to machinery room and the ability to alter safety settings on equipment.

MAINTENANCE/MECHANICAL INTEGRITY:

- Hazard Addressed: Leaks/releases from maintenance neglect
  - ❍ A preventative maintenance program is in place to, among other things, detect and control corrosion, deteriorated vapor barriers, ice buildup, and pipe hammering, and to inspect integrity of equipment/pipe supports.
  - ❍ All piping system openings except the relief header are plugged or capped, or valve is locked.
  - ❍ Equipment, piping, and emergency shutdown valves are labeled for easy identification, and pressure vessels have legible, accessible nameplates.
  - ❍ All atmospheric pressure relief valves have been replaced in the last five years with visible confirmation of accessible pressure relief valves [note – replacement every

five years is the general rule but there are two other options in IIAR Bulletin 110, 6.6.3].

MACHINERY ROOM AND SYSTEM DESIGN

- Hazard Addressed: Inability to isolate and properly vent releases
  - The System(s) has/have emergency shut-off and ventilation switches outside each machinery room.
  - The machinery room(s) has/have functional, tested, ventilation. Air inlets are positioned to avoid recirculation of exhaust air and ensure sufficient inlet air to replace exhausted air.

As EPA continues its focus on ammonia facilities through the NCI and efforts like the pilot program in New England, IIAR will remain actively engaged with the agency and key partners to ensure that industry has the information and tools it needs to promote compliance.

  - Documentation exists to show that pressure relief valves that have a common discharge header have adequately sized piping to prevent excessive backpressure on relief valves, or if built prior to 2000, have adequate diameter based on the sum of the relief valve cross sectional areas.

EMERGENCY ACTIONS

- Hazard Addressed: Inability to regain control and reduce release impact
  - Critical shutoff valves are accessible, and a schematic is in place to show responders where to access them.
  - EPCRA Tier II reporting is up to date.

Additional Compliance Items

IDENTIFYING HAZARDS

- For systems that employ hot gas defrost, the process hazard analysis/review includes an analysis of, and identifies, the engineering and administrative controls for the hazards associated with the potential of vapor propelled liquid slugs and condensation-induced hydraulic shock events.

OPERATING ACTIVITIES AND MAINTENANCE/MECHANICAL INTEGRITY

- Written procedures are in place for proper use and care of personal protective equipment.
- If respirators are used, facilities know the location of their respirators, and they are inspected and maintained per manufacturer or industry standards.
- All changes to automation systems (programmable logic controls and/or supervisory control and data acquisition systems) if present, are subject to management of change procedures.

MACHINERY ROOM AND SYSTEM DESIGN

- The facility has engineering controls in place to protect equipment and piping against overpressure due to hydrostatic expansion of trapped liquid refrigerant. Administrative controls are acceptable where hydrostatic overpressure can occur only during maintenance operations.
- Eyewash station(s) and safety shower(s) is/are present and functional.

EMERGENCY ACTIONS

- Emergency response communication has occurred or has been attempted with the Local Emergency Planning Committee and local responders.
- The facility has an emergency action plan pursuant to 29 C.F.R. § 1910.38(a) or an emergency response plan pursuant to 29 C.F.R. § 1910.120(q) and 40 C.F.R. § 68.95.

Members with ammonia facilities, regardless of the size of the ammonia charge, should review their operations to ensure that they have addressed the above items appropriately at their facility.

GENERAL DUTY CLAUSE PILOT IN NEW ENGLAND

In addition to the national efforts to address compliance at ammonia facilities, EPA Region 1 in New England is implementing a pilot program focused on facilities with less than 10,000 pounds of ammonia that are subject to the General Duty Clause.

The primary focus of this Initiative is facilities with more than 1,000 pounds of ammonia, but less than 10,000. EPA is sending targeted Information Requests to selected facilities that it has reason to believe may be out of compliance. Facilities will be required to respond to EPA answering four questions about their ammonia refrigeration systems, including whether a process hazard review has been performed. If a facility has not performed the required hazard review, EPA will inform the facility that it has violated the first duty of the General Duty Clause. Unless a significant release has occurred at the facility, EPA will offer to resolve this violation for a discounted penalty, provided the company agrees to perform a hazard review of its system with the help of an expert. The company will also be required to meet with emergency responders and submit any missing Tier II forms. EPA has indicated that it will inspect a small subset of facilities to determine if the Initiative has improved compliance with the General Duty Clause.

Members in New England are strongly encouraged to make sure they have conducted a hazard assessment related to accidental releases of ammonia and have plans in place to prevent releases and minimize the consequences of accidental releases that do occur.

As EPA continues its focus on ammonia facilities through the NCI and efforts like the pilot program in New England, IIAR will remain actively engaged with the agency and key partners to ensure that industry has the information and tools it needs to promote compliance.

Operating Cost Comparison between Transcritical CO_2 and Ammonia Recirculation Systems in a Cold Storage Warehouse

Chris Herzog, Principal
Industrial Refrigeration Equipment Partners and

Peter Lepschat, Director of Engineering
Henningsen Cold Storage

INTRODUCTION

Henningsen Cold Storage Co. (HCS) is a public refrigerated warehousing company based primarily in the Pacific Northwest. In business since 1923, HCS operates more than 60 million ft^3 of multi-temperature-controlled storage at 13 facilities. The company embraces a continuous improvement culture and has applied it countless times in designing new facilities and optimizing existing facilities.

For example, in terms of energy efficiency, continuous improvement efforts have driven specific electricity consumption at HCS facilities down to a fraction of industry averages. The International Association of Refrigerated Warehouses (IARW) periodically surveys its members, with one area of inquiry being energy consumption. Based on the data it collects, the IARW calculates an average specific energy consumption metric, expressed as annual kWh/ft^3. In a 2015 IARW survey, the industry average was 1.12 kWh/ ft^3 of refrigerated space. As a point of comparison, the HCS corporate average in FY 2017/2018 was 0.482 kWh/ ft^3. HCS's two most recently constructed ammonia refrigerated facilities operate at or below 0.3 kWh/ft^3. Table 1 illustrates HCS's specific energy consumption by facility over the past two fiscal years.

The newest Henningsen facility was installed in Grandview, WA, a roughly 100,000 ft² freezer designed to house approximately 20,000 pallets at -5°F and an 11,000 ft² of +40°F refrigerated dock space. This facility opened for business on June 28, 2018, to serve local fruit processors. It is not included in Table 1 due to a lack of meaningful energy data.

DECISION-MAKING PROCESS

Early in the process of planning its most recent facility, HCS decided to investigate alternative refrigerants/refrigeration systems to anhydrous ammonia. Past initiatives had focused on reducing the quantity of ammonia refrigerant in the system and had achieved much success in lowering charges while maintaining industry-leading levels of energy efficiency. The next logical step was to see if reducing or even eliminating ammonia from a system and still operating in an efficient manner as compared with the best ammonia systems was possible.

Table 1. HCS Annual kWh/ft^3

	FY17	FY18
Facility 1	0.745	0.770
Facility 2	0.400	0.398
Facility 3	0.311	0.301
Facility 4	0.323	0.496
Facility 5	1.114	1.019
Facility 6	0.569	0.553
Facility 7	0.557	0.641
Facility 8	0.508	0.496
Facility 9	0.256	0.273
Facility 10	1.056	1.133
Facility 11	0.359	0.347
Facility 12	0.000	0.264
Average	0.471	0.482

The following steps outline the process used to determine the viability of alternate technologies:

(1) State the goal: Reduce our ammonia charge to below its threshold planning quantity (TPQ) of 500 lb or eliminate it altogether.

(2) Identify options to explore:

- a. Packaged NH3,
- b. Packaged or split systems using synthetic refrigerants,
- c. CO_2/NH3 cascade systems,
- d. Transcritical CO_2 system, and
- e. Central ammonia system with reduced refrigerant charge.

(3) Generate a list of categories to compare:

a. First costs, including facility-related construction cost impacts;

b. Energy efficiency and other utility costs;

c. Operation and maintenance (O&M) costs;

d. Short- and long-term reliability;

e. Effects on construction schedule;

f. Regulatory compliance costs;

(4) Assemble a list of specific questions or comparisons for each category. Appendix 1 is an example of an outline illustrating the categories and specific questions. Note that this is not an exhaustive list; many other factors arose and were also included in discussions held during the process of evaluation.

(5) Obtain answers to each question for each system type, sourced via the following:

  a. Industry experts;

  b. Experienced end users;

  c. Independent engineering firms;

  d. Technical publications, such as white papers, textbooks, manufacturers' technical data, and trade publications;

  e. Trade associations, including peer networking, industry trade shows/ expositions, and technical presentations and papers; and

  f. System manufacturers.

(6) Perform a comparative analysis on the collected questions and answers.

Consider

  a. Advantages of each option for each question,

  b. Disadvantages of each option for each question, and

  c. "Deal killers" that would instantly eliminate an option.

(7) Assign weighting for each question to help drive a final decision.

Some of the identified refrigeration system types proved to be relatively easy to dismiss early in the process for various reasons. For instance, with the uncertain regulatory future of hydrofluorocarbons HFCs and other synthetic refrigerants and the known energy penalties associated with these types of systems as compared with proven options using natural refrigerants, the conventional HFC-charged split and packaged systems were not considered viable alternatives even after considering their reduced first costs and regulatory burdens. Relatively high energy costs, the high and escalating cost of HFC refrigerants, and a potential lack of suitable replacement refrigerants after projected refrigerant phase-out dates contributed to the decision to eliminate them from contention.

Likewise, the CO_2/NH3 cascade system was dismissed early on, but for different reasons: It provided little to no reduction in regulatory burden, minimal improvement in operator safety, greater complexity, higher energy consumption than existing NH3 systems, a higher first cost, and higher O&M costs.

Removing these options from the analysis left three options to compare: packaged ammonia, CO_2 transcritical, and low-charge conventional ammonia. The three remaining system options were inserted into a matrix, and each question was answered for each type of system. Clearly, this document became very large, and thus has not been included in its entirety in this paper. Instead, an abbreviated document illustrating sample questions as applied to each type of system can be found in Appendix 2.

COST ANALYSIS

The results of initial analysis done by HCS indicated that the most promising system types were the "traditional" central ammonia plant (with special design features to improve efficiency and reduce charge) and the transcritical CO_2 system. The ammonia system features were well known to HCS, and its costs could be reasonably well assumed from some of its existing facilities. But the new transcritical CO_2 system was somewhat of a wild card. Being a newer and less understood technology, determining the operating costs with high accuracy was important to make the best decision.

POWER CONSUMPTION

To assemble the most accurate data possible, particularly in the area of energy use, a company specializing in energy use in refrigerated facilities was engaged to predict the annual power consumption of the CO_2 system and the ammonia system, given the construction, system type, climate, and expected use of the facility.

This company also analyzed a third system type: a conventional packaged freon system with multiple roof-mounted air-cooled condensing units coupled with direct expansion electric defrost evaporators. This system was included because it has the lowest first cost, and the ability to compare energy savings and cost differential between this and the other system types was desirable. The information resulting from this comparison was used when negotiating with local energy providers for available financial incentives or rebates (Table 2).

Appendix 3 provides the energy analysis in its entirety. The first key finding is that the transcritical CO_2 system uses more energy than the NH3 system, but not that much more. Remember too that the comparison NH3 system has a specific energy use that is 75% lower than the industry average. In reality, when compared with an industry standard, the transcritical system is projected to use around 50% less specific energy.

The analyzed ammonia system included numerous energy-saving measures that have been successfully incorporated into other modern HCS systems: floating suction and head pressure controls, predictive hot gas defrost with float drainers, variable- frequency drive VFDs on all fan motors, VFD for at least one screw compressor, glycol oil cooling with heat recovery, and dock dehumidification. The transcritical CO_2 system also included many energy-efficiency measures (EEMs); they are part of the full energy analysis and also described in the CO_2 System Details section later in this paper. The HFC system was intended to be a baseline for comparison only, so it was analyzed in its simplest form, with no EEMs.

Although the predicted energy use is lowest for the NH3 system, the CO_2 system is close enough to warrant further investigation. After all, while energy use is the second largest operating cost in a facility of this type, it is certainly not the only cost.

