Arena Marcel Dutil, Les Coteaux, QC, Canada, is the first ice rink in the world to use a transcritical CO_2 refrigeration system.

CO_2 Refrigeration Systems Evolution for Ice Rinks

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The industry is most likely experiencing a shift in the way artificial ice rinks are refrigerated. After the first ice rink system using carbon dioxide (CO_2) as secondary refrigerant was built in 1999, it wasn't until 2010 that the first ice rink using a transcritical CO_2 system was realized. This article discusses the rationale behind using CO_2 in ice rinks and the most important steps of the evolution of the technology.

The history and evolution of ice rinks is well documented by Martin in "Evolution of Ice Rinks"[1] where it is concluded that the first known ice rink was The Glaciarium in London in 1876. Technically it is described as "Copper pipes were laid down, and through these, a mixture of glycerine and water was circulated after having been chilled by ether." Most modern ice rinks could be described similarly, although the fluids would be different.

Refrigerants

In the early days of refrigeration history, starting in the 19th century, only natural fluids were available. In the beginning of the 20th century, chemical science learned to create substances with more suitable properties such as R-12 and R-22. Today, R-22 is subject to phaseout according to the Montreal Protocol, but it is still in use in many ice rinks throughout North America. A review of the EPA's list of acceptable substitutes[2] will push many in the refrigeration industry toward natural refrigerants. Among the natural alternatives, only a few are suitable for ice rink refrigeration, and the following are normally considered: ammonia, hydrocarbons, and CO_2.

In the industrial refrigeration sector (which includes ice rinks), ammonia has been widely used for decades. In recent times, we have seen a growing interest in using CO_2 as refrigerant in many applications, especially in the commercial sector. This interest is present in the industrial sector as well, which will have considerable implications for the business.

Carbon Dioxide in the Refrigeration Industry

The history of CO_2 can be divided into two parts. The first is well described by Bodinus,[3] who explained how the systems evolved and developed during the 19th and 20th centuries. He concluded this era ended when the

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interest in CO_2 virtually disappeared in the 1950s since synthetic refrigerants were introduced and took over (*Figure 1*).

At the end of the 1980s, Norwegian professor Gustav Lorentzen brought up the idea of using CO_2 again, which introduced the second era of the history of CO_2. He investigated how CO_2 technology could be used in different applications and published many articles. In 1993 he stated that "CO_2 is as close to the ideal refrigerant as it is possible to come...."[4] One aspect of CO_2 that he discussed was how heat may be reclaimed, as well as the associated control strategies to optimize the process.

