INTERIOR VIEW OF THE RENOVATED GIMO ICE RINK.

Cooling and Heating Ice Rinks With CO_2

BY JÖRGEN ROGSTAM, MEMBER ASHRAE; SIMON BOLTEAU; CAJUS GRÖNQVIST

Ice rinks use a considerable amount of energy, and Sweden boasts more than 350 indoor rinks for ice hockey alone. An average Swedish ice rink uses about 1 million kWh of electricity and heat combined each year,[1] about 40% of which is from the refrigeration system. To reduce energy use, one municipality replaced its ice rink's old indirect refrigeration system with a direct 100% CO_2 system that is combined with a heat pump function. This article reviews the technology and how it reduced the ice rink's energy use by 50% to 60%.

Updated F-Gas Regulation Requires New Solutions

One reason to consider CO_2 as a refrigerant is updates to the European Union (EU) F-gas Regulation in 2015. To further control emissions from fluorinated greenhouse gases (F-gases), the EU updated the regulation in which refrigerants with high global warming potential (GWP) are to be gradually phased out and replaced by substances that fulfill the environmental requirements. A group of refrigerants highly affected by the F-gas Regulation are synthetic hydrofluorocarbons (HFCs), which have been very popular over the last decades. These refrigerants also have been used to some extent in ice rink refrigeration systems. This means many existing facilities will be facing renovations in the near future. New ice rinks should naturally apply the most energy-efficient technology available.

Using CO_2 Systems in Ice Rinks

Ammonia-based refrigeration systems that meet the GWP requirements are well documented. Lately, however, attention has also been directed toward the application of natural refrigerant CO_2 (R-744). As discussed by Rogstam,[2] CO_2-based technology is potentially well suited for ice rinks due to the combined refrigeration and heating demands of these facilities. The greatest source for lower energy consumption lies in the use of an optimized heat recovery system. CO_2 has very good properties in terms of heat recovery.

Figure 1 shows the share of used available heat on the x-axis at corresponding temperatures on the y-axis. The comparison is made at an ammonia (NH_3) condensing temperature of 35°C (95°F) and a CO_2 head pressure of 80 bar (1160 psi). The temperatures of each refrigerant are

Jörgen Rogstam is managing director, Simon Bolteau is project engineer, and Cajus Grönqvist is project engineer at EKA (Energi & Kylanalys) in Stockholm, Sweden.

at the compressor discharge level when starting from the left side, while getting cooled in the condenser/gas cooler as we move to the right. For example, when the refrigerant temperature is cooled to 35°C (95°F), only 19% of the available heat has been extracted in the ammonia (NH_3) case, whereas the corresponding figure for CO_2 is close to 60%, which implies that more heat is available at a higher temperature with CO_2. This advantage allows the CO_2 heat recovery system to cover all heating demands in a "normal" ice rink, reducing the cost of operation considerably, which coupled with lower service costs will yield long-term benefits for the owner.

CO_2 was previously used solely as the secondary refrigerant in ice rinks, but CO_2 today is also applied as the primary refrigerant. Systems using CO_2 as the primary refrigerant in this article are referred to as second-generation ice rink CO_2 systems. These systems can be applied in direct or indirect system solutions. "Direct" refers to if the CO_2 is used in the refrigeration loop as well as circulated in the rink floor. In "indirect" systems the refrigerant is only used in the machine room, together with a secondary refrigerant such as calcium chloride, glycol, or today (more commonly) ammonium hydroxide in Europe.

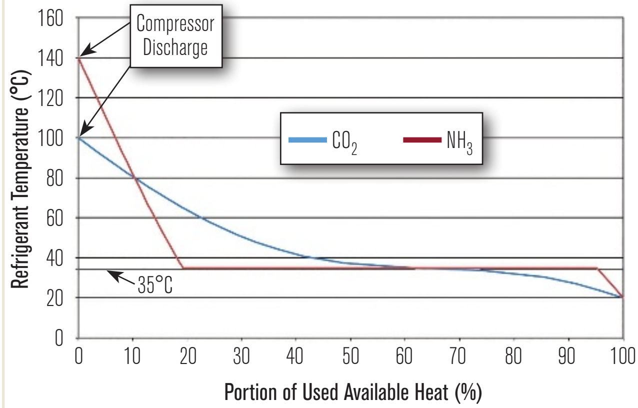
Until 2014 second-generation systems have been found especially in the Quebec province in Canada, where the results have been very good. Currently, there are around 30 CO_2-based refrigeration systems used in North American ice rinks, of which most are found in Canada and just a few in the U.S. Since 2014 the interest has grown in Europe as well, and today seven indoor ice rinks use CO_2.

