REFRIGERATION SYSTEM STUDY

MAY 2020

A Comprehensive Pricing Review of Alternative Refrigeration Systems

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Background

The refrigeration systems within a Supermarket are an extremely important consideration for the Operator. They are capital intensive upfront and consume a significant amount of energy. Additionally, their performance can affect product longevity, presentation, and can limit the ability to merchandise. Refrigeration systems also require a considerable amount of routine maintenance, which can be an unwanted distraction for the Owner in terms of downtime and unanticipated costs.

Since the Montreal Protocol was signed in 1987, there have been numerous environmental regulations which have affected these systems. The refrigeration industry has experienced multiple refrigerant conversion options during the transition from CFC to HCFC to HFC refrigerants. The next transition to lower GWP system consists of using mildly flammable HFO refrigerants, or non-flammable HFO/HFC refrigerant blends. In the meantime, there has been significant interest in the use of Natural Refrigerants for a "future proof solution" as their use would preclude any future transitions.

The traditional HFC refrigeration systems are a very established design, with parallel refrigeration racks used today widely adopted prior to the turn of the century. There are significant economies of scale and familiarity associated with this technology. Natural Refrigerants require design modifications as they have either some degree of toxicity, flammability, or operate at higher pressures than previously encountered with the traditional HFC system. Because of this, there has not been a clear singular path forward. Additionally, the OEMs are promoting various new technologies and contractors are concerned about technicians having the appropriate techniques and skillsets required to install and service the equipment. Thus, an economy of scale has yet to be achieved that provides an end-user a high degree of confidence in which refrigeration system type to use moving forward.

Most large retailers have deployed various versions of the Natural Refrigerant technologies. Generally, these have been test cases in an attempt to gain insight into the associated costs, benefits, and risks. Often times, however, conducting a store-to-store comparison of the system installation and equipment costs has been very difficult. Differences between store footprints, regional labor costs, and competitive bidding climates do not support a transparent comparison for these system types.

The goal of this study was to provide a comparison of results from a competitive bid process of various refrigeration designs across the U.S. to a degree that retailers could rely on the results to make informed decisions.

Methodology

The base design for this study was a 40,000 square foot market with 23,000 square feet of sales area. There were various service departments including Bakery, Deli, Prepared Foods, Service Meat & Fish, and Floral. There is 200 MBH of low-temperature load for reach-in freezer cases and walk-in boxes. There is 700 MBH of medium temperature load for cases, cooler boxes, and refrigerated preparation rooms. This basis of design was used for all designs for each of the refrigeration system types.

The Baseline Refrigeration Design consists of three (3) parallel rack systems utilizing R-448A refrigerant, reciprocating compressors, and adiabatic condensers. The systems are located on cooler boxes in a central location. The adiabatic condensers were applied due to the calculated energy payback. The system layout is a fairly typical design with a split-suction low temperature rack, two split-suction medium temperature racks with loop piping and electric defrost. All racks are mechanically subcooled by one of the medium temperature racks. With the split suction groups, subcooling, and adiabatic condensers, the design is extremely energy efficient and provides an aggressive baseline.

The same store footprint was redesigned for three (3) additional system types. This yielded a total of four (4) systems being reviewed:

1) Baseline 3-Rack R-448A HFC System
2) R-744 CO_2 Transcritical System utilizing a single Rack, and adiabatic gas cooler
3) Micro-Distributed Systems, utilizing 448A as a refrigerant and a hydronic loop for heat rejection, and adiabatic fluid cooler
4) Micro/Macro-Distributed Systems, utilizing R-290 Propane for standardized cases, and R-744 Carbon Dioxide for specialty cases, with a hydronic loop for heat rejection, and adiabatic fluid cooler

In addition to understanding the difference in system costs, it was desired to review Regional impacts on these systems. The goal was to identify the possible effects of these factors:

A) Regional Contractor Experience
B) Equipment Cost Differences due to Climate
C) Energy Cost Differences due to Climate
D) Effects of Mixed-Use Applications

ASHRAE Climate Design information was reviewed for sixteen (16) major metropolitan areas. These localities were: Atlanta, Austin, Baltimore, Boston, Chicago, Dallas, Denver, Kansas City, Las Vegas, New York, Phoenix, Portland, San Francisco, Seattle, St. Louis, and Tampa. The climate information was separated into four (4) distinct categories:

1) Cool, Dry
2) Cool, Humid
3) Hot, Dry
4) Hot, Humid

Each of the four (4) systems was then designed for these four (4) Climate Zones. Finally, a design modification was created for a mixed-use application. This included the use of brazed plate heat exchangers on the racks (as applicable), a pump skid, and a fluid cooler in lieu of direct air-cooled equipment.

Application

It was determined that pricing would be sought in five (5) key market areas:

1) Austin
2) Chicago
3) New York
4) Phoenix
5) San Francisco

These areas provided a broad view of geographical practices and cover the four climatic zones, with Chicago and New York being in the same approximate climatic zone from a peak design standpoint. Note that the energy calculations were done separately for each City with TMY3 weather data incorporated. This is covered further in the Energy Analysis Section.