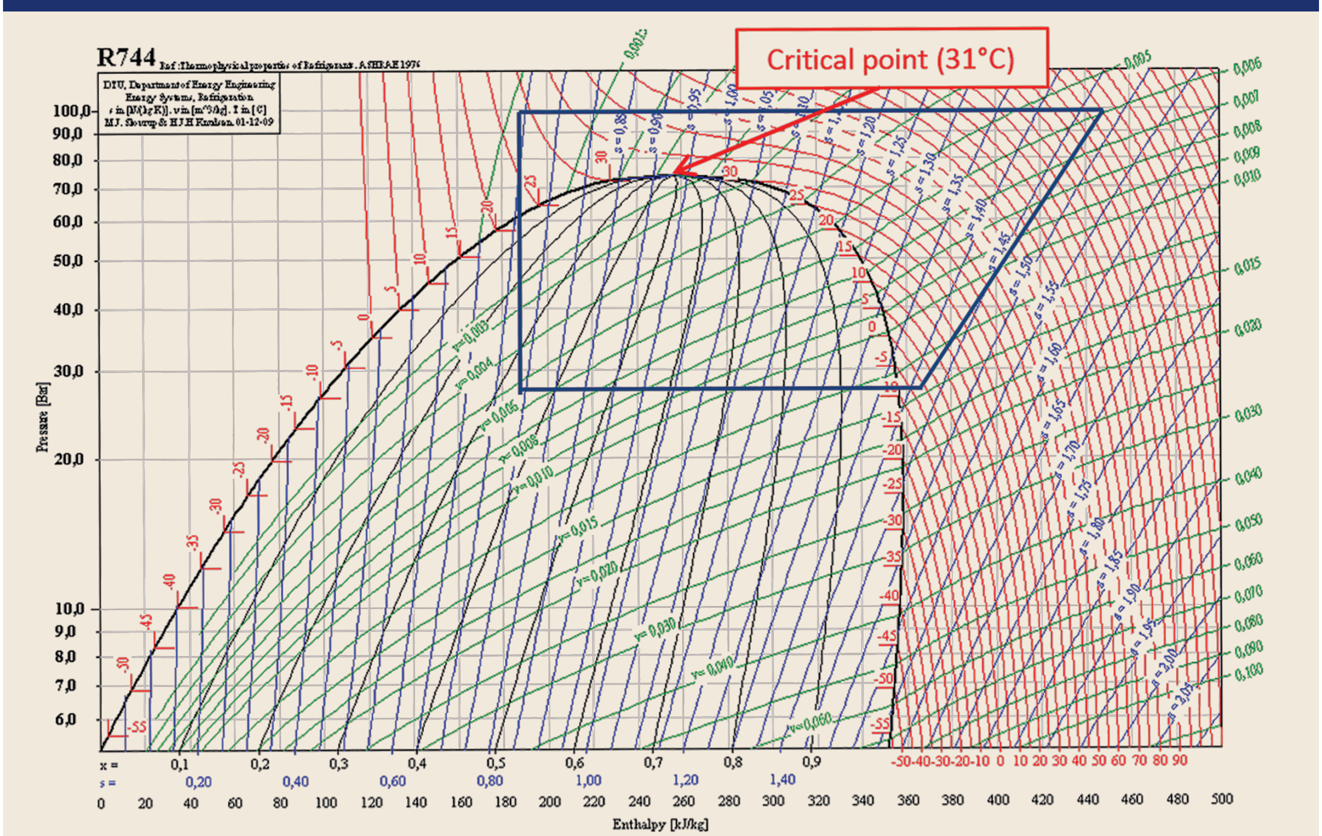
FIGURE 1 An advertisement for CO_2 systems originating from the early 20th century.

Properties of Carbon Dioxide

Carbon dioxide is a natural, nonflammable and nontoxic substance that offers technical advantages when compared to other natural alternatives. Regarding toxicity, codes such as the International Mechanical Code (IMC) and the European corresponding EN378 do impose certain safety measures for using CO_2 as a refrigerant.

The challenge with CO_2 basically stems from the fact that it has a critical point at a temperature of about 31°C (88°F) with a corresponding absolute pressure of about 74 bar (1070 psi). At conditions above the critical point, the difference between liquid and vapor disappears and no condensation occurs. With proper design,

FIGURE 2 Schematically illustrated transcritical CO_2 cycle in a p-h diagram (www.ipu.dk).



CO_2 systems offer good efficiency and low cost in many applications.

Transcritical Solutions

The transcritical mode of operation is relevant because most modern CO_2 systems are designed to operate this way. The term transcritical refers to the critical point. When the refrigeration cycle operates above and below the critical point, which is unique for CO_2, the mode of operation is called transcritical and can be seen in *Figure 2,* page 35.

Commercial Applications

In his Ph.D. thesis, Sawalha[5] reports that the first Scandinavian installation of a transcritical CO_2 system took place in Denmark in 2003 and was followed by two Swedish installations in 2004. One of the pioneers in the transcritical CO_2 supermarket area was Linde Kältetechnik (today Carrier Refrigeration) who promoted a CO_2 solution illustrated in *Figure 3*. This Swiss supermarket, which was commissioned in late 2004, comprised transcritical CO_2 systems including heat reclaim.[6]

Heat Reclaim

The concept of reclaiming heat from ice rink refrigeration systems for space heating, tap and resurfacing water, etc., is widely known. It has been implemented either passively by simply using the heat available, mostly desuperheat, or actively by controlling the head pressure to raise the associated temperature of the rejected heat. Most refrigeration systems can supply part of the rejected heat at temperatures around 60°C (140°F), which is mostly sufficient for tap water, and the rest at lower temperatures for space heating and snow melting.

