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Natural Refrigerant System Selection Comparisons in Commercial Systems

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Abstract

When natural refrigerants were new to commercial refrigeration, the competitive landscape for system selection was between traditional system types that used synthetic refrigerants or natural refrigerant technologies. Now that natural refrigerant technologies are becoming mainstream, we have begun to see the system selection process shift to comparisons between the various natural refrigerants. This paper will provide a brief historical review and comparison of early systems, and then provide a technical comparison of current popular 100% natural refrigeration systems being adopted. How do CO_2, NH_3, and R290 compare to each other in terms of market penetration, cost, and design options for commercial applications?

Introduction

Historically, supermarket and convenience store applications widely used synthetic CFC/HCFC and HFC refrigerants in commercial refrigeration market segment. The legacy refrigeration systems utilizing these synthetic refrigerants are typically parallel compressor designs with direct expansion systems using air-cooled, evaporative, or dry fluid coolers. Single compressor air-cooled condensing units have also been widely been utilized. Cascade systems utilizing a parallel compressor rack as the high side and propylene glycol as a secondary heat exchange fluid are less common but are still occasionally used.

Over the last several decades, there has been tremendous pressure on food retailers to reduce the environmental impact of their facilities. There are many national and international debates on the impacts of global warming which are helping push end users to look for ways to minimize total equivalent warming impact or TEWI. Reducing energy consumption and utilizing the lower GWP refrigerants has a significant impact on the TEWI of a facility, which can be a key driver for decision makers that care about those impacts.

Another key driver for end users is the regulatory requirements imposed for HCFC and HFC phase-outs. Planning for and staying head of legal requirements for refrigerant use are important in decision-making processes for end users. This paper will not focus on the complex regulatory environment surrounding refrigerant usage and phase-outs. However, it is worth noting that CFC/HCFC refrigerants are no longer legal options (EPA, 2015) and regulatory pressure is being placed on the phasedown for HFC refrigerants.

Although the recent EPA mandated phasedown of HFC refrigerants was challenged in court, many end users and equipment manufacturers continue to take steps towards reducing or eliminating the use of HFC refrigerants. Many individual states in the USA are currently working towards adopting refrigerant phase down regulations aligned with the EPA requirements that were challenged. For end users looking to stay ahead of legal requirements, regulatory phasedowns are an important driver in the decision-making process for adoption of natural refrigerants. This paper will describe some additional factors that make natural refrigerants an appealing choice, regardless of legal requirements.

Early Adoption of Natural Refrigeration in Commercial Applications

Early adoption of natural refrigerant systems for commercial applications in the US were met with a number of challenges from an engineering design perspective. Early adopters were eager to evaluate the benefits of natural refrigerants. However, they were also pessimistic about the known, perceived, and unknown risks. Naturally, this required consulting engineers to help end users develop comparisons and draw conclusions between legacy baseline HFC/HCFC designs and the newly emerging natural refrigeration systems.

Design Challenges

Some of the early challenges expressed by end users during the design process included:

- Higher than expected first cost of equipment
- Lack of availability of parts and/or service technicians for the equipment
- Safety concerns for natural refrigerants (pressures, toxicity, and flammability)
- Availability of Natural Refrigerants
- Unfamiliarity with installation requirements and design nuances
- Compatibility with legacy refrigeration control systems
- Delays in construction project schedules due to permitting delays of unfamiliar systems and additional scrutiny by authority having jurisdiction (AHJ)

Typical System Comparisons

It is important to provide an objective review of system options in order to help end users make the most informed decision possible. Often it is quite difficult to get a direct comparison between HFC/HCFC and natural refrigeration systems, because the system designs can vary substantially depending on the components selected.

Historically, the following metrics have been very useful in comparing the various refrigeration system types:

- Total life cycle cost
- TEWI analysis (total equivalent warming impact)
- First cost analysis
- Regulatory risk analysis
  - EPA regulations
  - Review of refrigerant safety classification and safe usage requirements
- Energy modeling comparison of systems
  - Comparison of natural refrigerant system to baseline HFC system
  - Comparison of natural refrigerant system to high efficiency HFC system
  - Comparison of different natural refrigerant systems against each other
- Interview of refrigeration contractors for feasibility of service/support at specific project locations
- Comparison with European systems and best practices
- Review system design options and selections
  - Condenser Technology Selection
  - Roof or Ground Mounted Equipment
  - Equipment foot print and weight review for space allocation
  - Electrical requirements
  - Fixture plan analysis for compatibility with selected refrigerated cases

Generally, it is not practical to provide the level of review described above for every individual project and maintain an affordable design fee. For example, a full energy model simulation completed by a consulting engineer to compare system types may cost $5,000 - $15,000 dollars depending on complexity of the systems evaluated. However, total design budgets for construction drawings typically range from $5,000 - $40,000 depending on complexity of the design. The high cost of evaluating different system types can be a barrier to adoption.