WATER USAGE

One area in which the CO_2 system may be superior to a conventional NH3

Table 2. Predicted Energy Use for HFC, NH3, and CO_2 Systems

System type	Annual kWh	Relative kWh	*kWh/ft³
Modern NH_3	717,652	1.0	*0.170*
Transcritical CO_2	868,462	1.21	*0.206*
Traditional HFC	2,620,859	3.65	*0.620*

**Note that kWh/ft³ values are for refrigeration system energy only and do not include other electrical use in the facility.*

system is water usage. Although this is frequently overlooked, the cost of water to operate an evaporative ammonia condenser is significant. A transcritical CO_2 system typically uses an air-cooled gas cooler/condenser, which uses no water at all. This, however, is not very good from an energy use perspective. In the Grandview facility's climate, the most cost-effective application was found to be an adiabatically assisted gas cooler. This heat exchanger uses material similar to the pads found in cooling towers. The pads are wetted with spray or drip headers, and air entering the dry gas cooler must first pass through these pads. The resulting air is precooled to nearly wet bulb temperature, which can greatly increase gas cooler efficiency. The new HCS facility was to be located in an area with a relatively dry climate (design wet bulb temperature of about 70°F or 21°C), even though temperatures frequently exceed 100°F (38°C) in the summer. The adiabatically assisted gas cooler is expected to keep the saturated discharge temperature below the critical point of CO_2 (88°F/31°C) even when the ambient temperatures are much higher. Because the CO_2 system efficiency suffers greatly when the critical point is exceeded, employing an adiabatically assisted gas cooler was found to be worthwhile, despite the extra cost of water. Fortunately, this type of heat exchanger uses less water than an evaporative condenser, as seen in Table 3.

Depending on the cost of water and water treatment, this can be a significant cost advantage for the CO_2 system. For this project, the predicted annual savings included approximately $20,000 for water, sewage, and maintenance. This value may be even higher if the assessment assigns a value to "environmental responsibility" based on not wasting millions of gallons of water every year.

Table 3. Predicted Water Use for NH3 and CO_2 Systems

System	Evaporation (gal/yr)	Bleed (gal/yr)	Total Annual Use (gal/yr)
NH_3	1,391,542	695,771	2,087,313
CO_2	261,905	86,167	348,072
Difference	**1,129,637**	**609,604**	**1,739,241**

BUILDING CONSTRUCTION

Building a cold storage is expensive, and the cost of a code-compliant ammonia refrigeration room is a significant part of that expense. Per the International Fire Code (2015) and IIAR 2 (2014), ammonia refrigeration rooms must be fire rated (or sprinklered) and contain safety systems with ammonia detection, alarms, and ventilation fans. Equipment must be anchored to engineered structural slabs, and large, heavy piping must be supported.

By contrast, a transcritical CO_2 system uses a factory-built high side (compressor rack) that is relatively compact compared with NH3 equipment and can be located outside. Piping tends to be smaller and lighter (frequently it is stainless tubing instead of S40 or S80 pipe). There are no large valve groups to support, as nearly all control valves are located on the compressor rack. Significant structure is still required to support the compressor rack and gas cooler (condenser). But the compressor rack may be sited outdoors, on the roof, or in a smaller, simpler machinery room space. Construction quotes were requested for the new facility with both conventional recirculated NH3 and transcritical CO_2 refrigeration systems. Including all costs except the refrigeration system, construction pricing came in about $300,000 less for the CO_2 option.

REFRIGERATION SYSTEM

Another area that favors CO_2 over traditional NH3 is the cost for the refrigeration system itself. The construction process is quite different, as Table 4 illustrates.

Given these differences, the total refrigeration system cost was quoted about $534,000 less for CO_2 than for NH3. Another important factor to consider is that the CO_2 facility had an estimated construction time 5-6 weeks less than the same facility with an NH3 system.

OTHER COST DIFFERENCES

Along with these major cost items, some other costs may favor the CO_2 system. These include

- Insurance,
- Decreased maintenance staff,
- In-house refrigeration system maintenance,
- Code compliance costs, and
- Employee safety training.

When the numbers were evaluated, the CO_2 transcritical system was a con-

Figure 2. First Cost Comparison NH3 vs. CO_2

Traditional NH_3	Transcritical CO_2
Numerous major components installed on site and connected with piping	Only two high side components: compressor rack and gas cooler
Separate machinery room with specific construction code requirements	Simpler requirements for indoor installation, may be installed outdoors
Large piping mains with smaller branches to each evaporator	"Home run" piping to each evaporator; only two pipes needed even for hot gas defrost, CO_2 pipes tend to be smaller
Heavy supports required for piping and valves	Lighter, smaller piping with fewer valves
Carefully engineered and installed piping insulation systems necessary to prevent pipe corrosion	Stainless steel piping or tubing has much greater corrosion resistance, allowing for simpler insulation materials and processes
Permitting process much more rigorous and expensive due to hazardous B2 refrigerant	Relatively simple permitting for A1 refrigerants
Elaborate, heavily engineered relief system with possible large diffusion tank	Greatly simplified relief system
Site security much greater (Homeland Security, ammonia theft)	No special security requirements
Onerous compliance requirements (PSM, RMP, General Duty Clause, etc.)	Very little regulation

vincing, and surprising, winner (Table 5). Despite a higher predicted energy usage, it offered big cost savings for initial construction and the potential to offset higher energy usage with reduced water usage, plus some other lower operating costs. Ultimately, HCS decided to build the CO_2 system.

CO_2 SYSTEM DETAILS

This paper does not intend to explain how transcritical CO_2 refrigeration works or offer instruction to designers. Numerous references are available on those topics. Rather, this paper aims to examine the design and operation of a particular system to compare the similarities and differences between it and ammonia refrigeration. Figure 1 shows a simplified schematic for this system.

Transcritical CO_2 high sides resemble grocery store and other commercial compressor racks. This is partly because these systems were the first to be used in commercial applications and partly because they are built with a currently limited selection of semi-hermetic compressors. This rack includes several units of two models, a 30 hp (22 kW) machine and a 50 hp (37 kW) machine. All the pressure vessels, heat exchangers, and control valves are also on the rack—with one exception. The motorized expansion valves are mounted directly on the evaporators. The gas cooler is mounted outdoors like a conventional condenser, and the evaporators are ceiling hung inside the warehouse.

The system described here is a two-stage refrigeration circuit starting with the booster compressors, which operate at around 212 psig suction (14.6 barg) and discharge into the intermediate pressure accumulator/intercooler (MT ACC) at 441 psig (30.4 barg). This vessel cools the booster discharge gas and is also the suction accumulator for the dock evaporators. Vapor from this vessel is drawn into the medium temp (high stage) compressors, which discharge at around 950 psig (65 barg) typically, but can get as low as 50°F/638 psig (10°C/44 barg), depending on ambient conditions. A holdback valve in the main discharge line serves to create a pressure differential for the heat recovery devices and hot gas defrost system to function.

High-pressure (and possibly transcritical) gas enters the gas cooler, and cooled gas drains to the flash tank through a regulating valve. This vessel is akin to a controlled pressure receiver (CPR) in an ammonia system; it is maintained at about 500 psig (34.5 barg) through another regulating valve connected to the MT ACC vessel.

The regulating valve on the inlet of the flash tank is the key to making the system work even when the condensing temperature exceeds 88°F/31°C (1,071 psig/73.9 barg). When CO_2 exceeds these pressures on the high side, it cannot be condensed to liquid (see "Critical Point" on CO_2 pressure/enthalpy diagram in Appendix 4). When a transcritical fluid passes through the regulating valve, its pressure drops to 500 psig (34.5 barg). At that point, a portion of it turns to liquid, and the remainder becomes vapor. The vapor is drawn into the MT ACC vessel. Although perfectly functional, this is not a desirable situation; during transcritical operation, the medium- temperature compressors are actually handling a portion of the condensing load. This situation reduces system operating efficiency.

Liquid in the flash tank is used to feed the medium-temperature (dock) evaporators and the MT ACC vessel to cool the discharge gas from the low-temperature (booster) compressors. Suction from the dock evaporators returns to the MT ACC vessel. Like the freezer evaporators, the dock evaporators are DX with hot gas defrost. Dock evaporators also include a hot gas reheat coil for extra dehumidification.

Liquid from the MT ACC is used to feed the freezer evaporators. It is first

Table 5. System Comparison

Metric	CO_2	Central Low-Charge NH_3
System Cost	$534k less	More
Building Costs	Approximately $300k less	More
Construction schedule	5–6 weeks saved	5–6 weeks extra needed
Efficiency	More electricity ($13,000 per year)	Less electricity
Utilities	Less water & sewer	More water & sewer ($20,000 per year)
O&M	Less costly	More costly
Water Treatment	No water treatment	Water treatment necessary
Reliability	Very reliable	Very reliable

piped through a liquid/suction heat exchanger against freezer evaporator suction, which provides a margin of subcooling and helps prevent flash gas in the liquid line. The freezer evaporator suctions are piped to the low-temperature accumulator (LT ACC). Dry suction from this vessel passes through the liquid/suction heat exchanger before reaching the low-temperature compressors, which completes the cycle.

All evaporator defrosts are by hot gas. Unlike ammonia hot gas defrost, the heat used to warm the coils and melt ice is mainly sensible, not latent. A very high sensible heat is one of the more useful qualities of CO_2. In this case, hot gas from the high- pressure side of the holdback valve is introduced via solenoid into the evaporator liquid line (remember that each evaporator has its own liquid and suction lines all the way back to the compressor rack). Normal liquid flow is stopped, as the defrost pressure is much higher than liquid pressure, but defrost gas is prevented from back feeding the liquid lines by check valves. On the return side, a motorized solenoid is closed in the evaporator suction line, and instead the defrost return is pushed into the main discharge line, downstream of the holdback valve. These defrost return lines also have check valves to prevent discharge gas from back feeding the suction lines.

FIRST COST COMPARISON

The initial cost comparison offers an opportunity to examine the preliminary projections. The Grandview facility was completed in spring of 2018, and the refrigeration commissioning began in May. By June 28, the facility was open for business and receiving frozen product.

To give a sense of relative construction, the new Grandview facility is compared with a different facility built by HCS in Salem, OR, in 2017, and referred to as "Salem II." The facilities are similar in footprint, operation, and construction methods, and both were built by the same team of contractors. Salem II has about 20% more refrigerated space, so pricing has been scaled to account for this. Appendixes 5 and 6 show layouts of each facility for reference, and Figure 2 shows the relative values.

The overall project cost came in about 6% less than Salem II built a year earlier. This is after adjusting for the difference in size between the two facilities. The overall cost savings were close to the predicted value, although the refrigeration system actually cost more than expected. This may be due to the contractor's "learning curve" during first exposure to new technology and construction methods. The actual difference in finished project cost is enough to buy about 15 years worth of electricity for the CO_2 refrigeration system, at current rates.

OPERATING COST COMPARISON

So how do the overall true operating costs for this facility compare with a similar facility that has a more conventional recirculated ammonia refrigeration system?

At the time of writing, the facility had been fully operational for a little more than six months. Those six months include most of a summer, all of fall, and the first half of winter. It's too early to make any absolute statements, but some data are already available.

Starting with energy usage, the preliminary model predicted about 20% more energy use for the CO_2 system on an annual basis. This figure was calculated by taking available energy use data and extrapolating it over a year's time.

Figure 3 suggests that assuming springtime refrigeration load closely approximates autumn load would be reasonable, and because energy use data for autumn are available this assumption was incorporated into an annual estimate. Figure 3 also shows that the smallest load occurs in January. January 2019 data are not yet available for this model, so the December data are used, which should provide a conservative prediction.

Pointing out some of the design features used on this system to minimize energy usage and help CO_2 compete with NH3 on a large industrial system is useful. The energy consultant on this project analyzed several different design improvements and predicted the energy savings and payback for each one. Each design improvement is known as an EEM. All EEMs qualified for some degree of funding from the utility provider. Among the EEMs chosen for this project are

- Refrigeration system heat recovery for underfloor heating: eliminates cost of external heating and takes load off the gas cooler.