All methods of heat reclaim were specifically excluded from the designs. There are multiple approaches, philosophies, and code requirements regarding the application of heat reclaim and it was determined this would have convoluted the results.

It is noted the base design, consisting of three (3) systems with mechanical subcooling could potentially be value-engineered to achieve lower first costs for the baseline HFC system. It was desired, however, to represent a fairly typical and also aggressive baseline in terms of energy usage. It is also noted the intent of the study was to compare existing practices against potential alternate technologies and not necessarily to review optimization of higher carbon footprint solutions.

It is further noted the CO_2 design consists of a single Transcritical rack. This is largely in keeping with standard industry practices for a facility of this size. There is some consideration as to the overall redundancy within the store when comparing a single CO_2 rack to a three-rack HFC design or to many self-contained cases.

Finally, it is noted the Base HFC design included Mechanical TXVs. This is in keeping with typical industry practice. There have been numerous studies indicating energy savings associated with the use of Electronic Expansion Valves (EEVs) as opposed to using TXVs. Additionally, there are potential labor savings associated with reducing the time to set valve superheats, as well as reduced sensor wiring to remote locations. The CO2 system as a requirement utilizes these EEVs. Bid Alternates to apply EEVs to the HFC system were included to evaluate the potential effectiveness of including these with the HFC system.

Cost Results

These bid sets, including detailed installation and equipment specifications, were set to several of the well-known Commercial Refrigeration Equipment Manufacturers. Multiple Contractors were also selected in each region.

A summary of all results are included in the Table below. This averages the results across all five (5) cities. Installation and Energy observations are included below.

It is noted the system architecture does not impact the refrigeration equipment and installation solely. Additional disciplines commonly affected include Electrical and Structural. No allowance was made for structural modifications as the potential variations are too numerous and all systems ultimately require roughly the same overall heat of rejection. It should be recognized the Micro-Distributed system requires the least indoor equipment coordination in terms of physical space and weight, and this may play an advantage in certain instance as described further below.

An allowance was made to include the cost implications from the Electrical installation for both the Micro-Distributed, and Micro/Macro Distributed systems. The allowances were made to account for electrical costs that are required regardless of the building infrastructure or design.

The primary electrical distinctions between Micro-Distributed and Centralized Rack systems are the case nameplate loads and defrost scheduling. The individual Micro-Distributed cases have the capability to support a broad range of product temperatures, and the cases show a nameplate rating that is for the largest potential electrical load, including energy consumption and overcurrent protection requirements. Some adaptations of the Micro Distributed case include a variable speed compressor, which will limit energy use to closely match what is required for maintaining the temperature set point. The NEC, however, requires the electrical design to only take into account the nameplate information for energy usage, which can be several times actual demand. This additional connected ampacity due to the nameplate values, taken over the sum of an entire store, can cause the store electrical service size to increase up to 20%, and panels and transformers tend to be larger than typically found with cases connected to a centralized HFC rack system. Since each Micro Distributed case has a 2-Pole circuit breaker, only 20 cases can be fed from each electrical panel, which also increases the total number of panels and transformers required to support the same case layout as a centralized rack system.

Additionally, Micro-Distributed systems, since they are similar to self-contained cases, may be able to decide for themselves when defrost is necessary. While it is understood that a coordinated control would likely be implemented, a substantial number of systems could defrost at the same time. While the Micro-Distributed cases are expected to match loads to reduce the overall energy use of the case, an individual Micro-Distributed case defrost system can use up to three-times the energy of the actual compressor demand load. The cumulative effect of the Micro-Distributed case defrost loads will prevent downsizing of electrical panels, even if the energy usage during normal operation of the case would make it appear possible.

Summary - Average of 5 Regions, Rounded	HFC	CO2	Micro-Distributed	Micro-Macro Distributed
Cases % difference (Average of 3 OEMs)	0.0%	14.0%	67%	16%
Equipment % difference (Average of 4 OEMs)	0.0%	-25%	-11%	-5%
Installation % difference (Average)	0.0%	-10%	-3%	3%
Net Total % difference	**0%**	**-4%**	**19%**	**9%**
Net Difference, Including Electrical		-4%	24%	13%

Note that the results above are the averages of the prices received during the competitive bid process. Different OEMs are more aggressive depending on the technology used. The results will differ depending on the OEMs used and actual project savings can be increased by using the low bidder.

Installation Observations

The installation numbers in general were are all very competitive, thus present a high degree of confidence in their accuracy. In some applications, adjustments needed to be made to the individual bids to account for exclusions made for trade issues or other reasons.

The CO_2 design yielded the lowest installation cost for all geographic Regions, with an exception noted in Chicago. There was a significant disparity in the installation bids received in the Chicago Region. The bids ranged from 14% lower for the CO_2 installation than the HFC, to 48% higher for the CO_2 install cost. The Distributed systems ranged from 5% lower than the HFC systems to 34% higher. Despite this disparity in the installation costs, overall, including the equipment cost, the CO_2 system was still lower than the HFC Design.