Many end users initially moved forward with "one off" demonstration projects to gain a better understanding of the real world benefits and challenges with adopting the new technologies. These early adopters received directionally accurate information that helped them make an educated decision regarding the best course of action for their needs.

However, from a consultant perspective, it became evident that more industry resources and references were required to evaluate technologies on a broader scale. This would allow end users to make better and informed choices for adoption of natural refrigeration systems.

Technical Resources Developed

The retail landscape is very competitive from an operation standpoint, however, the industry has provided cooperation and knowledge sharing related to natural refrigeration systems throughout the last decade. Additionally, organizations such as the North American Sustainable Refrigeration Council (NASRC) have further acted to facilitate efforts to grow the overall knowledge base of the commercial refrigeration industry.

Credit should be given to the following key resources for providing a platform for sharing learnings from early demonstration projects, providing guidance for acceptable use of alternate refrigerants, publishing technical information and providing recognition for early adopters of natural refrigeration systems. These resources aided in accelerating the adoption of energy efficiency measures and adoption of natural refrigeration systems.

- EPA: Greenchill Partnership (2007 – Present)
- EPA: SNAP Program
- Department of Energy: Better Buildings Alliance (2009-Present)
- ASHRAE: Advanced Energy Design Guide for Grocery Stores (ASHRAE, 2015)
- NREL: Natural Refrigeration Playbook (NREL, 2015)

The EPA SNAP Program enabled alternative refrigerants such as R290 to be approved for limited usage. The program provided end users a legal basis to utilize R290 and other alternatives for specific end uses, which would have otherwise been illegal.

The EPA Greenchill Partnership is a platform where the EPA provides recognition to end users and OEM's for design and installations of lower GWP systems. 100% natural refrigerant systems generally exceed the requirements to obtain the highest-level award given by the EPA. End users are then able to market the environmental results and achievement of national recognition by the EPA to their customers.

The Better Buildings Alliance provides a neutral platform for end users and manufacturers to share best practices in design and results from demonstrations projects, in a non-commercial setting. This is an invaluable forum to connect end users, equipment manufacturers, design consultants and national laboratories to share technical findings from demonstration projects and further promote development of design and application resources.

Advanced Energy Design Guide for Grocery Stores

To help consolidate best practices for highly energy efficient design, a key technical resource was developed called, "The Advanced Energy Design Guide for Grocery Stores". ASHRAE, The American Institute of Architects (AIA), U.S. Green Building Council (USGBC), Illuminating Engineering Society of North America (IES), and the

U.S. Department of Energy, played key roles in developing the Advanced Energy Design Guide (AEDG) for Grocery Stores (ASHRAE, 2015).

This publication allowed end users to evaluate best practices for refrigeration system design to achieve significant energy reduction as compared with a reference standard of ANSI/ASHRAE/IESNA Standard 90.1-2004. The guideline promotes a full building design approach to achieve up to 50% energy reduction compared with a baseline building. It covers all aspects of store design including refrigeration, HVAC, lighting and the building envelope.

Refrigeration systems are a large percentage of the overall energy usage for grocery stores, so the recommendations are very impactful for reducing overall building energy usage. These recommendations apply to both standard systems as well as natural systems, and represent many of the industry best practices utilized today.

The AEDG published 31 energy efficiency measures for commercial systems. The key categories for the measures are:

- Good design practices (system design)
- Compressors
- Display cases and walk-in boxes
- Heat recovery

Applying the recommendations outlined in this guideline for HFC or natural refrigerant systems allows the end user to minimize the energy consumption, but more importantly minimize the total refrigeration load in the store.

Often natural refrigeration systems are more costly than traditional systems. Therefore, optimizing designs and selecting fixtures to minimize refrigeration load and energy usage allow for a more favorable comparison by keeping the system sizes as small as possible. For a fair comparison though, HFC and natural systems should use common assumptions based around the design best practices when running energy models. Table 1 illustrates some of the recommendations provided in the AEDG for display cases and walk-ins for example.