Figure 1. Simple Schematic of Refrigeration System

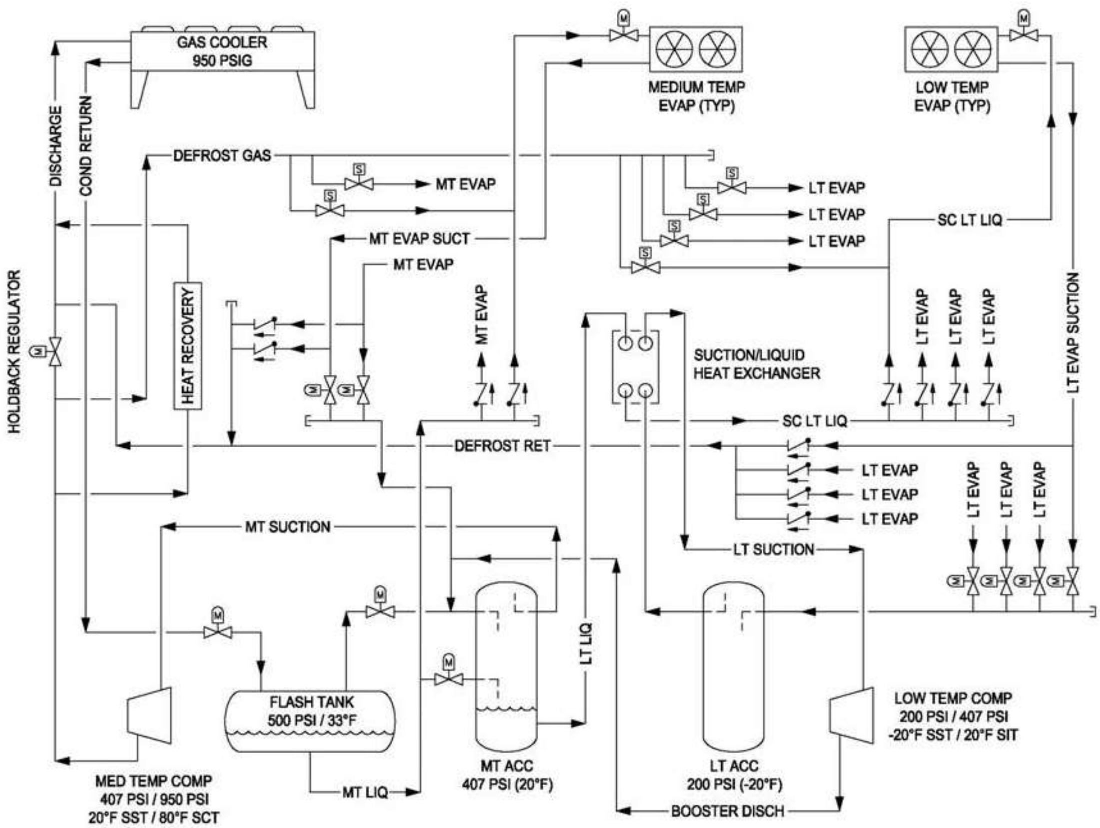
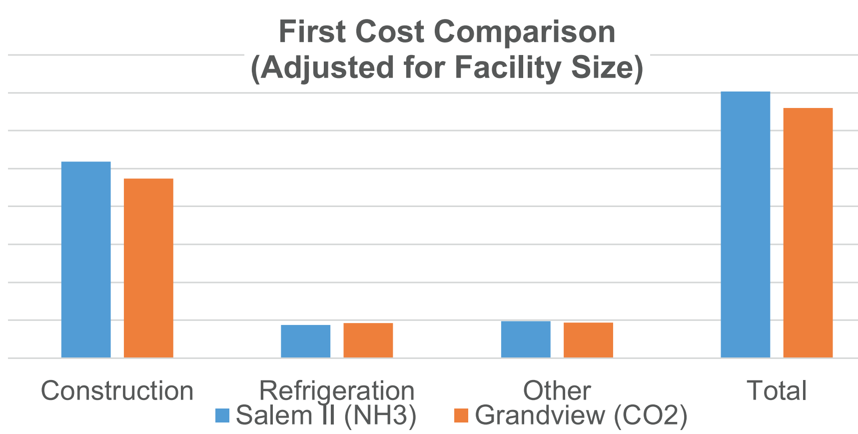


Figure 2. First Cost Comparison NH3 vs. CO_2



- Dock dehumidification: Adding hot gas reheat coils on the dock evaporators to maintain low humidity levels in the refrigerated dock reduces the latent load in the freezer and allows for less frequent defrost cycles.

- Efficient freezer evaporators: This measure increases the evaporator coil size, improving capacity without increasing connected fan motor power.

- Optimal evaporator fan control: Selecting electronically commutated, or EC, motors provides a more efficient operation than AC motors. These motors also vary speed to maintain zone temperature setpoints. Fan motor power varies with the cube of speed, thus significant energy savings are realized whenever the evaporators are under part-load conditions. Evaporator fan motors vary speed from 36% to 90% of maximum motor RPM.

- Hot gas defrost for evaporators: Utilizing hot gas for evaporator defrost instead of electric resistance heat offers significant energy savings. Though not often seen with transcritical systems, as it requires evaporators rated for very high pressures, it is very effective and an efficient use of the high sensible heat available in CO_2 discharge lines.

- Gas cooler optimization: Selecting a gas cooler with additional heat transfer surface area allows for more efficient heat rejection. An adiabatic upgrade cools the incoming air during hotter weather to allow for lower condensing (or gas) temperatures, reducing compressor lift. EC motors are also recommended for improved efficiency and variable speed capability. Gas cooler fans vary speed from 10% to maximum motor rated RPM. A floating head pressure strategy is also included for optimum gas cooler performance.

- Fire riser room heating: This measure comprises the installation of uninsulated copper glycol manifolds in each of the riser rooms, for protection against freezing. This eliminates the need for electric unit heaters.
- Glycol pump VFD: Using a pump VFD to vary flow in the glycol loop based on under-floor temperature setpoints saves pump energy whenever temperatures are satisfied.
- High-speed freezer doors: Installing insulated, bi-parting freezer doors that rapidly open and close further reduce sensible and latent loads in the freezer. Door openings are triggered with motion sensors.

These items are nearly the same as at the Salem II facility, where they are applied to a conventional recirculated ammonia system.

Based on the values at Grandview for January through May, which are predicted using Figure 3, Figure 4 compares energy use between the two systems.

One finding that immediately stands out is how much energy the CO_2 system used in June, July, and August. These were expected to be the worst months, but actual use far exceeded the predicted value. This anomaly was investigated in late summer and was attributed to several EEMs that were not properly implemented, including

- Evaporator fan speeds were fixed and not modulating;
- Gas cooler fan speeds were fixed, and floating head pressure was not enabled;
- Freezer evaporations were being defrosted every 8 hours, instead of every 48 hours as recommended (this long interval possible due to dock dehumidification);
- Low-temperature suction setpoint at -25°F (-32°C) instead of the recommended -17°F (-27°C);
- Intermediate temperature suction setpoint at +19°F (-7°C) instead of +25°F (-4°C); and
- Underfloor glycol pump VFD not enabled.

Once these items were addressed, energy use began to more closely resemble predicted values. The CO_2 system energy use has been very close to that of the NH3 system since the "recommissioning." It remains to be seen what the effect will be during the warm weather months.

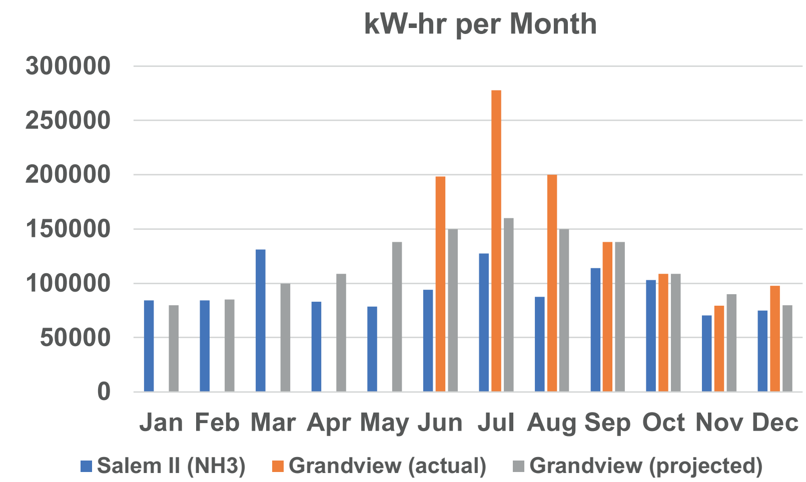
Bear in mind that the energy figures reflect use for the entire facility, because the refrigeration system power is not metered separately. The current "best projection" is that the CO_2 system will use about 22% more energy than the NH3 system— approximately the predicted 20% value.

The seemingly inconsistent values for Salem II energy usage are attributed to the period of data collection (not always the same number of days for the month) and the possibility that some months may be "averaged," rather than true measurements.

A key advantage of the CO_2 system in this comparison is its decreased water use. Even with an adiabatic gas cooler, it uses much less water than a conventional NH3 system with evaporative condenser. There is also no need for chemical treatment. Figure 5 shows water use for the two facilities.

Water use was negligible in May because the system was being started and there was very little load. June and July are higher than expected, but still less than the NH3 system (values have been scaled for the relative sizes of the facilities). After recommissioning in late August, actual water use aligned with predicted values.

Figure 4. Energy Use Comparison



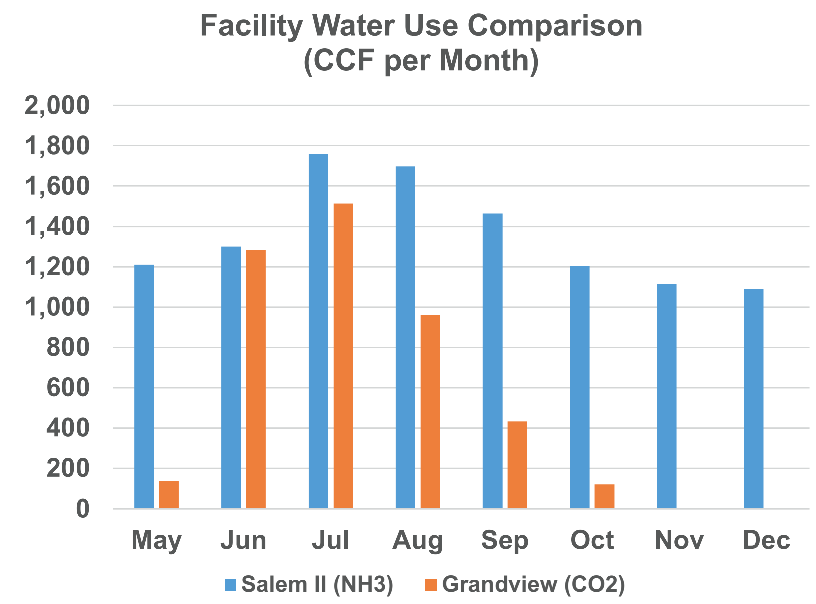
When weather turned cooler in late fall, water use went to essentially zero as the gas cooler stayed in dry operation at all times.

Energy and water use are very important performance metrics for cold storage, but they are not the only factors. Examining the two systems under discussion provides an opportunity to compare the two facilities' operating costs and investigate the actual cost of ownership in a CO_2 refrigeration system versus a conventional NH3 system.

Because Salem II is a larger facility, costs have been scaled proportionately, with ft3 of refrigerated space. Energy use was scaled similarly to provide a fair comparison, and costs unrelated to refrigeration have been ignored. With those factors taken into consideration, and using a random divisor on the true cost to protect sensitive financial information, an operating cost comparison can be developed (Figure 6).

The May data from the Salem II facility are an aberration; this is when startup and pulldown began for the Grandview

Figure 5. Water Use (1 CCF = 100 cubic feet of water = 748 gal)

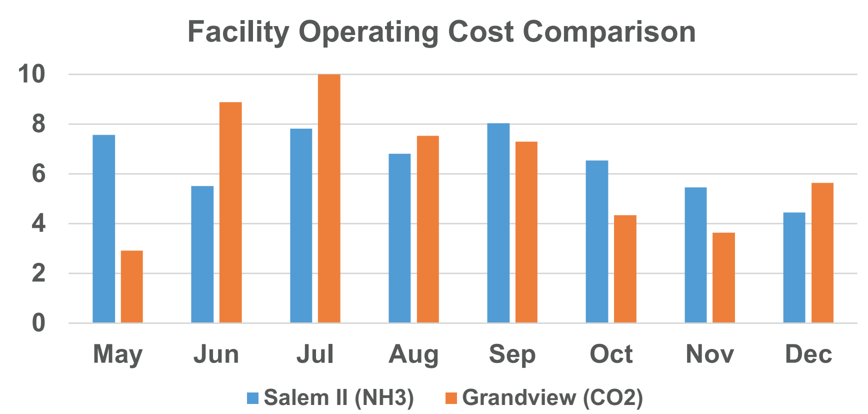


facility. By the end of June, Grandview was fully operational, and the data begin to have meaning. For June and July, Grandview operating costs are higher than those of Salem II. Remember, however, that the Grandview system had not yet been correctly commissioned for maximum efficiency; this was not done until nearly the end of August. The impact of this is immediately seen. Starting in October, the Grandview facility is operating at lower cost than Salem II. This trend reverses slightly in December, due to quarterly refrigeration maintenance by an outside vendor.

The most significant point in this analysis is that for the seven months with meaningful data, the CO_2 facility has an overall operating cost just slightly higher (about 6%) than the ammonia facility. This analysis counts only costs that the refrigeration system affects, and it is normalized to account for the size differences between facilities. Power costs about 8.5% more in Salem than Grandview, but water and related costs are about 60% higher in Grandview than Salem.

Note also that the preliminary data suggesting a 6% higher cost for the facility with a CO_2 system is based on the first seven months of operation. These include the three hottest months of the year, and for nearly that entire time the CO_2 system operated sub-optimally.

Figure 6. Operating Cost Comparison



With that issue corrected, and cooler months ahead (January through May), the CO_2 system at Grandview is expected to result in about 5–10% lower annual cost than a comparable, highly efficient ammonia system.