The same principle applies to CO_2, with the only difference being that there are some further implications as to the optimization of the head pressure when operating above the critical point. This mode of operation and associated control was described by Lorentzen[4] and further illustrated by Madsen.[7] Although the ambient air temperature may be low during winter, the head pressure is elevated above what is required for the refrigeration process to work to reclaim the heat at a useful temperature.

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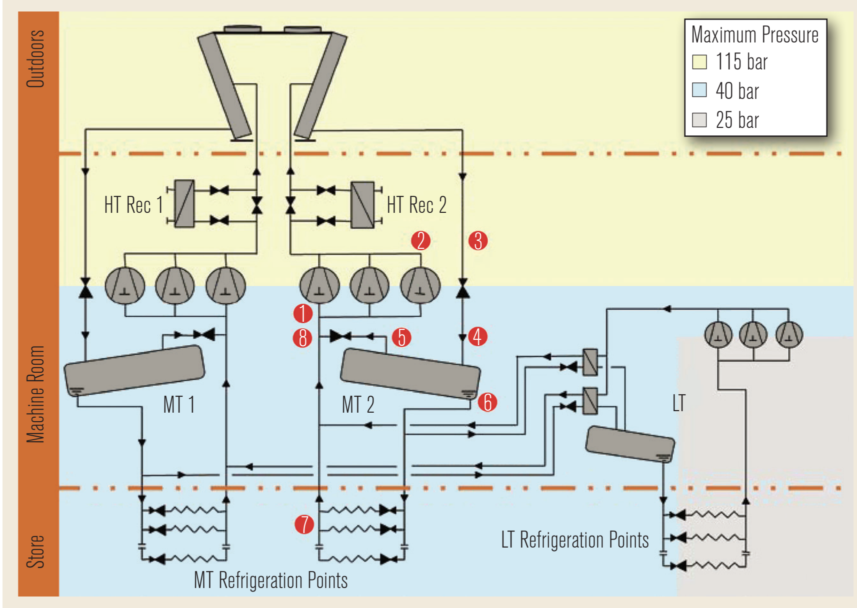
FIGURE 3 A schematic figure of the Linde Kältetechnik transcritical CO_2 system from 2004.[5]



CO_2 Ice Rinks—First Generation

Most ice rinks in recent years have been built as indirect systems using a secondary refrigerant. A couple of secondary refrigerants are commonly used in the industry such as calcium chloride, propylene glycol, ethylene glycol, and, more recently, carbon dioxide.

Both propylene and ethylene glycol are relatively environmentally friendly, but otherwise have rather poor properties that result in high pumping power and a lower overall performance of the refrigeration system.

Calcium chloride, which is a salt, offers better efficiency in terms of pumping power than the glycols and is still the most common solution, at least in European ice rinks. Calcium chloride has practical challenges such as corrosion and is losing popularity in favor of CO_2 or ammonia–water. When CO_2 is used as a secondary refrigerant, it offers interesting advantages due to its low pumping power. Compared to calcium chloride, it requires less than 10% of the pumping power.[8] On the other hand, the system operating pressure is high, so the rink floor piping system needs to be made of metal to withstand the pressure.

Ice rinks that use CO_2 as the secondary refrigerant in combination with any primary refrigerant are referred to here as "first generation." The first ice rink to be built with pump-circulated CO_2 as a secondary refrigerant and ammonia as the primary refrigerant was the Dornbirn ice rink in Austria in 1999.[9] Sulzer (today Axima) was the system designer, and in its information sheet they present the system.[10] *Figure 4* shows the essential components of the ammonia- and CO_2-based system.