ITEM	COMPONENT	RECOMMENDATION
Display Cases and Walk-in Coolers/Freezers	Case Type	Open Cases: Red Meat , Wet Rack Produce, Specialty Reach In Door: All Frozen, Dairy, Beverage, Deli packaged salads, Horizontal (tub)
	Case Door Heater	Medium Temp: No Heat Doors Low Temp: 50-120 Watts/door with Pulse Width Modulation Controller
	Walk-In Construction	Cooler Insulation Value: R-25 Walk-in Freezer Insulation Value: R-40
	Walk-in Doors	Doors < 48in.: Spring assist or cam-lift gravity hinge Doors >48 in.: Spring action door closer All Doors: Utilize hydraulic door closer
	Walk-in Door switches and alarms	Freezer: Fan and cooling off when door is open Cooler: Fan and cooling off when door is open All Doors: Override and alarm integration
	Walk-in Box fan control	Two-Speed Fan Control Reduce to 80% speed when refrigeration load is <50%
	Lighting Design	Open/Closed Cases: <10 W/ft. Meat Cases: < 25 W/ft. Motion Sensors with 3 min. Time-out Walk-ins: LED with motion / vacancy sensor and/or door trigger switch
	Defrost	Electric: Low Temp Cases / Freezers / Meat Coolers Air Defrost: All Others Time Initiation, temperature termination
	Temperature and Superheat Control	Electronic modulating temperature control with floating suction pressure integration
	Unit Cooler	EC Motor; select coils at 8 F TD on freezers Freezer Fin Spacing 4 FPI
	Liquid Suction Heat Exchanger	High-efficiency heat exchange at piping exit,; sized for additional suction superheat at design of 12 F for freezers and 6 F for coolers

Table 1: Recommended Case Energy Saving Measures from ASHRAE Advanced Energy Design Guide (ASHRAE, 2015)

Refrigerated display case manufacturers now must comply with the commercial refrigeration equipment standards published by the Department of Energy (eCFR, 2018). For each application and type of display case, the DOE standard sets a maximum allowable kWh/day. This energy standard has helped drive OEM's to incorporate many of the same recommendations for display cases as outlined in the AEDG. ANSI/AHRI Standard 1200 – "Performance Rating of Commercial Refrigerated Display Merchandiser and Storage Cabinets" (ANSA/AHRI, 2013) provides the required testing method for manufacturers to show compliance with the standards.

The DOE energy standards have had a large impact in pushing end users to install doors on the medium temperature cases that historically have not included them, which yields significant load reductions on the systems. It is recommended to include doors on medium temperature cases, where practical, on natural refrigeration systems as a way to minimize overall system requirements.

NREL Refrigeration Playbook

In 2015, the National Renewable Energy Lab published a valuable reference comparing Natural Refrigerant systems with HFC systems titled, "Refrigeration Playbook: Natural Refrigerants". (NREL, 2015)

The playbook outlined system architectures for various systems and described the design considerations for each. This tool helped to review system options and draw system comparisons between HFC, combination, and natural refrigerant systems which included:

- Direct expansion R404a parallel rack (baseline system)
- Various NH_3 and CO_2 cascade systems
- CO_2 trans-critical booster system
- Self-contained water-cooled R290.

The playbook provided energy modeling results utilizing Energy Plus, comparing several popular system options at the time.

- Air-Cooled direct expansion R404a parallel system
- Air-cooled direct expansion R-134A system cascaded with a combined CO_2 system
- Water-cooled direct expansion NH_3 system cascaded with a combined CO_2 system

Table 2 below summarizes the results presented in the playbook by climate zone for energy consumption. Table 3 summarizes the total TEWI impact of the systems including direct and indirect impacts. The modeling assumptions are outlined in appendix B of the playbook.

		SYSTEM ENERGY USAGE (kWh)		
Climate Zone	City	R-404A Parrallel System	R-134/C02 Cascade System	NH3/CO2 Cascade System
1	Miami	615,440	656,612	646,363
2A	Houston	560,264	609,922	610,520
2B	Phoenix	597,754	629,670	562,100
3A	Atlanta	509,065	564,954	562,615
3B	Las Vegas	532,001	572,023	544,314
3B	Los Angeles	500,876	565,762	625,081
3C	San Francisco	460,718	531,108	578,474
4A	Baltimore	474,188	533,914	537,633
4B	Albuquerque	459,358	514,814	502,546
4C	Seattle	436,734	505,771	535,224
5A	Boston	446,391	510,051	526,736
5A	Chicago	449,793	512,326	530,975
5B	Denver	437,316	496,080	491,943
6A	Minneapolis	433,550	496,320	512,087
6B	Helena	406,985	470,572	480,217
7	Duluth	400,569	468,087	500,489
8	Fairbanks	367,520	434,972	456,108
AVERAGE		**475,795**	**533,703**	**541,378**

Table 2: REFRIGERATION SYSTEM ENERGY USAGE (NREL, 2015)

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Table 3: REFRIGERATION SYSTEM TEWI IMPACT (NREL, 2015)

The results of this study indicated that hybrid HFC/natural refrigerant systems and purely natural refrigerant systems are competitive from an energy consumption standpoint.

However, from a TEWI perspective, both the hybrid systems and natural only systems are vastly better performance than HFC only system. The HFC only system has a greater than 2.2 times higher TEWI than the other options. This is mainly due to the direct impact of refrigerant leaks in the systems as noted in the playbook. Typical leak rates for commercial HFC systems range from 10-20%, but can be substantially higher (NREL, 2015).