CONCLUSIONS

With less than a full year of operation at Grandview, reaching any conclusions with 100% certainty is difficult. However, based on currently available data, the key points are these:

- Depending on climate, for a CO_2 system to have a lower operating cost than a conventional NH3 system is entirely feasible. The key to determining this is probably humidity, or the wet bulb design temperature. The facilities compared in this paper are in climates with similar wet bulb design temperatures (around 68–69°F or 20°C). A transcritical system with a generously sized adiabatic gas cooler will be able to condense below the critical point at nearly all times.
- The CO_2 system will use more energy in the summer months, but about the same as the NH3 system in colder months.
- The key to CO_2 system efficiency is proper commissioning, which can potentially reduce energy consumption by 50% or more. Operator and technician training is therefore vital.
- The CO_2 system will use much less water than the NH3 system (although, to be fair, fitting an NH3 system with an adiabatic condenser similar to the CO_2 system gas cooler is possible).
- A facility with a CO_2 system can be built significantly faster than the same size facility with an NH3 system (5–6 weeks in this case).
- The permitting process is usually easier for a CO_2 system as compared with an NH3 system.
- To compete with a modern, efficient NH3 system, a CO_2 system must have an adiabatic gas cooler, variable speed

motors for all fans, and hot gas defrost.

- A CO_2 compressor rack may be placed outdoors if needed, making CO_2 an option for facility expansion where existing machinery room is maxed out or inconveniently located for future expansion.
- Return on investment can be increased with increased heat recovery efforts.
- A leak in a CO_2 refrigerated warehouse will not necessarily damage product. This may be a competitive advantage because cold storage customers will have a reduced risk of spoiled product and will presumably have better insurance rates than for product going into an ammonia refrigerated warehouse.

For groups considering construction of a new refrigerated warehouse or expansion of an existing facility, CO_2 should be a consideration among the natural refrigeration options. Depending on climate, CO_2 may prove to be equal or superior to ammonia in terms of safety, water use, and overall operating cost.

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APPENDIX 1. COMPARATIVE ANALYSIS ITEMS

CO_2 Transcritical vs. NH3 Packaged and Centralized Refrigeration Systems

(1) First costs

a. CO_2 vs. NH3 system direct cost comparison,

b. Deletion of engine room construction savings,

c. Addition of enclosure for compressor rack,

d. Addition of structural support for compressor rack,

e. Elimination of rooftop support pipe rack,

f. Addition of interior piping supports,

g. Elimination of PRV system,

h. Elimination of machine room ventilation system, and

i. System scalability for future loads or building additions.

(2) Energy and utilities

a. Annual kWh consumption comparison;

b. Annual demand cost comparison;

c. Annual water use comparison;

d. Water treatment cost comparison; and

e. Reclaim heat availability, quantity, and quality:

i. Use within facility, underfloor heat, dock dehumidification, other; and

ii. Suitability for sale, as a revenue source.

(3) Operations and maintenance

a. Compressor replacement cost versus overhaul costs,

b. Refrigerant cost comparison,

c. Spare parts inventory and availability considerations,

d. Worker hours per year for PM activities,

e. Worker hours per year for predictive maintenance activities,

f. Worker hours per year for repairs, and

g. Leak point (valves, gaskets, flanges, shaft seals) count comparison.

(4) Reliability

a. Compressor lifespan,

b. Effect of compressor failure,

c. Effect of loss of refrigerant,

d. Effect of control system failure,

e. Effect of fan drive failure, and

f. Effect of loss of water.

(5) Schedule

a. Speed of construction and

b. Task integration with other construction activities.

(6) Regulatory

a. Cost of Occupational Safety and Health Administration PSM compliance;

b. Cost of United States Environmental Protection Agency RMP compliance;

c. Costs of a major release:

i. Onsite, people;

ii. Onsite, product;

iii. Offsite, people; and

iv. Offsite, environmental;

d. Department of Homeland Security chemical security considerations; and

e. Tier II reporting considerations.

APPENDIX 3. HCS PRELIMINARY ENERGY ANALYSIS AND COMPARISON BY ENERGY 350

Owner: Henningsen Cold Storage

Facility: Cold Storage

Location: Grandview, WA

Subject: Projected energy use for NH3 vs. CO_2 and estimated incentives from electric utility for high-efficiency operation

Background: Henningsen Cold Storage (HCS) recently constructed a new cold storage facility in Grandview, WA, to house approximately 20,000 American pallet positions. The facility consists of 99,000 ft² of 5°F freezer space and 11,000 ft² of +40°F refrigerated dock space. The site is staffed for one or more shifts per day, but the refrigeration system operates around the clock for a total of 8,760 hours per year.

A detailed energy study, funded by the electric utility, was conducted for the facility to analyze and quantify energy savings associated with upgrades to a

Appendix 2. Comparative Analysis Worksheet Sample

Vhat happens if we have a catastrop eak and lose the majority of our efrigerant outdoors?	Environmental: Possible offsite consequence, must report to NRC. Safety: Potential for injury to HCS or neighboring personel. Financial: Potential Fines from regulators. Relatively low costs to	mental: No offsite impacts, No ıg requirement No risk to neighbors, and HCS ıel ıl: No fines, Low costs for ment charge	vironmental: Possible offsite nsequence. May have to report to ?C. fety: low risk to neighbors and HCS ırsonnel. ıancial: Possible fines form
Vhat Happens if a compressor fails?	Capacity: large effect on system capacity(100%), requires redundant compressor to be installed. Financial: Industrial size screw compressors are very expensive to replace, $35k - $55k. Operational: Extended downtime to get replacement compressor and install it. Not stocked locally. More complex to install	׳: Minor effect on system(17%), parallel compressors are d for each stage. ıl: Low financial impact, ment compressor $10k - $13k. onal: short downtime, ment compressors stocked at ıtributor. Relatively easy ːion.	pacity: Large effect on system(50%) ıly one or two compressors typically ıtalled per system. No backup pacity available. ıancial: Low financial impact, placement compressor cost $10k - 0k. ıerational: Extended downtime to t replacement compressor and insta Not stocked locally. Relatively easy
Vhat happens if we lose cooling wat ın a hot day?	Major negative effect on capacity, likely total loss of cooling. Evaporative condensers require water to operate.	Minor negative effect on capacity. System would run in trans-critical mode with higher energy consumption. Gas cooler can operate either dry or with adiabatic assist.	› effect on capacity. No effect on ıergy, typically these systems use dı ndensing
Vhat are the regulatory compliance ıurdens?	Very High, Tier II reportable, EPA and PSM general duty clause mandates a robust management system regardless of charge.	No leak or release reporting ments, no Tier II, no EPA RMP or SM programs.	edium, Tier II reportable, EPA and M general duty clause mandates a bust management system regardles charge.

transcritical CO_2. Washington State Energy Code (WSEC 2015) was used a guideline for the energy analysis; though it does not apply to transcritical CO_2 refrigeration systems.

Methodology: As a refrigerated storage facility, loads are highly weather dependent, with peak loads occurring in the summer months. Concurrently, the facility is also used for seasonal pull-down loads of fruit, namely blueberries. Because this was a new construction project, data logging was not possible for the energy study. Rather the annual cooling load was determined from heat transfer calculations based on the building envelope construction, equipment specifications, and discussions with HCS.

A custom, MS Excel-based 8,760 energy model using typical meteorological year data for nearby Yakima, WA, was developed (from the U.S. Department of Energy's National Renewable Energy Laboratory's TMY3 dataset) to calculate energy use for the baseline case and each efficiency measure. Where applicable, this included the following:

- Conduction through the building envelope;
- Solar load on the roof;
- Infiltration loads;
- Internal heat gains;
- Underfloor heating energy;
- Pump energy for underfloor heating;
- Riser room heating loads;
- Loads from defrost heat gain into the refrigerated spaces;
- Evaporator fan and motor heat;
- Head pressure as a function of gas cooler specifications, control strategy, and ambient outdoor air conditions;
- Heat rejection load, which was determined by the cooling load and compressor heat;
- Compressor performance for a range of suction pressures, head pressures, and partial load conditions for variable speed machines, based on multivariate regression analyses.

System Details: The transcritical CO_2 refrigeration system consists of a two-stage compressor rack design. All compressors are semi-hermetic recips. One compressor on each suction group is controlled with a VFD for trim. All constant speed compressors cycle on/off to maintain suction. The low and high stage groups are operated at suction pressures of 212 psig and 441 psig, respectively.

Due to high compressor discharge temperatures, low specific volume, and high conductivity of CO_2 refrigerant, the system is particularly well suited for waste heat recovery. The system includes a CO_2 hot gas heat exchanger that sends a portion of the hot gas discharged from the compressors to dock reheat coils and evaporator hot gas defrost circuits. Hot gas is also used to heat glycol for the underfloor heating system and provide freeze protection for sprinkler riser rooms.

One adiabatic gas cooler rejects any heat loads in excess of heat recovery applications. It is capable of operating sub-critically or super-critically. Unlike a typical condenser, when operating supercritically, the gas cooler can reject sensible heat at constant pressure. Minimum head pressure is controlled to 638 psig for the system. Although water is consumed in adiabatic mode, the system still allows for large water, sewer, and chemical treatment savings when compared with an evaporative condenser.

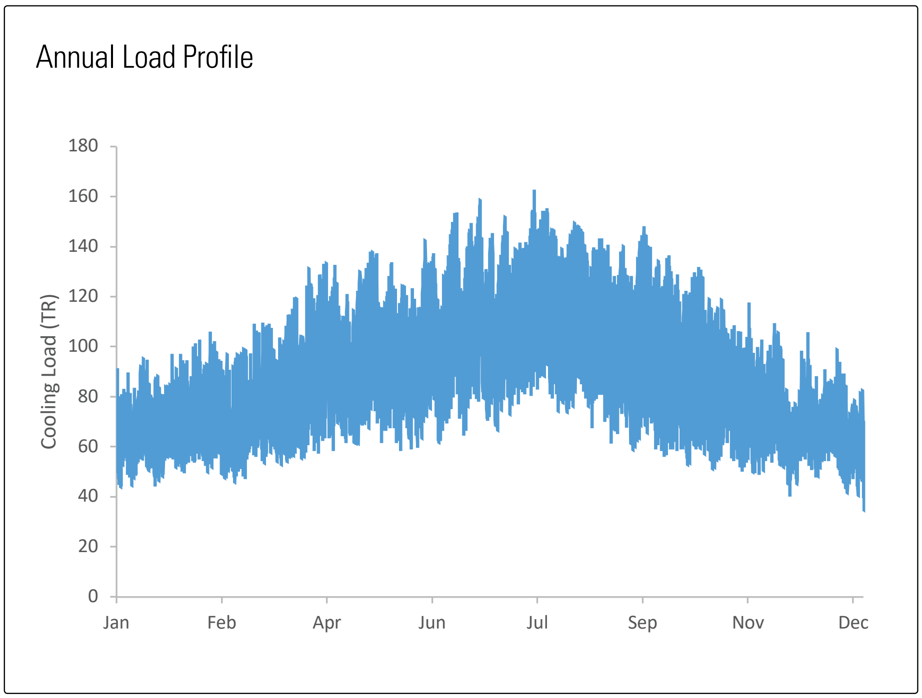
Six freezer evaporators and two dock evaporators are included. Evaporator defrost cycles are initiated on an operator-defined schedule. Along with the refrigeration equipment comes a sophisticated control system capable of evaporator and gas cooler fan speed control, floating head pressure strategy, compressor sequencing, variable glycol pump control, and dock reheat control.

Energy Efficiency Measures: The following energy efficiency measures were analyzed for this study:

Dock dehumidification: Adding hot gas reheat coils on the dock evaporators to maintain low humidity levels in the refrigerated dock reduces the latent load in the freezer and allows for less frequent defrost cycles.

Efficient freezer evaporators: This measure increases the evaporator coil size, increasing capacity without increasing connected fan motor power.

Optimal evaporator fan control: Selecting EC motors provides a more efficient operation than AC motors. These motors also vary speed to maintain zone temperature setpoints. Fan motor power varies with the cube of speed, thus realizing significant energy savings whenever the evaporators are under part-load conditions. Evaporator fan motors vary speed from 36% to 90% of maximum motor RPM.



Gas cooler optimization: Selecting a gas cooler with additional heat transfer surface area allows for more efficient heat rejection. An adiabatic upgrade cools the incoming air during hotter weather to allow for lower condensing (or gas) temperatures, reducing compressor lift. EC motors are also recommended for improved efficiency and variable speed capability. Gas cooler fans vary speed from 10% to maximum motor rated RPM. A floating head pressure strategy is also included for optimum gas cooler performance.

Riser room heating: This measure comprises the installation of uninsulated glycol manifolds in each of the riser rooms, thus eliminating the need for electric unit heaters.

Glycol pump VFD: Using a pump VFD to vary flow in the glycol loop based on under- floor temperature setpoints saves pump energy whenever temperatures are satisfied.

High-speed freezer doors: Installing insulated, bi-parting freezer doors that rapidly open and close further reduce sensible and latent loads in the freezer. Door openings are triggered with motion sensors.