Mixed use application may favor the Micro/Macro-distributed solution with appropriate installation techniques and cost verifications. These costs were at parity, or lower, than the HFC solution. While the CO_2 systems still showed an overall edge, the Micro/Macro system already utilizes a hydronic loop, which makes the upcharge to accommodate a mixed-use installation much less. The incorporation into a hydronic system, as well as the reduced need for centralized equipment, may make the Micro/Macro systems easier to adapt into restrictive tenant build-out conditions. Additionally, some areas restrict the size of racks to less than 300 pounds of refrigerant charge and compressors to less than 50 hp. This would require more equipment to accommodate for the CO_2 and HFC solutions than has been priced, likely making the Micro/Macro solution ultimately much less expensive comparatively in that scenario.

Energy Analysis

The energy analysis calculations were performed on each of the 4 solutions using weather data from the 5 cities. For each of the calculations, sample 8760 TMY3 weather data from a representative airport was used. The peak design caseloads (BTUH) were used for all energy calculations, and the loads were kept constant during all calculations in an attempt to keep the results comparative.

The Energy usage calculations only include the compressors, condensers, fluid coolers, and pumps. Case fans, lights, anti-sweats, and defrost energy usages were excluded.

Although every attempt was made to maintain an "apples to apples" comparison, due to the limits in the various calculation tools available, different calculation tools were used. *Pack Calculations Pro* software was used for all calculations of HFC and CO_2 energy usage. The Micro-Distributed energy use was conducted using an excel spreadsheet containing the compressor and OEM pump mass flow and energy use curves. The Micro-Macro energy results were provided from two sources. Pack Calculation Pro was used for the CO_2 portion and the Propane (used in both cases and walk-ins) systems energy use came from the vendor's internal calculation tool.

Energy Calculation Tools Used

HFC	CO2	Micro-Distributed	Micro-Macro Distributed
Pack Calculation Pro	Pack Calculation Pro	Excel, compressor/ pump curves	Pack Calculation Pro, Vendor supplied

Summary - Energy % Higher Than HFC (kWh)	HFC	CO2	Micro-Distributed	Micro-Macro Distributed
Austin	100%	119%	136%	164%
Chicago	100%	118%	150%	191%
New York	100%	114%	146%	183%
Phoenix	100%	132%	165%	199%
San Francisco	100%	109%	185%	222%

Recommendations

This study was a detailed effort at obtaining full pricing implications for the four (4) different system types reviewed. The results came back with a fairly tight tolerance from both the OEMs and the Contractors, indicating a high level of confidence in the results. The following items are offered for additional consideration:

1) When soliciting pricing, it can be advantageous to define specific terms and length of Agreement. It was indicated by some of the OEMs that pricing can be influenced if the terms and expected volume are specified.
2) Provide detailed Equipment Specifications. This helps keep the bids competitive and can improve the margins provided by the OEMs as any unknowns are eliminated. A mechanism should be provided that allows for unique technologies to be brought forth by the OEMs, but these need to be specifically identified and evaluated.
3) Review the use of various component manufacturers. More players are providing energy efficient Natural Refrigerant solutions, and there can be significant pricing advantages by soliciting prices from additional vendors, down to the component and heat exchange surfaces.
4) Develop standard installation specifications and details. There was a variance in terms of installation exclusions, applications and notes provided by the Installing Contractors. With any technology there are benefits in deploying best-practices across all installations.
5) Contractor training sessions should be provided to the Contractors when a new technology is deployed in their respective regions. All Contractors with the exception of one (1) provided a lower installation cost for CO_2 than HFC. The one bid for a higher cost was partially driven by the use of use of more expensive piping material throughout the CO_2 system than was required. To ensure competitive bidding, a high-level review of the requirements should be provided to the Contractors.
6) The use of Electronic Expansion Valves (EEVs) should be reviewed further for application with HFCs. Contractors showed a wide price variance based upon the application of controls. It is feasible to see both a labor savings and material savings with the use of EEVs. The material savings is due to the potential of running a network wire out to the cases versus running individual case temperature sensor wiring back to a remote IO panel. The labor savings is due both to the easier installation as well as the reduction of time spent setting superheats. The installation savings ranged from roughly 9% in high labor cost areas down to 6% in lower labor cost areas. Other Contractors showed either a push, or a cost premium of anywhere from 2% to 7%, again based upon expected control architecture. It is noted the specification of EEVs drove both the case cost and equipment cost higher (roughly 8%).
7) The use of Specialty Mechanical Contractors for the installation of the Hydronic loops used with the Micro-Distributed and Micro/Macro-Distributed Systems would likely yield cost savings and installation benefits for those systems. The majority of the contractors quoted copper piping for

the hydronic loops, with one contractor indicating the use of steel for the larger sizes. Per the graph below, copper is typically the most expensive piping material for larger sizes, and may be the most susceptible to erosion. Micro-Distributed and Micro/Macro-Distributed systems could feasibly be more competitive with the application of different means and methods for the hydronic system.