Natural Refrigeration Systems for Commercial Applications (2016- Present)

Based on the collaboration and knowledge sharing of the early adopters and utilization of the references noted above, end users are now better able to educate themselves on the pros and cons of the different types of natural refrigeration systems. It seems end user interest has shifted towards comparing options for 100% natural refrigerant systems. The hybrid HFC systems provide benefits but still have the same concerns as 100% HFC systems relating to refrigerant compliance and regulations.

Current adopters of natural refrigeration systems are now drawing comparisons between different natural refrigeration system types and optimizing between those selections. They seem to have determined the benefits of these systems, for their operations, are superior and thus they may not even consider any HFC alternatives. Some of the factors end users note driving the decision to adopt natural refrigerants include:

- TEWI improvements (mainly due to direct emissions)
- Refrigerant first cost ($/Lbs.)

- Reduced risk related to refrigerant phase-out regulations uncertainty
- Energy efficiency on parity with HFC systems (depending on system design and location)

Others may find that the benefits of natural refrigerants are not significant to their decision, and thus, would not consider a natural refrigerant solution unless otherwise required by regulatory demands. HFC adopters note the following important factors contributing to their decision making:

- Familiarity of the systems for service technicians
- Lower equipment first cost
- Flexibility for re-use of equipment at other locations already using similar HFC refrigerants.
- Design Requirements and permitting/construction process are well understood for scheduling

Current Natural Refrigerant System Market Penetration:

Although many options exist, the four options noted are of high interest for comparisons in commercial applications in the USA:

- CO_2 Transcritical
- NH_3 / Subcritical CO_2 Cascade
- R290 / Subcritical CO_2 Cascade
- Self-Contained / Distributed R-290 Systems

It is difficult to track market penetration for these refrigeration systems, as not all market data is publicly available. However, natural refrigerant systems are a relatively small percentage of the overall installation base in the United States. There are more than 38,000 total retail grocery stores in the United States, the vast majority of which have existing installations of HFC or HCFC refrigerants. Additionally, there are over 150,000 convenience stores with vary small percentage having natural refrigeration systems.

The transcritical CO_2 and NH_3 or R290 cascade CO_2 systems are generally best candidates for full system replacements at existing stores or new construction projects. Self-contained R-290 and distributed R-290 systems have been very intriguing for adoption on smaller scale remodels, due to the high flexibility of the system design. For remodels using the self-contained cases, the end user is able to replace a sub-set of refrigeration in their existing facility, and expand as they go, when retiring existing equipment.

Of the 100% natural refrigeration system installations, transcritical CO_2 has the most deployments. In 2015 there were 52 transcritical CO_2 installations reported, which is far less than <1% of the total refrigeration installations. (SHECCO, 2015). However, the rate of adoption is accelerating. In 2018 there were 370+ systems reported, which is a 7x increase in 3 years.

There are very few total store system installations of the other system types utilizing 100% natural refrigerants. However, self-contained R290 cases for bunker islands are being more widely adopted for partial store installations and remodels.

There is significant interest by end users and we expect to see significant increases in market penetration of natural refrigeration systems, especially as first cost curves become more attractive.

Natural Refrigerant Systems Cost Comparison:

It is widely reported by end users that one of the major barriers to implementing natural refrigeration systems in commercial applications is the first cost. As the systems are becoming more competitive with multiple manufacturers offering them, it is expected that the cost will become more competitive in the future.

Cost comparison data is very difficult to compile because the specific design requirements between various projects vary substantially, so it is difficult to compare one project to another.

However, in order to get an order of magnitude comparison multiple system OEM's were asked to provide budgetary pricing for the system options outlined below.

OPTION 1: CO_2 transcritical system with gas cooler
- Single rack on a platform
- Electronic expansion valve with case / circuit controller per fixture or coil.
- Parallel compressor and multi-ejector assembly
- Hybrid gas cooler

OPTION 2: R448A direct expansion system with hybrid condensers
- 3 racks on platform (suction grouping)
- Electronic expansion valve with case / circuit controller per fixture or coil.
- Standard compressor and rack controls with staging
- Hybrid condensers