Energy Model Results: The energy study quantified energy savings by analyzing upgrades to the CO_2 refrigeration system, in other words, a basic CO_2 system was compared with a highly efficient CO_2 system. The energy study also served to estimate financial incentives to offset the simple payback and improve the return on investment. Total energy savings for each efficiency measure is presented in the following table. Incentives are based on eligible costs and paid on either a $/kWh basis or a percentage of total project cost, the lesser of the two. Because this energy study was based on a new construction project, the eligible costs represent the difference between a baseline case and a high-efficiency option, not the full project cost. Please note that at the time of writing the following savings calculations are estimates and are awaiting verification.

For this paper, a comparison was also made with other system types, a halocarbon system and an NH3 system.

Halocarbon system energy use was

modeled alongside the CO_2 system. Annual energy use for each refrigeration component was calculated in the same manner: by building a ground-up refrigeration model to predict the cooling load for each hour of a typical weather year and using manufacturer performance data to estimate energy use. Not surprisingly, this is an inefficient system by comparison, but typical of the equipment. Much of the inefficiency is a result of simplistic controls and lack of heat recovery. This system consisted of the following:

- Packaged, air-cooled condensing units with R507 refrigerant;
- Remote piped evaporator air units with electric defrost;

Annual Energy Savings Including System Upgrades

Efficiency Measure Description	Annual kWh Savings	kW Savings (avg. per mo.)	Annual Electric Cost Savings	Eligible Cost
Basic CO2 System vs. Pkgd R507 System	1,032,553	129	$59,192	$375,623
Dock Dehumidification	63,027	13	$3,649	$39,028
Efficient Freezer Evaporators	56,323	5	$3,215	$20,880
Optimal Evaporator Fan Control	315,987	50	$18,187	$27,664
Gas Cooler Optimization	196,088	69	$11,549	$47,440
Riser Room Heating	16,369	0	$924	$6,277
Glycol Pump VFD	44,676	5	$2,557	$18,748
High Speed Freezer Doors	27,374	3	$1,566	$29,755
Totals	**1,752,397**	**274**	**$100,839**	**$565,414**
Simple Payback without Incentives			**5.6 years**	
Estimated Financial Incentive			**$262,860**	
Simple Payback with Incentives			**3.0 years**	
Return on Investment			**33%**	

- Evaporator fans that operate continuously except during scheduled defrost cycles;
- Electric under-floor heating system; and
- Simple controls.

HCS's recent facility constructed in Salem, OR, known as S2, was used for an ammonia system comparison as this site represents HCS's most advanced NH3 design to date. We recently verified the annual energy use of the refrigeration system at this site funded by a similar utility-backed efficiency program. Again, the vast amount of data available made this site a worthy selection for comparison. A metric for annual energy use per conditioned volume was calculated and applied to the Grandview facility to estimate NH3 system energy consumption. The NH3 system includes the following features:

- Economized screw compressors, one with VFD for trim;
- High-efficiency compressor oil cooling;
- Variable and automated volumetric index control;
- Evaporative condenser;
- Liquid subcooler;
- Remote piped evaporator air units with hot gas defrost;
- Dock air units with glycol feed reheat coils for dehumidification;
- Heat recovery used for under-floor system heating, freeze protection in sprinkler riser rooms, and evaporator defrosts;
- Variable speed evaporator and condenser fan motors;
- Optimally sized heat exchangers (evaporators and condenser);
- Low overfeed recirculated liquid evaporators to minimize NH3 charge;
- Liquid drainers; and
- A sophisticated control system capable of dynamic compressor sequencing, demand-based defrost initiation and termination, fan speed control, and floating suction and head pressures.

SYSTEM SUMMARY

R507 system: 2,620,859 kWh/yr

NH3 system: 717,652 kWh/yr

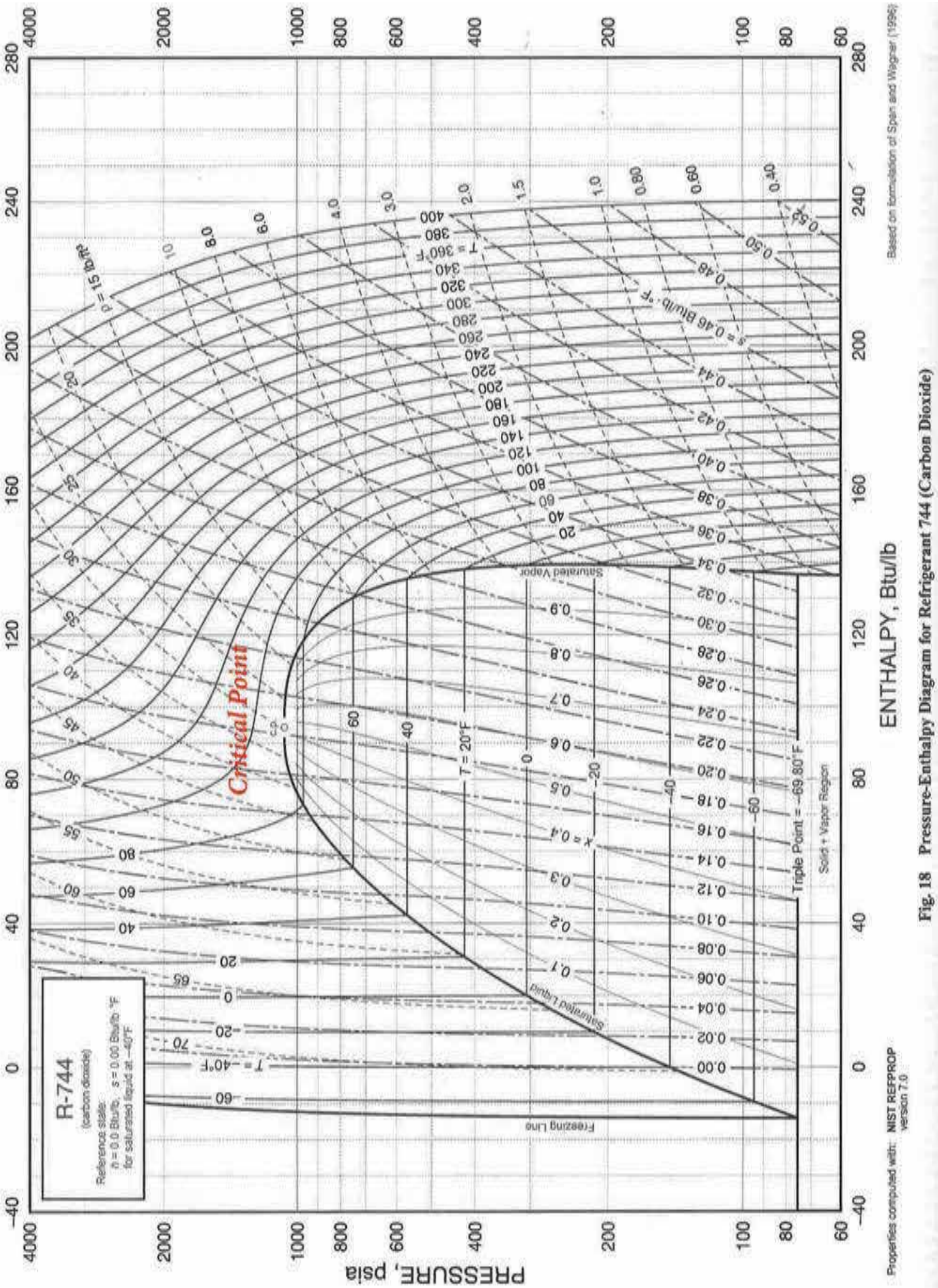
CO_2 system: 868,462 kWh/yr

Additional savings are realized beyond energy. For example, the CO_2 system relies on an adiabatic gas cooler (with a switchover temperature of 72°F) in lieu of an evaporative condenser typically found in industrial NH3. The following estimates are based on 3 gpm/100 TR and 3.0 cycles of concentration for bleed of an evaporative condenser.

Annual Energy Savings Including System Upgrades

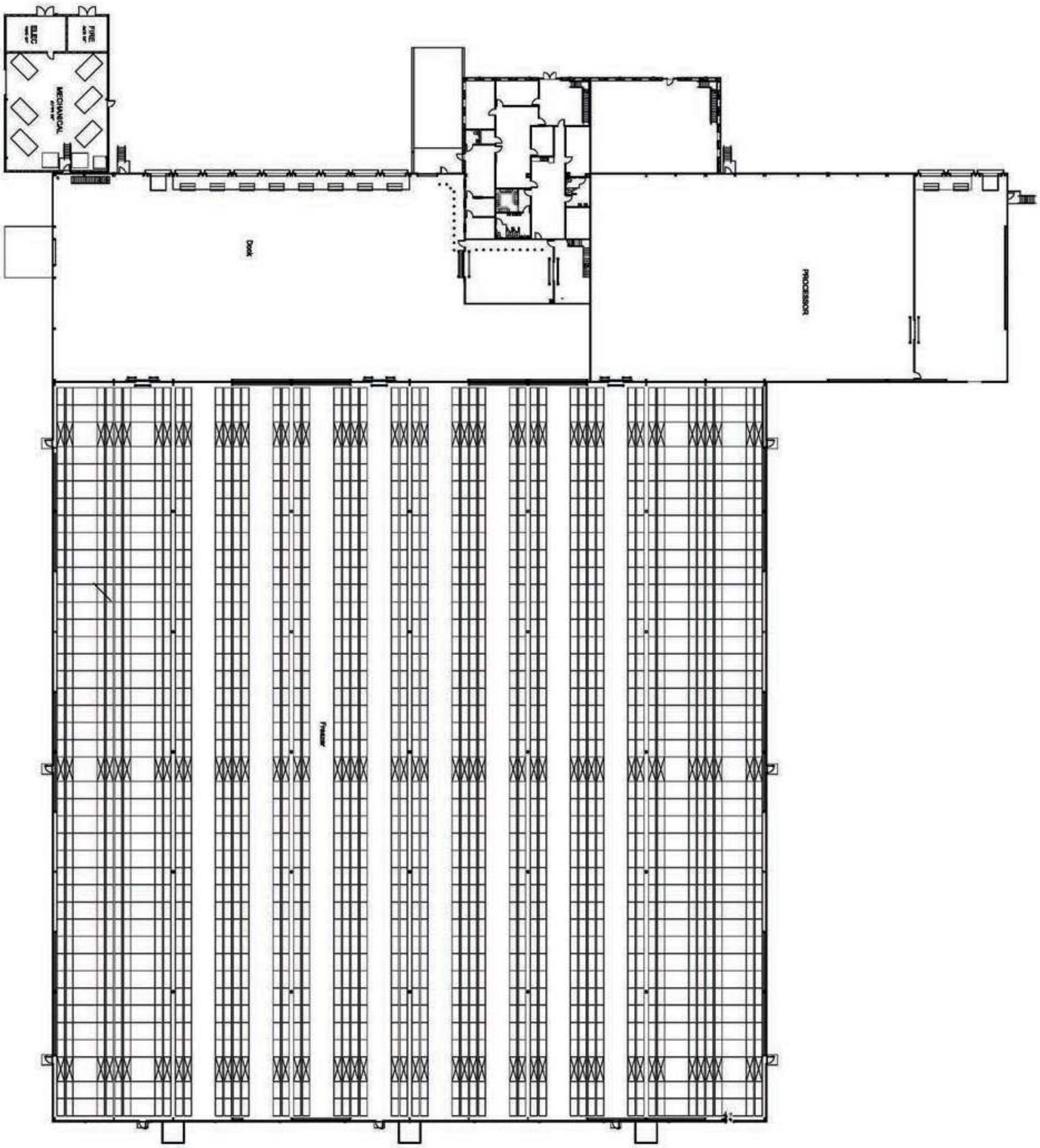
System	Evaporation (gal/yr)	Bleed (gal/yr)	Total Annual Use (gal/yr)
NH_3	1,391,542	695,771	2,087,313
CO_2	261,905	86,167	348,072
Difference	**1,129,637**	**609,604**	**1,739,241**