Axima and other companies in Austria, Germany, Switzerland, the Netherlands, Japan and Scandinavia continued using CO_2 as secondary refrigerant in both new construction and retrofit after 1999. In 2015, there were 56 known ice sheets cooled with CO_2 as secondary refrigerant. A step forward in the development that reduced the installation cost was to use copper tubing in the rink floor. A Swedish project investigated this solution in 2004 and resulted in the construction of the Backavallen ice rink in 2006.[11] The ammonia compressors and the CO_2-pump module of the Backavallen ice rink can be seen in *Figure 5*. Another 15 rink floors have been built with this copper tubing technology from 2006 until 2015.

CO_2 as Primary Refrigerant—Direct Systems

In light of what has been discussed so far, the use of CO_2 as primary refrigerant in an ice rink application seems to be a natural consequence. We normally refer to ice rink systems using CO_2 as primary refrigerant as the "second generation." With the pump circulation CO_2 systems evolving from the Dornbirn ice rink in 1999 and the parallel development of transcritical CO_2 systems in the commercial sector, it became obvious to combine the two. In the early 2000s the components for transcritical CO_2 systems were not yet mature enough to build ice rinks, for instance in terms of compressor cooling capacities. As a consequence a CO_2 ice rink refrigeration system would have required about 15 compressors to meet the capacity needs where a typical ammonia system would only use two compressors, which made the CO_2 system seem expensive and impractical. This contributed to a relatively late introduction of the technology in ice rink applications, although the potential advantages were known.

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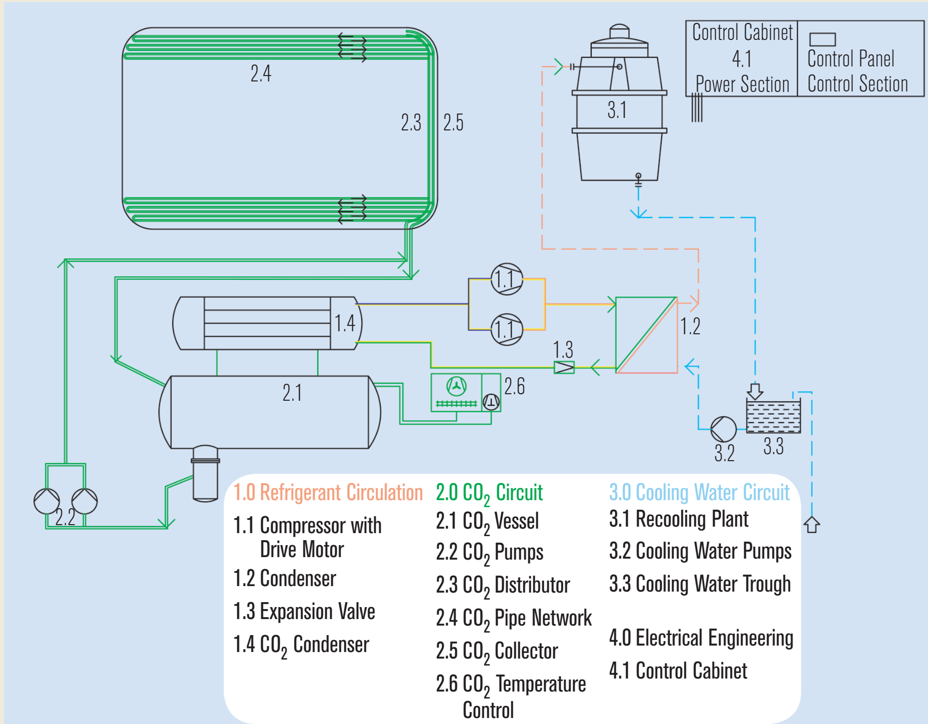

FIGURE 4 The ammonia-CO_2 system layout of the 1999 Dornbirn ice rink.[9]

The first known CO_2 transcritical ice rink design is the one proposed by a Swedish contractor for the Katrineholm city ice rink in January 2006.[12] The proposed design had 12 compressors designed to meet the specified cooling capacity of 300 kW (85 tons). Therefore, Katrineholm eventually chose to install the prescribed first-generation CO_2 system, the first in Sweden, so this proposed transcritical CO_2 system was never built.

FIGURE 5 The Backavallen ice rink built in 2006 with CO_2 as secondary refrigerant (Picture: J. Rogstam).