COMMON TO BOTH OPTIONS	ADIABATIC GAS COOLER OR CONDENSERS			
	EEV AND CASE CONTROLLER PER FIXTURE OR COIL			
	1,000, 000 BTUH, 50,000 SQ FT STORE			
	OPTION 1			**OPTION 2**
EQUIPMENT		**ESTIMATED** COST INCREASE VS OPTION 2		
	CO2 Transcritical	**OEM 1**	**OEM 2**	**R-448A Standard**
SYSTEM CONFIGURATION	1 RACK ON PLATFORM PARALLEL COMPRESSORS AND MULTI-EJECTOR ASSEMBLY R-744, RACK CONTROLS	**23%**	**36%**	3 RACKS ON PLATFORM STANDARD COMPRESSORS WITH CR II CAPACITY CONTROL ON LEAD R-448A, RACK CONTROLS
	(1) HYBRID GAS COOLER		**28%**	(3) HYBRID CONDENSERS
WALK-IN COILS	R-744 W/ EEVs,	**0%**	**29%**	R-448A W/ EEVs,
DISPLAY FIXTURES	R-744 W/ EEVs,	**7%**	**NA**	R-448A W/ EEVs,
CONTROLS GENERAL	TYPICAL OEM	**0%**	**0%**	TYPICAL OEM
INSTALLATION (Total Store)		**Instllation Contractor 1**		
	(1) CO2 TRANSCRITICAL RACK W/EEVs AND SYSTEM SUMMARY ABOVE	**10 - 20 %**		(3) STANDARD HFC RACKS W/EEVs AND SYSTEM SUMMARY ABOVE

TABLE 4: System Cost and Installation Comparison of a 50,000 SF Grocery Store

This comparison is budgetary equipment pricing only and may not reflect actual bid pricing for fully designed installations. The important result is there would likely be an expected first cost increase to utilize the CO_2 transcritical system compared to a state of the art HFC system.

Current Natural Refrigeration System Design Options Overview:

The following schematics illustrate some of the current system options being compared to each other currently. The intent is to provide an overview of system types and options, but is not intended to be an endorsement of any one particular system over another. There is still a lot of work being done to develop these systems for the US market and optimize factors such as first cost and energy efficiency, as well as address some of the less tangible factors like service technician availability.

CO_2 Transcritical:

CO_2 transcritical refrigeration systems operate at much higher pressures than a typical HFC system. CO_2 transcritical systems have two distinct operating conditions, defined by the system high side pressure. The transcritical region, where the efficiency is the lowest and the operating pressures the highest, is above the refrigerant “critical point” where the CO_2 will not condense into a liquid.

The second operating condition occurs at lower ambient conditions when the high side pressure of the CO_2 is below the critical point. This is referred to as “subcritical” operation and is the most efficient mode of operation. Figure 1 below shows the differences on the pressure enthalpy diagram for subcritical CO_2, transcritical CO_2 and HFC processes.

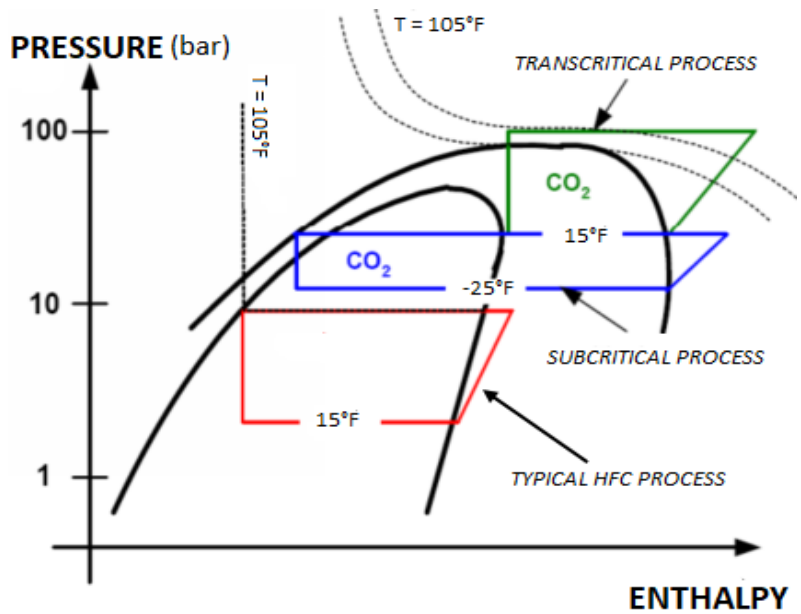

Figure 1: Pressure Enthalpy Schematic comparison of transcritical CO_2 Process

Figure 2 below shows a schematic of a transcritical system layout. This particular design utilizes a "booster" compressor to provide the lift for the low temperature cases separately and therefore improves the overall system efficiency. These systems function most efficiently in lower ambient conditions where the high stage operates in subcritical mode as much as possible.

A major difference between a transcritical system and standard HFC design is the high side uses a "gas cooler" in place of a standard condenser. The gas cooler works in two modes. When in subcritical it acts as a typical condenser. In transcritical mode, the gas cooler provides cooling of the supercritical CO_2 vapor before it enters the high-pressure control valve.