Appendix 4. CO_2 Pressure-Enthalpy Diagram

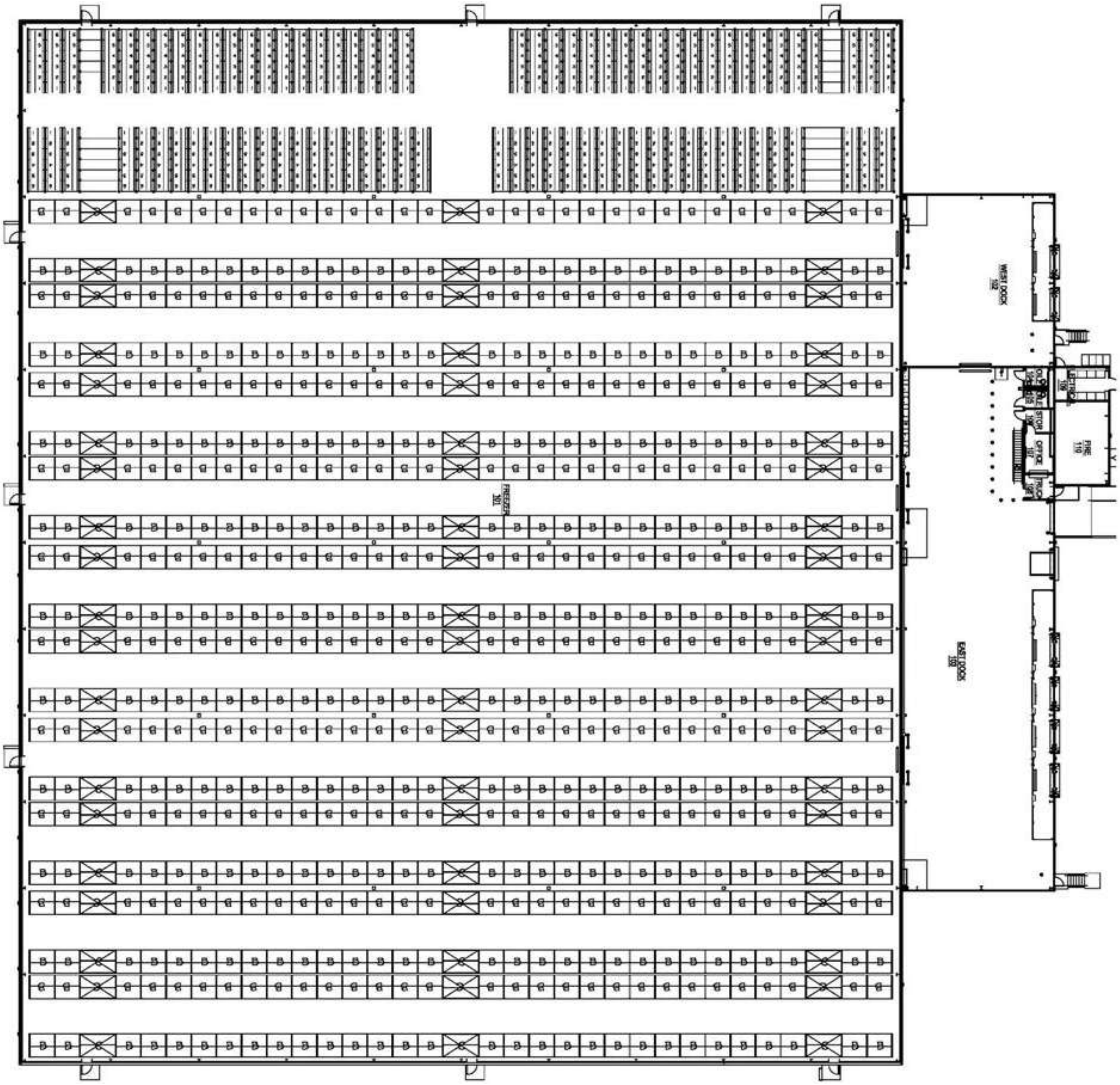


Source: ASHRAE (2017)

Appendix 5. Facility Layout Salem II



Appendix 6. Facility Layout Grandview



Appendix 7. ASHRAE Weather Data for Salem

Meaning of acronyms:
DB: Dry bulb temperature, °F — *WB: Wet bulb temperature, °F*
MCWB: Mean coincident wet bulb temperature, °F
Lat: Latitude, °
DP: Dew point temperature, °F
MCDB: Mean coincident dry bulb temperature, °F
Long: Longitude, °
HR: Humidity ratio, grains of moisture per lb of dry air
HDD and CDD 65: Annual heating and cooling degree-days, base 65°F, °F-day
Elev: Elevation, ft
WS: Wind speed, mph