The second known transcritical CO_2 ice rink proposal is the 2009 Gentofte ice rink extension project in Denmark where one alternate proposal consisted of a direct transcritical CO_2 system. The ice rink extension project was postponed, and eventually a traditional indirect ammonia solution was selected.

The first known direct second-generation CO_2 ice rink is the Arena Marcel Dutil in St Gedeon, Quebec, Canada, in 2010. Due to its being the first built second-generation CO_2 ice rink, it has been well documented, and a relevant article about it was included in *ASHRAE Journal* in March 2012.[13]

Figure 6 shows the relationship and how the transcritical CO_2 supermarket systems have been combined with the pump circulation CO_2 systems introduced in Europe. To the center left, the liquid receiver is connected to the "green" circuit, which essentially shows the pump circulation part of the system. Directly under the receiver, the liquid pumps are placed, which distribute the CO_2 to the rink floor. In the bottom left part, four of seven compressors can be seen that are connected with the blue suction line to the liquid receiver. The red lines indicate the high-pressure part from the compressor via

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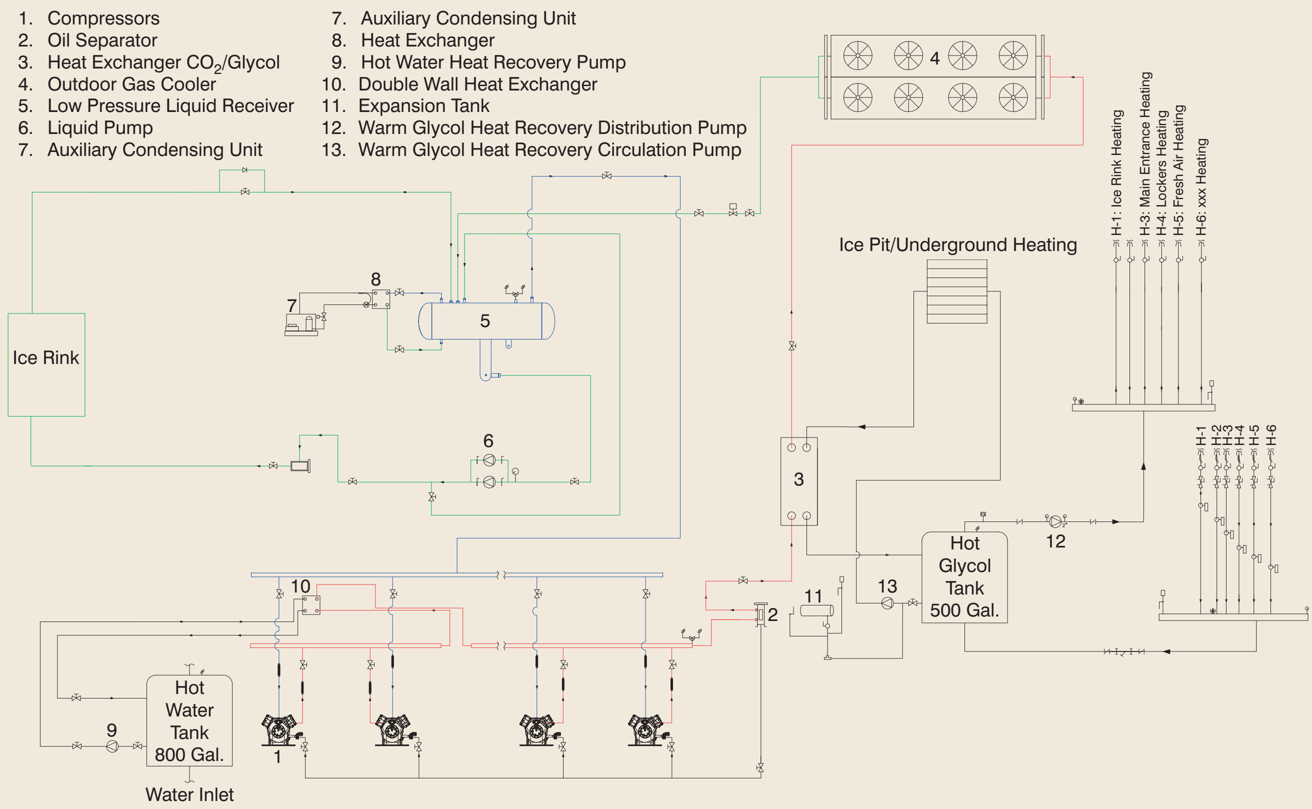
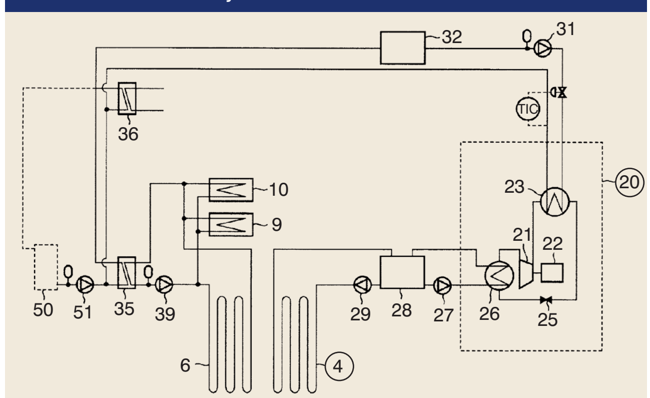
FIGURE 6 The transcritical CO_2 system installed in Arena Marcel Dutil, St Gedeon (CA) 2010.[12]