The high-pressure control valve controls the amount of sub-cooling in the gas cooler when acting as a normal condenser. The flash tank thus acts as a normal receiver in sub-critical mode and delivers liquid to evaporator loads.

When in transcritical mode the high-pressure control valve expands vapor into the flash tank at around 540 PSIG. The flash tank has a flash gas bypass valve to return gas to the medium temperature compressors to help regulate the flash tank pressure in transcritical mode.

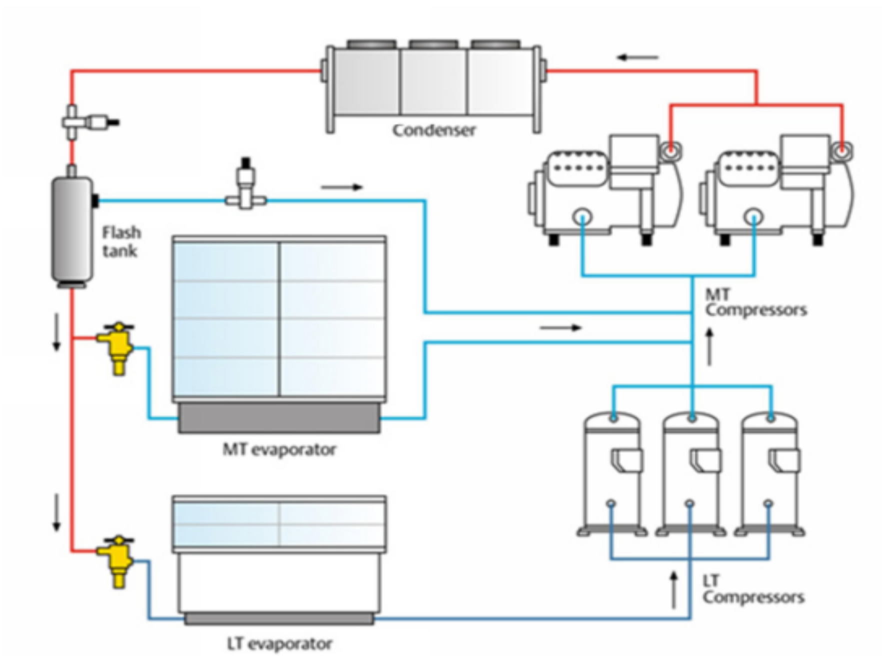

Figure 2: Transcritical CO_2 Booster system schematic (DOE, 2015)

NH_3 / CO_2 Cascade System:

Figure 3 below illustrates a NH_3 / CO_2 cascade system design. The system utilizes a low charge (< 500 Lbs.) NH_3 direct expansion system to provide condensing for the CO_2 system. This allows operation of the CO_2 system to remain in subcritical mode.