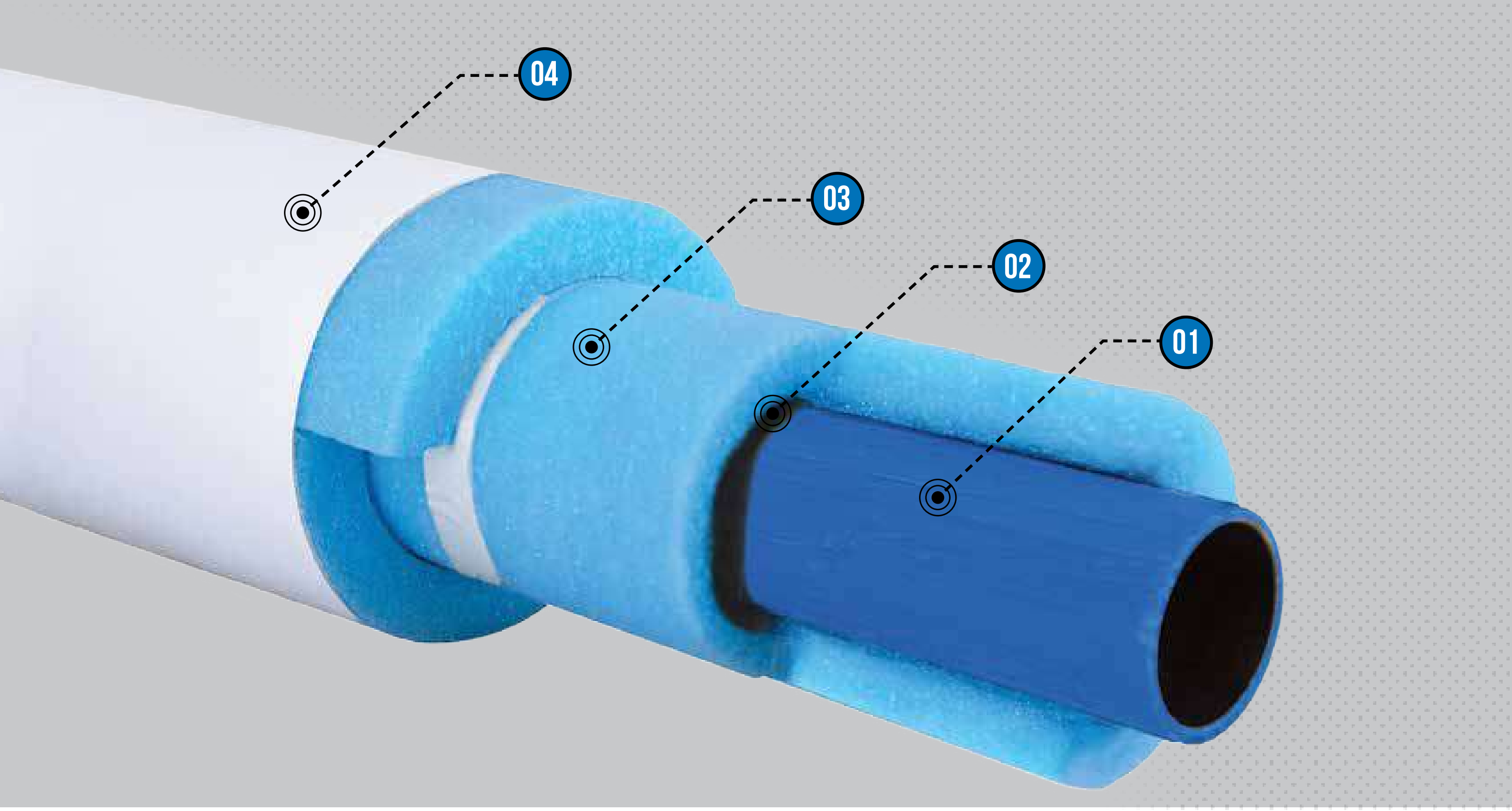
Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB				Dehumidification DP/HR/MCDB						Extreme Annual WS			Heat./Cool. Degree-Days	
						0.4%		1%		2%		0.4%		1%		0.4%			1%							
				99.6%	99%	DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	DP	HR	MCDB	DP	HR	MCDB	1%	2.5%	5%	HDD	CDD 65
North Dakota																										*6 sites, 6 more on CD-ROM*
BISMARCK MUNICIPAL ARPT	46.77N	100.75W	1660	-20.0	-13.9	93.9	69.4	90.3	68.6	86.8	67.4	74.3	85.8	71.9	84.5	70.7	120.4	81.4	68.0	109.3	78.3	27.3	24.4	20.8	8471	539
FARGO HECTOR INTERNATIONAL AP	46.93N	96.81W	899	-20.4	-15.2	91.0	72.1	87.7	70.3	84.7	68.8	75.4	85.4	73.4	83.6	72.4	123.9	81.8	70.0	113.9	80.1	28.3	25.4	23.1	8793	553
GRAND FORKS AFB	47.97N	97.40W	906	-20.4	-15.8	90.8	71.3	87.7	70.1	84.2	68.3	76.2	84.4	73.6	82.5	73.4	128.4	80.0	71.4	119.9	78.8	28.3	25.3	22.2	9167	477
GRAND FORKS INTERNATIONAL AP	47.95N	97.18W	833	-22.2	-17.2	90.0	71.0	86.6	69.4	83.7	68.0	75.0	84.7	72.7	82.5	71.8	121.0	81.2	69.4	111.3	78.9	26.9	24.2	20.9	9310	434
MINOT AFB	48.42N	101.35W	1631	-22.2	-17.3	93.2	68.6	89.3	67.8	85.6	66.5	73.1	86.3	70.8	83.5	69.4	114.9	79.9	66.4	103.2	77.1	28.9	25.9	22.6	9097	433
MINOT FAA AP	48.26N	101.28W	1713	-19.9	-15.0	91.4	68.9	88.0	68.1	84.3	66.2	73.6	84.4	71.2	82.1	70.3	118.8	79.8	67.7	108.6	77.5	27.5	24.7	21.4	8763	450
Ohio																										*13 sites, 2 more on CD-ROM*
AKRON AKRON-CANTON REG AP	40.92N	81.44W	1237	1.8	7.1	88.7	72.9	85.9	71.7	83.3	70.2	75.4	84.6	73.9	82.3	72.7	126.9	80.3	71.3	120.8	78.3	23.4	19.8	18.1	6044	676
CINCINNATI MUNICIPAL AP LUNKI	39.10N	84.42W	499	6.3	12.4	92.8	74.9	90.2	74.4	87.9	73.2	77.9	88.0	76.7	86.2	75.1	134.1	82.5	73.8	128.2	81.1	20.2	18.3	16.6	4754	1151
CLEVELAND HOPKINS INTL AP	41.41N	81.85W	804	2.5	8.5	89.4	73.9	86.7	72.5	84.1	71.1	76.3	85.6	74.7	83.1	73.3	127.4	81.4	71.9	121.6	79.6	24.7	21.0	19.0	5904	743
COLUMBUS PORT COLUMBUS INTL A	39.99N	82.88W	817	3.2	9.1	91.1	73.8	88.7	72.8	86.3	71.6	76.7	86.8	75.2	84.5	73.6	129.0	81.2	72.3	123.4	80.2	21.9	18.9	16.9	5322	971
DAYTON INTERNATIONAL AIRPORT	39.91N	84.22W	1004	0.6	6.9	90.3	73.6	87.9	72.8	85.4	71.3	76.5	86.2	75.1	84.0	73.4	128.8	81.8	72.2	123.6	80.4	24.4	20.7	18.7	5549	924
FINDLAY AIRPORT	41.01N	83.67W	814	-0.4	5.6	90.4	73.5	87.8	72.6	84.8	70.8	76.8	86.2	75.0	83.3	73.7	129.5	82.1	72.3	123.1	80.1	24.4	20.7	18.8	5994	777
LANCASTER\FAIRFIEL	39.75N	82.65W	866	3.1	9.9	90.5	74.0	88.3	73.5	85.6	71.9	76.8	86.6	75.4	84.0	73.3	127.8	80.9	72.5	124.6	80.1	20.2	17.9	16.1	5474	776
MANSFIELD LAHM MUNICIPAL ARPT	40.82N	82.52W	1312	0.1	5.7	88.0	73.0	85.5	71.7	83.1	70.4	75.8	84.6	74.3	82.5	73.1	129.0	80.8	71.7	122.8	79.3	24.6	21.1	19.1	6150	659
OHIO STATE UNIVERSI	40.07N	83.07W	928	6.9	11.7	90.4	73.7	88.2	73.1	85.3	71.9	76.4	86.1	75.1	83.8	73.0	126.9	81.1	72.3	123.9	80.1	21.6	19.0	17.2	5343	899
RICKENBACKER ANGB	39.82N	82.93W	755	4.3	10.3	92.5	75.7	90.1	74.9	87.7	73.9	79.8	86.7	77.7	86.1	78.5	152.4	84.2	75.1	135.6	81.3	22.1	18.9	16.8	5172	1028
TOLEDO EXPRESS AIRPORT	41.59N	83.80W	692	-0.3	5.3	91.2	74.2	88.4	72.7	85.7	71.4	77.2	86.9	75.4	84.2	74.2	131.0	82.9	72.7	124.2	80.7	24.3	20.6	18.6	6156	773
WRIGHT-PATERSON AFB	39.83N	84.05W	820	1.4	8.5	91.3	74.5	89.2	73.6	86.4	72.2	77.5	87.1	75.9	85.0	74.8	134.3	82.5	73.0	126.4	80.8	21.5	18.8	16.8	5381	974
YOUNGSTOWN REGIONAL AIRPORT	41.25N	80.67W	1188	1.8	7.1	88.5	72.7	85.8	71.1	83.4	69.7	75.1	84.7	73.5	82.1	72.1	124.3	79.6	70.7	118.1	77.7	21.9	19.0	17.4	6218	577
Oklahoma																										*9 sites, 6 more on CD-ROM*
FORT SILL	34.65N	98.40W	1211	12.6	18.9	100.5	72.8	98.2	73.0	95.5	73.2	77.4	90.6	76.4	89.6	74.1	133.1	82.6	72.8	127.3	81.7	24.8	21.2	19.2	3268	2111
LAWTON MUNICIPAL	34.57N	98.42W	1109	17.9	20.8	102.4	73.4	100.2	73.7	98.9	73.8	78.1	92.9	77.2	91.6	73.4	129.4	83.9	72.9	127.2	83.3	26.0	23.1	20.1	3163	2248
OKLAHOMA CITY WILL ROGERS WOR	35.39N	97.60W	1306	11.4	17.4	99.5	74.1	96.8	74.1	94.0	73.8	77.7	90.8	76.7	89.9	74.1	133.6	83.7	73.0	128.7	82.4	27.2	24.7	22.2	3516	1926
OKLAHOMA CITY/WILEY	35.53N	97.65W	1299	12.1	17.9	99.5	73.8	97.2	73.9	94.2	73.7	77.4	91.1	76.4	89.9	73.4	130.2	83.4	72.6	126.7	82.5	26.4	24.1	21.3	3493	2045
STILLWATER RGNL	36.15N	97.08W	1010	13.6	18.2	101.8	75.0	99.2	75.3	96.6	75.2	79.0	93.4	77.9	92.2	75.1	136.8	85.7	73.4	128.8	83.8	24.6	21.5	19.5	3571	1982
TINKER AFB	35.42N	97.38W	1260	12.1	17.9	99.3	73.6	96.7	74.0	93.6	73.9	78.2	90.8	77.1	89.8	74.8	136.8	84.8	73.3	129.8	82.9	25.5	22.7	20.0	3407	1971
TULSA INTERNATIONAL AIRPORT	36.20N	95.89W	676	10.9	16.8	99.4	75.8	96.8	76.0	94.2	75.6	79.2	92.3	78.1	91.2	75.5	136.9	85.4	74.4	131.9	84.5	24.5	21.0	19.2	3494	2060
TULSA/LLOYD JONES	36.03N	95.98W	633	15.8	18.8	100.1	76.5	98.8	76.8	95.4	76.7	79.6	94.3	78.5	92.7	75.4	136.1	85.5	74.8	133.5	85.1	19.8	17.8	16.1	3481	2004
VANCE AFB	36.33N	97.92W	1339	6.5	13.1	100.6	73.5	98.6	73.5	95.5	73.7	77.4	91.8	76.4	90.9	73.4	130.7	83.2	72.4	126.2	82.6	26.7	23.9	20.7	3996	1903
Oregon																										*9 sites, 12 more on CD-ROM*
AURORA STATE	45.25N	122.77W	197	27.5	29.7	91.2	67.2	88.2	67.1	83.9	65.8	70.2	85.6	68.4	83.8	64.0	90.0	76.5	63.1	87.2	74.1	18.2	15.9	12.9	4333	385
CORVALLIS MUNI	44.48N	123.28W	253	25.0	27.7	92.9	66.7	89.8	65.7	85.7	64.1	68.4	89.5	66.8	86.9	60.6	79.9	77.8	57.4	71.0	74.6	19.7	17.7	15.9	4204	412
EUGENE MAHLON SWEET ARPT	44.13N	123.21W	374	22.4	26.3	91.4	66.6	87.6	65.5	83.9	64.4	68.7	87.2	67.0	84.5	62.0	84.3	74.5	60.2	79.0	72.1	19.6	17.5	15.9	4676	259
MC MINNVILLE MUNI	45.18N	123.13W	167	27.6	29.8	91.4	65.8	89.5	66.1	84.1	64.6	68.5	87.4	66.9	85.5	61.5	82.0	72.2	60.7	79.7	71.7	20.9	18.0	15.8	4559	300
MEDFORD ROGUE VALLEY INTL AP	42.39N	122.87W	1329	22.9	25.7	98.9	67.2	95.3	65.9	91.9	64.7	69.0	94.0	67.5	91.4	60.4	82.4	74.5	58.6	77.1	73.9	18.4	15.5	12.5	4323	790
PORTLAND INTERNATIONAL AP	45.59N	122.60W	108	23.9	28.6	91.2	67.5	87.1	66.5	83.4	65.3	69.4	87.0	67.8	84.5	62.9	86.1	75.2	61.4	81.6	73.1	23.8	19.8	17.6	4222	423
PORTLAND/HILLSBORO	45.53N	122.95W	203	21.8	26.6	91.8	68.1	88.1	67.1	83.9	65.6	70.5	87.9	68.3	85.1	63.8	89.2	77.3	61.8	83.0	74.1	18.9	17.1	14.6	4750	280
REDMOND ROBERTS FIELD	44.25N	121.15W	3084	5.4	11.9	92.8	61.9	89.9	61.0	86.5	59.7	63.8	88.4	62.2	85.9	54.8	71.7	67.4	53.0	66.9	67.0	20.6	18.5	16.7	6540	229
SALEM MCNARY FIELD	44.91N	123.00W	200	21.9	26.2	92.0	67.0	87.9	65.8	84.1	64.6	68.7	88.2	67.1	85.0	61.4	82.0	73.9	59.8	77.4	72.6	20.8	18.3	16.3	4576	292
Pennsylvania																										*14 sites, 5 more on CD-ROM*
ALLENTOWN LEHIGH VALLEY INTL	40.65N	75.45W	384	7.0	11.5	91.0	73.8	88.2	72.5	85.6	71.3	76.7	86.3	75.2	83.8	73.8	127.8	81.1	72.5	122.0	79.7	24.2	20.3	18.1	5564	828
ALTOONA BLAIR CO ARPT	40.30N	78.32W	1470	4.7	9.6	88.5	72.0	85.7	70.7	83.0	69.6	74.7	83.9	73.2	82.0	72.0	125.0	79.6	70.3	118.0	77.7	21.9	18.8	17.2	5959	617
BUTLER CO. (AWOS)	40.78N	79.95W	1247	3.1	8.9	88.0	72.4	84.4	70.6	82.1	69.1	74.6	83.5	73.0	81.7	72.1	124.6	79.8	70.4	117.1	77.3	17.8	15.3	12.9	6098	535
ERIE INTERNATIONAL AP	42.08N	80.18W	738	5.2	9.7	86.4	72.9	84.0	71.6	81.7	70.7	75.3	82.6	73.8	81.0	72.8	125.2	80.5	71.3	118.7	78.6	24.7	21.7	19.5	6092	643
HARRISBURG CAPITAL CITY ARPT	40.22N	76.85W	348	8.7	13.3	92.4	73.8	89.6	72.5	86.7	71.5	76.5	86.8	75.2	84.5	73.4	125.7	80.4	72.4	121.5	79.4	20.5	18.4	16.6	5228	990
MIDDLETOWN HARRISBURG INTL AP	40.19N	76.76W	312	10.7	14.8	92.6	74.8	89.8	73.9	87.0	72.6	78.0	87.7	76.4	85.4	75.2	133.6	82.9	73.5	126.1	81.0	25.3	22.9	19.0	5035	1114
PHILADELPHIA INTERNATIONAL AF	39.87N	75.23W	30	12.6	16.9	93.2	75.4	90.6	74.5	88.0	73.0	78.3	88.5	77.0	86.3	75.4	133.4	82.5	74.3	128.2	81.4	24.4	20.6	18.5	4579	1273
PHILADELPHIA NE PHILADELPHIA	40.08N	75.01W	118	11.0	15.6	93.1	75.7	90.4	74.6	88.1	73.4	78.7	88.8	77.0	86.8	75.6	134.6	83.3	74.0	127.4	81.4	21.1	18.7	17.3	4822	1132
PITTSBURGH ALLEGHENY CO AP	40.36N	79.92W	1273	4.3	9.8	89.9	72.5	87.4	71.1	84.6	69.8	75.2	84.9	73.7	83.1	72.3	125.4	79.9	70.9	119.5	78.4	20.3	18.5	17.0	5356	875
PITTSBURGH INTERNATIONAL AP	40.50N	80.23W	1204	3.7	9.4	89.5	72.5	86.6	71.1	84.2	69.8	75.2	84.8	73.7	82.6	72.2	124.7	79.9	70.8	118.8	78.3	23.4	19.7	17.8	5624	751
READING SPAATZ FIELD	40.37N	75.96W	354	9.4	13.4	92.4	74.1	89.6	73.0	86.5	72.0	77.2	87.5	75.5	84.6	73.7	127.0	82.3	72.7	122.7	80.8	22.6	19.2	17.9	5191	946
WASHINGTON (AWOS)	40.13N	80.28W	1184	2.7	8.8	88.4	71.1	85.4	69.8	82.8	68.7	73.5	83.0	72.1	82.1	70.4	117.0	79.1	69.6	113.5	77.8	19.5	17.1	14.8	5988	542
WILKES-BARRE SCRANTON INTL AP	41.34N	75.73W	961	3.5	8.3	88.9	72.1	86.0	70.6	83.3	69.1	75.0	84.0	73.3	81.6	72.2	123.5	79.3	70.7	117.3	77.6	20.3	18.2	16.5	6105	625
WILLOW GROVE NAS	40.20N	75.15W	361	10.2	14.4	92.7	75.0	90.0	73.8	87.4	72.6	77.7	88.6	76.3	86.1	74.5	130.7	83.2	73.1	124.6	81.7	18.3	15.9	13.5	4959	1059

Appendix 8. ASHRAE Weather Data for Grandview

Meaning of acronyms:
DB: Dry bulb temperature, °F *WB: Wet bulb temperature, °F*
MCWB: Mean coincident wet bulb temperature, °F
Lat: Latitude, °
DP: Dew point temperature, °F
MCDB: Mean coincident dry bulb temperature, °F
Long: Longitude, °
HR: Humidity ratio, grains of moisture per lb of dry air
HDD and CDD 65: Annual heating and cooling degree-days, base 65°F, °F-day
Elev: Elevation, ft
WS: Wind speed, mph

Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB				Dehumidification DP/HR/MCDB						Extreme Annual WS			Heat./Cool. Degree-Days	
						0.4%		1%		2%		0.4%		1%		0.4%			1%							
				99.6%	99%	DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	DP	HR	MCDB	DP	HR	MCDB	1%	2.5%	5%	HDD	CDD 65
SHELTON/SANDERSON	47.24N	123.15W	269	24.7	27.0	87.6	64.8	82.8	64.5	79.3	63.0	67.2	83.9	65.4	80.5	61.1	81.3	70.3	59.4	76.3	68.5	20.4	18.3	16.4	5337	108
SNOHOMISH CO	47.90N	122.28W	620	27.7	30.1	79.4	62.7	75.3	62.0	72.8	61.0	65.2	75.9	63.4	73.4	61.1	82.4	68.2	59.2	76.8	67.0	24.2	20.0	17.4	5151	68
SPOKANE INTERNATIONAL AP	47.62N	117.53W	2365	2.9	9.6	92.8	63.0	89.4	61.9	85.9	60.7	65.2	87.0	63.6	84.7	58.1	78.6	68.0	56.0	72.9	67.9	25.6	21.9	19.1	6687	423
TACOMA NARROWS	47.27N	122.57W	299	29.5	32.6	83.7	64.1	80.7	62.9	77.0	61.8	65.9	80.7	64.3	77.3	60.9	80.8	68.5	59.1	75.7	67.1	19.6	17.6	15.7	4631	154
WALLA WALLA CITY COUNTY AP	46.10N	118.29W	1204	8.1	16.2	98.9	66.8	94.9	65.5	91.1	64.2	68.8	93.2	67.0	91.0	60.9	83.4	74.0	58.3	76.0	73.2	23.7	19.8	17.8	4866	912
WEST POINT (LS)	47.67N	122.43W	30	29.0	33.2	70.6	60.8	68.2	60.0	66.2	59.3	62.1	67.5	61.0	65.6	59.9	77.0	63.9	59.0	74.6	62.9	38.0	31.3	26.1	4884	9
YAKIMA AIR TERMINAL	46.56N	120.53W	1066	6.3	12.1	95.7	66.5	92.4	65.3	89.0	63.8	68.4	90.7	66.6	88.5	60.3	81.3	76.4	58.0	74.8	74.9	23.5	19.3	16.7	5946	488
West Virginia																									*3 sites, 6 more on CD-ROM*	
CHARLESTON YEAGER ARPT	38.38N	81.59W	981	8.5	14.7	91.3	73.4	88.8	73.0	86.5	72.1	76.7	86.3	75.3	84.3	74.0	131.4	80.8	72.7	125.7	79.4	17.3	15.0	12.5	4443	1066
HUNTINGTON TRI-STATE ARPT	38.38N	82.56W	837	8.4	14.6	91.9	73.8	89.4	73.5	87.0	72.6	77.3	86.7	76.0	84.9	74.5	133.2	81.5	73.3	127.6	80.1	17.1	15.2	12.9	4429	1139
PARKERSBURG WOOD COUNTY AP	39.35N	81.44W	863	5.4	11.8	90.8	73.7	88.3	72.8	85.9	71.9	76.8	86.3	75.3	84.0	73.9	130.4	81.3	72.6	124.6	79.7	18.2	16.0	14.0	4906	964
Wisconsin																									*14 sites, 13 more on CD-ROM*	
APPLETON/OUTAGAMIE	44.25N	88.52W	919	-5.8	-0.1	88.5	74.8	85.5	73.1	82.3	70.7	77.6	85.6	75.3	82.5	75.1	136.1	81.5	72.9	126.4	79.6	24.7	21.3	19.0	7184	603
EAU CLAIRE COUNTY AP	44.87N	91.49W	896	-15.6	-9.6	90.8	73.4	87.3	71.4	84.3	69.5	76.0	86.1	74.2	83.7	72.9	126.2	82.0	71.0	118.1	79.8	19.8	17.9	16.3	7859	615
FOND DU LAC CO.	43.77N	88.49W	807	-3.9	0.4	88.5	74.3	85.6	72.7	82.3	70.1	76.6	85.3	74.7	82.4	73.3	127.4	82.3	72.3	123.1	80.6	23.7	20.2	18.3	6992	591
GREEN BAY AUSTIN STRAUBEL INT	44.51N	88.12W	702	-9.9	-4.3	88.4	73.8	85.2	72.0	82.4	70.3	76.4	85.0	74.4	82.3	73.7	128.8	81.6	71.7	120.3	79.4	23.9	20.2	18.3	7684	470
KENOSHA RGNL	42.58N	87.92W	761	0.5	5.1	90.3	75.0	87.8	73.8	83.9	71.9	77.4	87.3	75.4	83.9	73.4	128.0	81.9	72.5	124.0	80.7	24.9	21.8	19.4	6554	630
LA CROSSE MUNICIPAL ARPT	43.75N	91.26W	656	-12.3	-5.8	92.1	75.1	89.0	73.5	85.9	71.7	78.0	87.9	75.9	85.0	75.0	134.7	83.9	73.0	125.5	81.5	23.0	19.5	18.1	7076	813
MADISON DANE CO REGIONAL ARPT	43.14N	89.35W	866	-9.1	-2.9	89.8	74.4	86.8	72.8	84.0	71.1	77.1	86.4	75.0	83.5	74.0	131.0	83.5	72.2	123.0	80.7	23.6	20.2	18.3	7197	608
MANITOWAC MUNI AWOS	44.13N	87.68W	650	-4.2	0.5	84.5	71.3	81.7	69.9	79.3	68.1	74.6	82.5	72.2	79.3	72.2	122.0	80.3	70.1	113.3	77.7	24.2	20.8	18.8	7538	338
MILWAUKEE MITCHELL INTL AF	42.95N	87.90W	692	-4.0	1.8	90.3	74.6	86.8	72.6	83.6	70.8	77.0	86.9	75.0	83.5	73.9	129.8	82.6	72.2	122.2	80.6	25.7	23.0	20.0	6774	684
MOSINEE/CENTRAL WI	44.78N	89.67W	1276	-10.7	-6.4	87.6	72.6	83.8	70.7	81.4	68.3	74.4	83.5	72.3	80.9	71.8	123.1	80.9	69.8	114.8	78.7	22.9	19.6	17.6	8227	374
SHEBOYGAN	43.78N	87.85W	748	-1.9	1.1	88.2	74.0	84.0	71.4	81.3	69.3	76.2	85.3	74.1	82.3	73.0	125.9	82.1	71.9	121.3	80.0	24.6	21.1	18.9	7309	432
SHEBOYGAN	43.75N	87.68W	620	-2.2	2.5	83.2	72.2	79.3	70.6	76.5	70.1	76.7	80.2	74.4	77.6	75.6	137.1	78.1	73.5	127.5	76.7	41.8	34.1	28.5	7284	321
WAUSAU MUNICIPAL ARPT	44.93N	89.63W	1198	-13.6	-7.9	88.1	71.7	84.8	70.0	82.0	67.9	74.5	83.4	72.7	81.3	71.8	123.0	79.1	69.9	114.8	77.6	19.3	17.4	15.6	8013	472
WITTMAN RGNL	43.98N	88.55W	830	-5.6	-0.2	88.4	74.0	84.4	72.4	82.1	70.2	76.6	85.0	74.5	82.2	73.3	127.6	81.3	72.3	123.1	80.0	23.3	20.1	18.2	7258	550
Wyoming																									*2 sites, 10 more on CD-ROM*	
CASPER NATRONA CO INTL AP	42.90N	106.47W	5289	-10.3	-2.1	93.8	60.0	91.1	59.2	88.2	58.6	63.6	83.3	62.1	82.0	58.0	87.5	66.6	55.9	81.2	66.6	32.2	28.2	25.7	7346	469
CHEYENNE MUNICIPAL ARPT	41.16N	104.81W	6142	-6.4	1.7	89.2	58.6	86.3	58.0	83.5	57.5	63.0	77.6	61.8	76.8	59.0	94.0	65.9	57.2	87.9	65.3	33.7	28.9	25.9	7148	324
Canada																									*102 sites, 378 more on CD-ROM*	
Alberta																									*13 sites, 40 more on CD-ROM*	
CALGARY INT'L A	51.11N	114.02W	3556	-20.4	-14.2	83.5	60.3	80.0	59.2	76.6	58.1	63.1	77.7	61.2	75.3	57.7	81.1	68.3	55.8	75.6	66.1	27.3	23.4	20.6	9154	67
COP UPPER	51.08N	114.22W	4052	-18.3	-12.4	82.7	58.3	78.8	57.2	75.2	56.6	62.9	74.1	60.7	72.4	59.0	86.7	67.1	56.6	79.3	64.5	23.4	20.4	17.9	9070	75
EDMONTON CITY CENTRE A	53.57N	113.52W	2201	-21.5	-16.4	82.5	64.1	79.1	62.1	76.2	60.5	66.0	78.6	64.1	76.1	61.4	88.1	72.2	59.4	81.9	69.5	21.7	18.6	16.4	9495	114
EDMONTON INT'L A	53.32N	113.58W	2372	-26.5	-20.9	81.5	63.6	78.1	61.8	75.3	60.5	66.2	77.6	64.2	75.2	61.7	89.7	72.7	59.7	83.6	70.1	23.0	19.9	17.3	10359	41
EDMONTON NAMAO A	53.67N	113.47W	2257	-23.1	-18.0	80.9	63.2	77.9	61.6	74.9	59.9	65.5	76.8	63.7	74.6	61.3	88.0	71.0	59.2	81.8	68.6	23.2	20.2	17.6	9889	63
FORT MCMURRAY A	56.65N	111.22W	1211	-34.2	-29.3	84.1	63.8	80.4	61.8	77.0	60.3	65.9	79.8	64.0	76.8	61.0	83.8	70.5	59.1	78.2	68.4	18.5	16.3	14.2	11492	85
GRANDE PRAIRIE A	55.18N	118.88W	2195	-33.5	-25.6	81.4	61.8	77.9	60.0	74.8	58.5	64.3	77.1	62.1	74.1	59.5	82.4	68.9	57.4	76.3	66.1	25.0	21.5	18.7	10595	44
LACOMBE CDA 2	52.45N	113.76W	2822	-27.2	-20.0	82.9	64.2	79.1	62.6	76.0	60.7	66.3	78.8	64.4	76.4	61.5	90.8	73.0	59.4	84.1	70.5	21.1	18.2	15.6	10323	38
LETHBRIDGE A	49.63N	112.80W	3048	-21.6	-15.5	88.5	61.8	84.8	61.0	81.2	60.1	65.4	80.9	63.5	79.3	60.0	86.4	71.5	57.8	79.8	68.8	36.2	31.4	27.9	8380	164
LETHBRIDGE CDA	49.70N	112.78W	3022	-19.0	-13.1	89.5	62.1	85.7	61.1	82.0	60.5	65.7	81.5	63.9	79.4	60.2	87.2	71.6	58.1	80.8	69.4	29.7	26.4	23.3	8115	210
MEDICINE HAT A	50.02N	110.72W	2352	-24.1	-17.9	90.4	63.6	87.1	62.6	83.6	61.3	66.0	84.4	64.3	82.1	60.0	84.4	71.3	57.9	78.3	69.7	24.9	21.5	18.8	8447	303
RED DEER A	52.18N	113.89W	2969	-26.8	-20.0	82.3	62.6	78.8	61.1	75.7	59.7	65.1	78.1	63.2	75.3	60.2	87.0	71.1	58.2	80.9	68.8	20.6	18.4	16.7	10289	40
SPRINGBANK A	51.10N	114.37W	3940	-25.0	-18.3	80.3	60.0	76.7	58.3	73.6	57.3	62.3	75.5	60.4	73.2	57.1	80.6	68.0	55.2	75.1	65.3	24.8	21.2	18.6	10293	8
British Columbia																									*27 sites, 50 more on CD-ROM*	
ABBOTSFORD A	49.03N	122.36W	194	16.5	21.8	85.4	67.1	81.7	65.7	78.2	64.1	68.5	83.1	66.5	79.7	62.3	84.5	76.5	60.7	79.8	73.0	19.0	16.6	14.2	5333	121
AGASSIZ CS	49.25N	121.77W	49	18.6	23.4	86.2	68.1	82.9	67.1	79.7	66.2	70.7	82.8	68.8	80.2	66.0	96.0	78.3	64.1	89.7	75.3	23.2	18.2	14.4	5082	199
BALLENAS ISLAND	49.35N	124.16W	43	30.7	33.6	75.1	67.1	72.8	66.0	70.9	64.8	68.6	73.7	67.0	71.8	66.6	98.1	72.0	65.0	92.6	70.3	35.5	30.5	26.9	4492	123
COMOX A	49.72N	124.90W	85	22.4	26.3	80.1	63.3	76.4	62.2	73.3	61.1	64.8	76.0	63.5	73.5	60.5	79.0	68.2	59.3	75.7	66.8	30.1	25.7	21.8	5574	88
DISCOVERY ISLAND	48.42N	123.23W	49	31.8	36.9	73.7	N/A	70.2	N/A	67.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	36.6	29.2	22.6	4566	25
ENTRANCE ISLAND CS	49.22N	123.80W	16	29.1	32.8	75.1	N/A	72.2	N/A	70.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	32.0	28.0	25.1	4753	111
ESQUIMALT HARBOUR	48.43N	123.44W	10	28.2	31.8	72.6	61.1	69.5	59.9	66.9	59.1	62.6	69.5	61.3	67.2	59.7	76.4	64.8	58.6	73.4	63.5	21.6	18.7	16.4	5194	15
HOWE SOUND - PAM ROCKS	49.49N	123.30W	16	27.2	31.6	77.2	66.9	74.0	65.2	71.7	64.1	68.3	74.5	66.6	72.3	65.7	94.9	72.6	64.1	89.7	70.7	40.5	35.6	30.3	4636	155
KAMLOOPS A	50.70N	120.44W	1132	-5.5	2.8	92.7	64.7	88.8	63.6	85.0	62.2	66.4	87.7	64.8	84.5	59.6	79.4	70.3	57.6	73.7	69.5	22.2	19.2	17.6	6421	461
KELOWNA A	49.96N	119.38W	1411	-1.0	6.2	90.9	64.5	87.4	63.5	83.6	62.0	66.5	85.4	64.8	83.0	60.2	82.1	70.4	58.4	76.7	69.3	16.8	14.0	11.7	7067	224
MALAHAT	48.57N	123.53W	1201	21.9	26.6	81.7	62.7	78.2	61.8	75.2	60.6	65.9	77.4	64.1	74.6	61.1	84.0	73.1	59.4	79.0	70.6	14.9	12.8	11.0	5783	173
PENTICTON A	49.46N	119.60W	1129	6.4	11.3	90.6	65.2	87.0	64.0	83.8	62.7	66.8	86.0	65.2	83.6	59.9	80.4	72.0	58.1	75.2	71.4	22.8	19.9	17.9	6250	369

THE OPTIMAL COLD SERVICE SYSTEM



01 The optimal Cold Service System starts with RG-2400® gel on the pipe to prevent corrosion.

02 VaporGuard™ for use as a vapor stop on sub-freezing insulation systems.

03 Dow® Styrofoam™ insulation provides long-term stable R values.

04 The insulation is covered with Polyguard ZeroPerm® or Insulrap™ vapor retarders to keep the insulation dry. Or complete the system with our Alumaguard® family of flexible weatherproof cladding products.

GEA