the heat reclaim exchanger to the gas cooler. As reported by Simard,[13] a significant reduction of the energy cost was recorded, which to a large extent can be explained by the heat reclaim.

Further, the ice quality was recognized as being very good, which is a potential advantage with direct refrigeration of rink floors since they are typically easier to control. Due to the CO_2 circulation in the rink floor, the total charge for a single sheet ice rink is about 2000 kg (4,400 lb). As mentioned earlier, codes such as the European code EN378 address relevant measures to handle the associated safety implications.

FIGURE 7 An indirect ice rink refrigeration system using CO_2 as primary refrigerant with heat recovery.[14]



CO_2 as Primary Refrigerant–Indirect Systems

CO_2 can also be used as primary refrigerant in indirect ice rink systems where it cools a secondary refrigerant such as calcium chloride, glycols, etc. This solution is slightly less favorable from an energy standpoint, but it is still interesting in the case of a refrigeration system retrofit. The use of CO_2 as primary refrigerant together with a secondary refrigerant in ice rinks has been proposed in the past, but it would take until 2012 before it was realized. The first to propose CO_2 as primary refrigerant was the International Ice Hockey Federation's ice rink manual in 2002[14] and later a patent application from Mayekawa.[15] In *Figure 7* the transcritical CO_2 system from the patent application is indicated as box number 20 and the rink floor as number 4.

Still, it would take until 2012 before the first indirect CO_2 ice rink was built, the installation at Dollar des Ormeaux, Quebec, Canada. This facility is an interesting