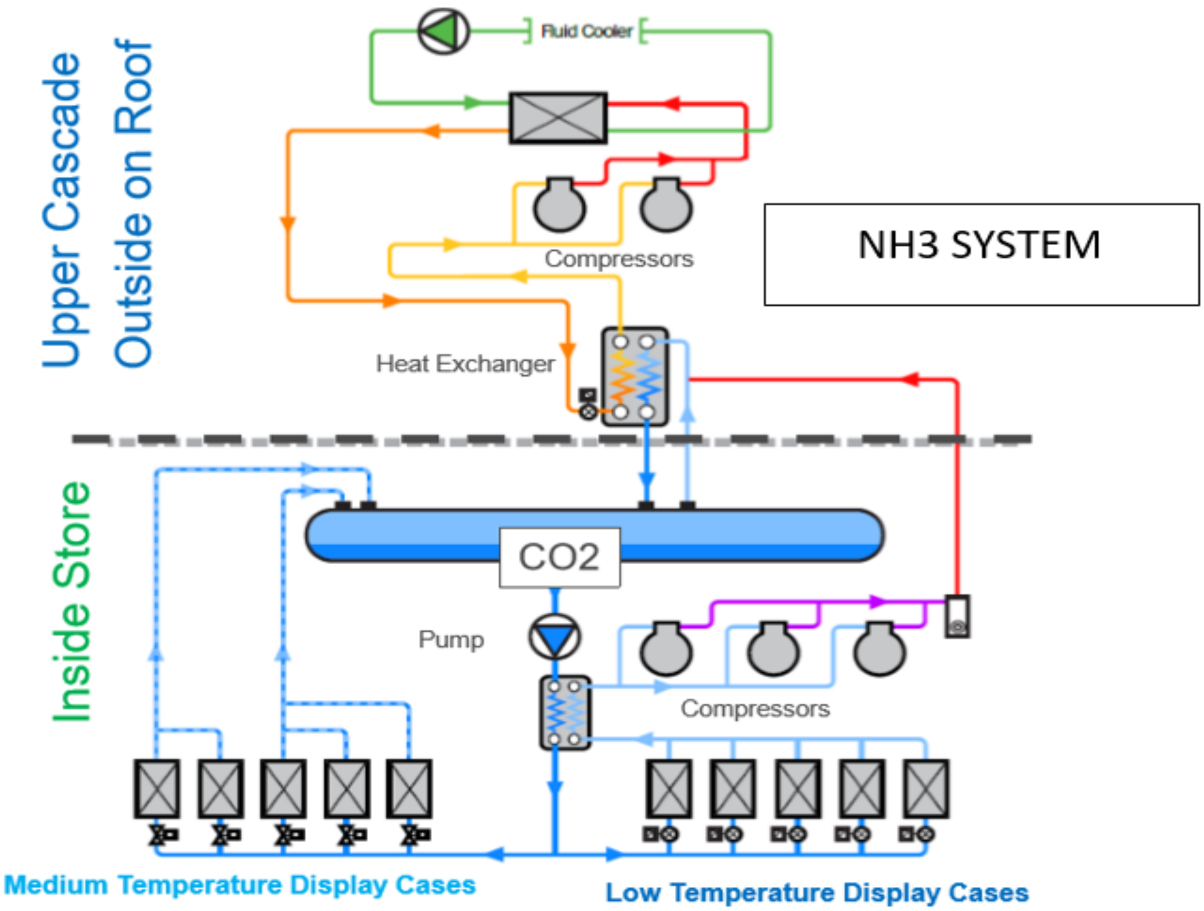

Figure 3: NH_3 / $C0_2$ Cascade Schematic

Self-Contained / Distributed R290:

A number of USA based end user are discovering the potential for using R290 as a refrigerant. R290 and other hydrocarbon refrigerants are becoming more popular in Europe and worldwide due to its very low GWP and high thermodynamic capacity. The flammability of R290 becomes the largest barrier to widespread use in the USA. The current US regulatory requirements limits the total charge to 150 grams of R290 per one, continuous, refrigeration circuit.

To meet this code requirement, number self-contained or "Micro-Distributed" systems are being deployed in the US. These designs utilize small condensing units, coupled directly to the case or evaporator coil, and typically reject heat through a water (or glycol) loop to lower discharge pressures and reduce the amount of R290 required in each system to below 150g. Figure 4 shows a typical configuration of water-cooled R290 condensing units installed on a 12 foot refrigerated display case.