This ice rink refrigeration technology has evolved from, and is basically the same as, the one used in grocery stores. CO_2 entered the market in the early 2000s, and its application has grown exponentially over recent years. This has positive effects on the ice rink market both from the technical and the financial perspective, as it guarantees the good availability of refrigeration packaged systems manufacturers, components, and service companies.

Heat Recovery System Makes Ice Rink Self-Sufficient

The 3500 m^2 (37,674 ft^2) Gimo ice rink in Östhammar, Sweden, which can hold 805 spectators, was renovated in 2014 after the roof partially collapsed during the winter of 2013. It was decided that the existing old indirect

FIGURE 1 Comparison of the heat available between CO_2 and NH_3.



refrigeration system (two 18.5 kW [two × 24.8 hp] pumps and calcium chloride, 25%) based on ammonia (two reciprocating compressors with a total motor power of 165 kW [221 hp]) should be replaced with a modern, energy-efficient solution. A holistic approach was taken, resulting in the choice of a direct CO_2 refrigeration system with full heat recovery. Its CO_2 charge is 2000 kg (4,400 lb) including distribution via copper tubes in the rink floor. The system has the latest CO_2-based technology, in which the ice rink refrigeration is combined with a heat pump function (*Figure 2*).

Furthermore, the system stores excess heat in geothermal storage to be used when the ambient temperature gets low or during the off-season. The ice rink used to depend on district heat and electricity for heat, but is now self-sufficient with the heat recovered from the refrigeration system; the heat recovery system is the sole heating source, with no backup needed.

The ice rink became the first of its kind in Europe, where the good results together with its growing reputation have sparked the concept "the ice rink of the future."

Lower Life-Cycle Cost With CO_2

An important factor in the choice of the CO_2-based technology was the decision to conduct the procurement process with a focus on life-cycle costs. The higher initial cost was still estimated to lead to a significant reduction in operating cost. The energy consumption was estimated to be cut by half, i.e., the ice rink would annually consume about 500,000 kWh less energy (electricity and heat) than before. Lower energy consumption, lower service cost, and an optimized heat recovery function led to a calculated life-cycle cost for the CO_2-based system solution that was considerably lower than modern competing alternatives. The municipality of Östhammar could, therefore, only see benefits in choosing a CO_2 system.

FIGURE 2 Overview of the refrigeration and heat recovery system in the Gimo 100% CO_2 ice rink.

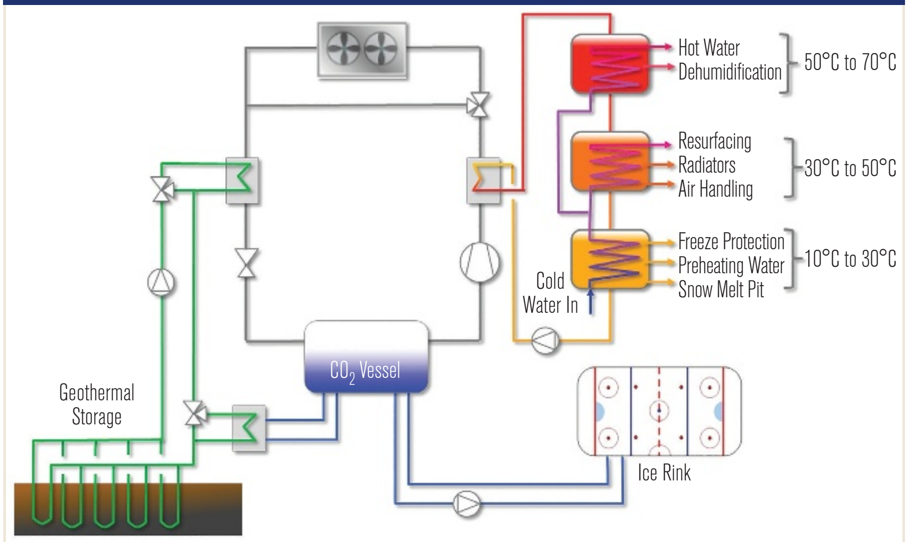


ILLUSTRATION BY EKA

Refrigeration System

The refrigeration system is a direct system, in which carbon dioxide functions both as the primary and secondary refrigerant. CO_2 has very good properties in terms of cooling distribution, and its ability to recover heat is much more effective than what is usually seen in today's ice rinks. The heat recovery system has been designed to embrace the properties of CO_2, maximizing the amount of heat that can be recovered from the refrigeration system.