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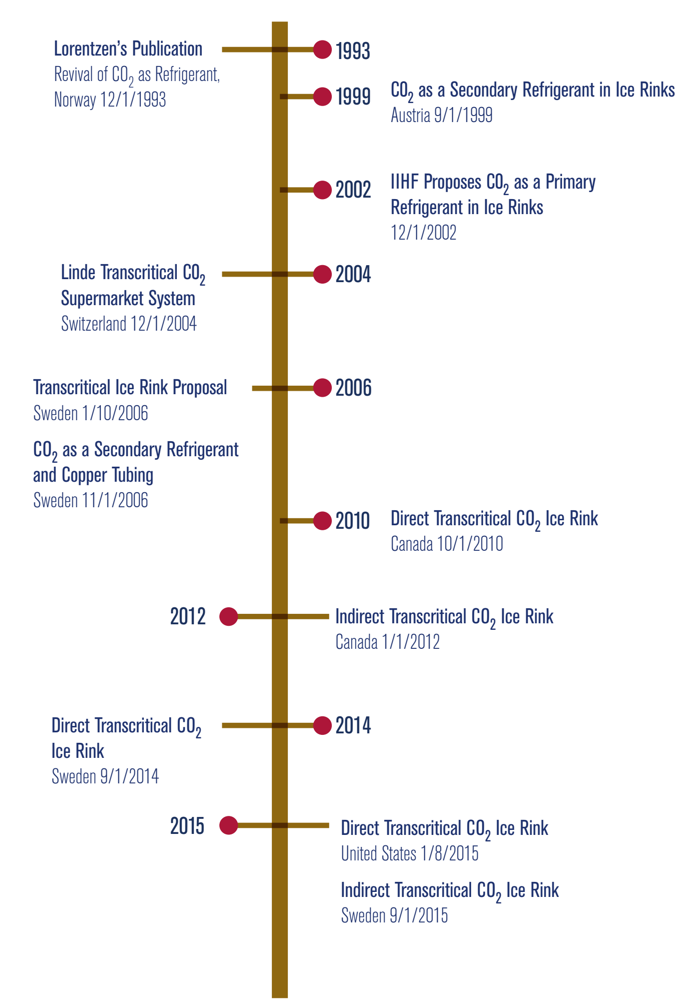
example of how reclaimed heat from a CO_2 ice rink system can be used to heat a swimming pool complex in addition to the ice rink itself. This installation is described in *ASHRAE Journal*.[15] It was awarded First Place in the ASHRAE Technology Awards in 2015.

FIGURE 8 CO_2 ice rink technology evolution timeline.



Discussion and Conclusions

The basic system principles and functions of today's transcritical CO_2 ice rinks principally work exactly as the direct refrigeration systems from the past did. The difference is simply the choice of refrigerant. As a matter of fact, the same system solutions and basic components apply regardless of the refrigerant being ammonia, R-22 or CO_2. CO_2 has properties suitable for ice rink applications, so it is difficult to understand why it took so long for it to be introduced, although it was identified as a potential solution several times prior to Arena Marcel Dutil in 2010.

To find the answer we need to look back to the point where natural refrigerant alternatives started their comeback. As described earlier, the revival of CO_2 started with Professor Lorentzen's work, and the first applications to be developed were automotive AC systems in the early 1990s. In the beginning of this new CO_2 era, components such as compressors, etc., were developed and adapted for the rather small cooling capacities required in the automotive systems.

The next stage in the development was when the commercial sector began to adapt systems for CO_2 at the end of the 1990s. Primarily, the compressors were challenging to adapt for larger cooling capacities, so the first supermarkets to be built had 10 to 20 compressors. The ice rink industry was still used to working with two compressors. Using a large number of compressors would therefore inevitably affect the cost of the system in a negative way.

For CO_2 to become a generally accepted system solution in the industrial sector, all components had to be adapted to allow for higher allowed pressures. Since the designs were new and the number of components manufactured were low, the price was often high. As the systems became more popular and the designs were further optimized, the price decreased.

The compressor is a vital component in the system as far as performance and cost are concerned. Therefore, it is relevant to illustrate the development in terms of the number of compressors required to maintain a single-sheet ice rink. In the first transcritical proposal from 2006,[12] 12 compressors were required to meet the 300 kW (85 tons) cooling capacity requirement. When the Marcel Dutil Arena was built in 2010 it used seven compressors that corresponded to 317 kW (90 tons) of cooling.

A recent CO_2 ice rink project in Sweden uses four compressors to meet the specified cooling capacity of 250 kW (71 tons). These figures show the rapid development of the CO_2 technology in terms of components in recent years.

The first ice rinks using CO_2 as secondary refrigerant in Europe[9,10] all used ¾ in. (19 mm) steel pipes in the floor. Three of the first seven installed systems during

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1999 and 2000 were "retrofits," which used existing pipe systems that previously carried ammonia. New systems with newly installed steel pipe systems were built as well, and between 1999 and 2004 about 23 ice sheets were built, where half of them were new and the rest were retrofitted. The challenge with the steel pipe design was the cost of installation, which indeed is the reason why the steel pipe design was abandoned in the 70s in favor of plastic pipes. To use CO_2, however, there is no choice since the system pressure of CO_2 requires metal pipes.