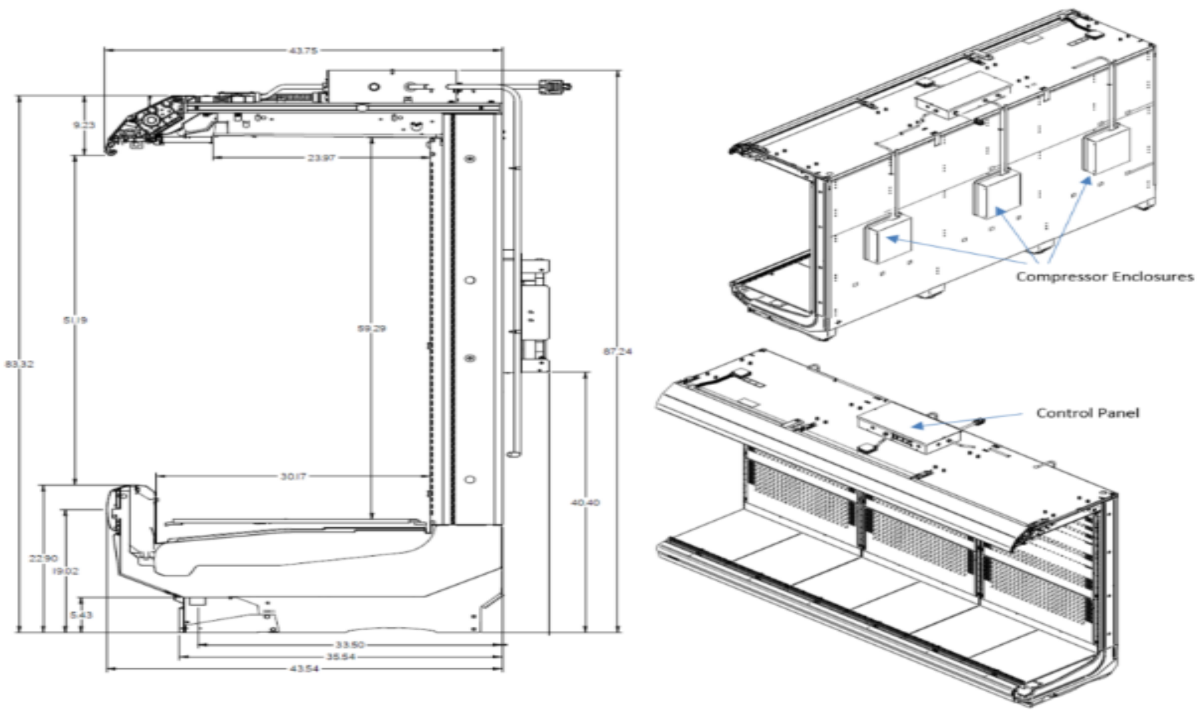

Figure 4: R290 Self Contained Display Case

The self-contained DX systems utilize an air-cooled condenser in lieu of the water loop to reject the heat directly into the building space. These systems are useful when only replacing a small portion of the display cases in a remodel, or for smaller footprint stores. Rejecting the heat into the building shifts work to the HVAC system, which is significant and needs to be accounted for in the HVAC design.

Typically, for a reach in door case one condensing unit per 4 feet of display case is required, due to the low charge limit of 150g. A charge limit increase to 500g is being considered by regulating agencies and would allow a single unit to have enough capacity to cover a 12' case, thus making this a much more affordable solution.

R290/CO2 Cascade System:

Another all-natural refrigerant solution can be accomplished using R290 and CO_2 in a cascade refrigeration design. The R290 is contained in small independent "chillers" that condense the CO_2 at pressures below the critical point and thereby keep the CO_2 system operation in the subcritical mode. Due to safety considerations, these R290 units need to be located exterior to the building, preferably on the roof. The charge size on each of these chillers is approximately 30 lbs. of R290.

The CO_2 system can be designed to operate as a liquid feed system or standard direct expansion. Specific variances must be granted by the local AHJ before a charge above 150 grams of R290 may be used. This can lead to significant permitting delays, or complete denial of the installation. Additional safety standards and code development are needed before this system type can be widely deployed.

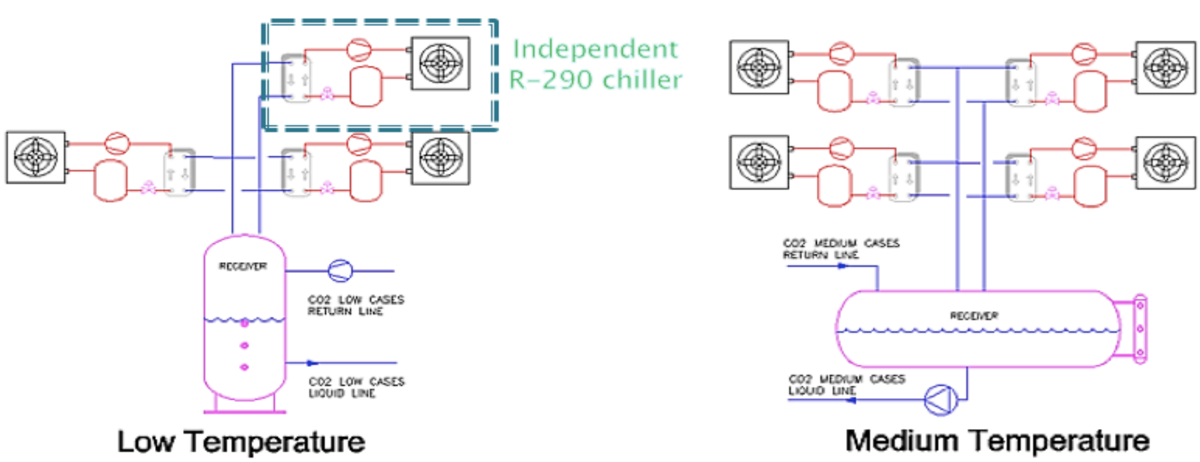

Figure 5: R290 / CO_2 Cascade System

Conclusions

End users have many options to choose from when designing and selecting commercial refrigeration systems. Natural refrigerants have become more widely accepted as a viable alternative to HFC's and concerns with contractor unfamiliarity, code requirements, and operation are quickly becoming a thing of the past.

Natural refrigeration systems are rapidly becoming more competitive from a cost and technology availability perspective. End users have a high interest in these types of systems because they help to avoid regulatory concerns and promote a more environmentally friendly solution. The global warming potential benefits of natural refrigerant systems are significant and are clearly demonstrated when comparing the TEWI calculations for stores with HFC to those that utilize a natural option.

Whichever type of refrigeration system used, the end users should conduct a comprehensive engineering analysis to understand how the system will affect the lifecycle costs of the facility. The four key system designs outlined in the presentation represent a popular range of solutions for both new construction and retrofit opportunities. Depending on the end user requirements, we anticipate a variety of these options will continue to evolve and gain traction in US.

While first cost is still a challenge for these systems, the costs are within a range where additional improvement in energy efficiency and higher implementation volumes can bring them into a reasonably competitive position.

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