The heart of the ice rink's energy system is the transcritical CO_2 refrigeration unit (*Photo 1*), with a designed cooling capacity of 250 kW (71 tons). Due to the unique properties of CO_2, this unit covers both the refrigeration and the heating function of the facility. The technology is well-proven, as it is the same type of refrigeration unit used in numerous grocery stores across Europe and North America.

The CO_2 refrigeration system loop may be described starting with the compressors marked with (A) in *Figure 3*. These evacuate the evaporated refrigerant from the accumulator tank and circulate it in the primary loop. The working pressure on the high-pressure side is typically above the critical pressure of CO_2, making the system transcritical. After the compressors, the refrigerant passes through a heat recovery heat exchanger (B).

The refrigerant is then cooled further using a gas cooler (C) and/or a subcooler connected to a geothermal heat storage (D). After expanding the refrigerant back into the accumulator tank (E), it can be passed through the ice rink tube system, which is the evaporator (F). There is an additional evaporator (G) connected to the geothermal storage as well, where additional heat can be provided to the system when the heat demand is high.

As mentioned above, the combined refrigeration and heat pump system is also connected to a geothermal storage, which provides further possibilities both during warm and cold weather. When it's warm, the storage can be used to improve the subcooling of the refrigeration process, resulting in higher energy efficiency of the system, by storing excess heat in the boreholes. The same heat can later be recovered during colder periods when there is an increased demand for heat.

PHOTO 1 The CO_2 pack providing 250 kW (71 tons) cooling capacity and the 2.5 m^3 (88.3 ft^3) CO_2 receiver.

PHOTO BY EKA

Distribution System Advantages

Using carbon dioxide as the secondary refrigerant in the distribution system has several advantages over traditional solutions, e.g., calcium chloride and glycol. Perhaps the most prominent ones are that CO_2 uses phase change (evaporation) and has a low viscosity, which leads to a considerably lower pumping power. Measurements done in traditional ice rinks indicate that about 20% to 25% of the refrigeration system's energy consumption stems from the auxiliary equipment, such as fans and pumps.

By applying CO_2 as the secondary refrigerant, pumping power can be reduced to about 1 kW (1.3 hp)

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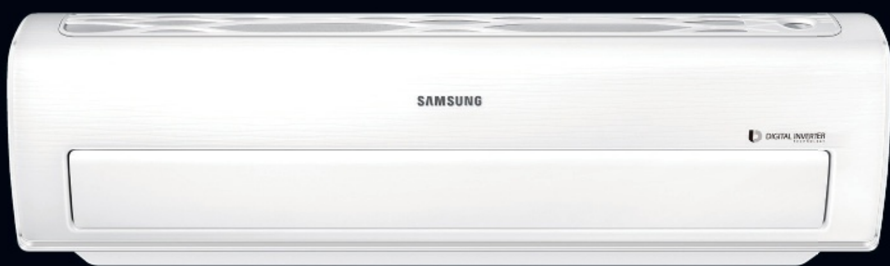

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compared with traditional fluids, which require 5 kW to 15 kW (6.7 hp to 20.1 hp). Thus, the energy consumption of the auxiliary equipment in the Gimo ice rink's refrigeration system becomes less than 3% of the grand total.

The pipes in the ice rink floor must be adapted to the properties of CO_2, as the substance has a much higher working pressure than other secondary refrigerants typically used. Welded steel pipes used to be the norm, but are now often substituted with more convenient copper tubes designed for ice pads. However, in renovations where the rink floor is left untouched, very good results can also be achieved by installing an indirect CO_2-system that uses, for instance, ammonium hydroxide as the secondary refrigerant in the existing plastic pipes.

FIGURE 3 Overview of the refrigeration system in the Gimo ice rink.