The copper tube concept with CO_2 as secondary refrigerant that was installed in the Swedish Backavallen ice rink proved to be a good technical solution, but it was still not enough to make a commercial success. The same concept was used in five to six new installations in Sweden, Norway, Japan and Finland during 2005 to 2010 that still used CO_2 as the secondary refrigerant and, in most cases, in combination with ammonia.

In the beginning of the 2000s, the so-called transcritical CO_2 systems gained popularity, and the first systems in commercial use were installed in 2003. With the introduction of the technology in the commercial sector, which had a significant cost focus, the cost of the system components decreased. Furthermore, it triggered the development of new and better adapted components that would allow for higher design pressures, make systems more practical and safer to handle and ultimately lead to more energy-efficient solutions.

The reason it took until 2010 before the ice rink industry accepted the second-generation systems is probably because there were no customers ready to take the risk and because of the somewhat higher cost for installing a transcritical CO_2 system. There was no demand for these systems, but as the technology gradually became more refined in supermarkets, primarily in Europe but also in Canada, the confidence in the technology grew. The cost of components, and eventually the systems, decreased, which opened the market for the second-generation CO_2 ice rink refrigeration systems. Today we experience a rapid growth in the number of CO_2 ice rink systems in Canada, the U.S. and Sweden.

References

1. Martin, T. 2004. "Evolution of ice rinks." *ASHRAE Journal* (11).
2. EPA. 2016. "Acceptable Substitutes in Industrial Process Refrigeration." U.S. Environmental Protection Agency. http://tinyurl.com/jgyyt9x.
3. Bodinus, W. 1999. "The rise and fall of carbon dioxide systems." *ASHRAE Journal* (4).
4. Lorentzen, G. 1994. "Revival of carbon dioxide as a refrigerant." *Int J Refrig* 17(5)292–301.
5. Sawalha, S. 2008. "Carbon Dioxide in Supermarket Refrigeration." Doctoral thesis, KTH Royal Institute of Technology.
6. Haaf, S. et al. 2005. "First CO_2 refrigeration system for medium- and low-temperature refrigeration at Swiss megastore." *KK Die Kälte und Klimatechnik* (2).
7. Madsen, K. 2010. "High Efficient Heat Reclaim with CO_2." Danfoss A/S. http://tinyurl.com/zmuzhw2.
8. Rogstam, J, et al. 2005. "Ice rink refrigeration system with CO_2 as secondary fluid." *IIR International Conference on Thermophysical Properties and Transfer Processes of Refrigerants.*
9. *Die Klima und Kältetechnik*. 1999. "Weltweit erste eislaufbahn mit CO_2 als kältetråger" ("The world's first ice rink with CO_2 as secondary refrigerant"). (4).
10. AXIMA. 2004. "Most Modern Ice Technology with CO_2 in the "Messestadion Dornbirn." www.aximaref.com.
11. Rogstam, J., M. Prakash. 2007. "Energy Analysis of Backavallen Ice Rink Refrigeration System with CO_2 as Heat transfer Liquid in Copper Tubes." Sveriges Energi & Kylcentrum.
12. Larsson, H-O. 2006. "Anbud Ishall Katrineholm—Kyla för ispist. Katrineholms Kommun." Anbud 50119 HOL Bilaga 2.
13. Simard, L. 2012. "Ice rink uses CO_2 system. *ASHRAE Journal* (3).
14. IIHF. 2002. *Ever Thought of Building an Ice Rink? Ice Rink Manual of the International Ice Hockey Federation*. International Ice Hockey Federation. http://tinyurl.com/hd3mlcj.
15. Kazutoshi, et al. 2007. System and method for creating rink ice and utilizing high temperature heat when creating rink ice. Canadian patent CA 2599769.
16. Heon, K., P. Guerra. 2015. "CO_2 showcase for ice rinks, pools." *ASHRAE Journal* (8). ■