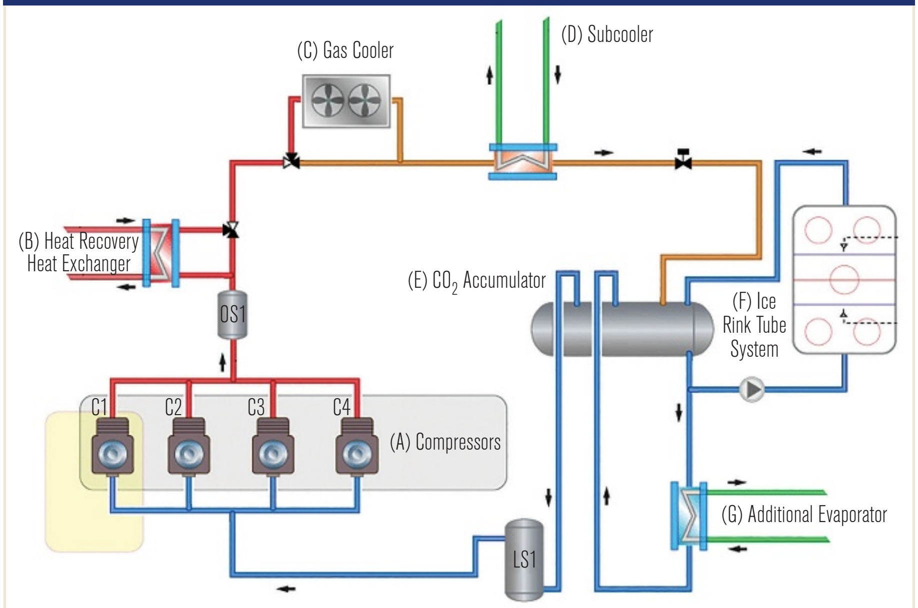

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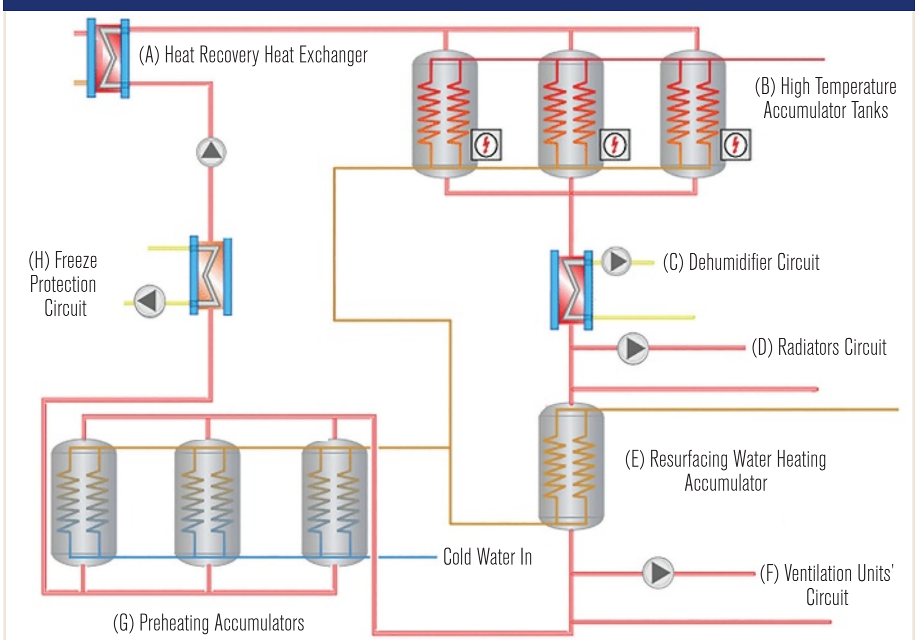
FIGURE 4 Heat recovery system.



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Optimized Heat Recovery System

The design of the new heat recovery system separates the Gimo ice rink from traditional facilities by following what is referred to as the "waterfall concept." The idea behind the concept is to extract heat to various heating systems in temperature steps, where the heating system with the highest temperature demand comes first and others with lower temperature demands follow. This concept should provide the lowest possible return temperature, which is beneficial from a heat recovery point of view.

The heating system connects to the refrigeration system through a heat exchanger marked as (A) in *Figure 4*. The primary circuit water first passes through high temperature accumulator tanks (B) where hot water is heated to about 60°C (140°F) and distributed throughout the facility for hot tap water and showers. The heat required for the dehumidifier is supplied using a heat-exchanger marked as (C), and the primary circuit water is then circulated as radiator water (D). In the following section (E), the resurfacing water is heated. The ventilation units, which normally require slightly lower temperatures than the upstream functions, are supplied from system (F). Further, the preheating of cold water takes place in the accumulators

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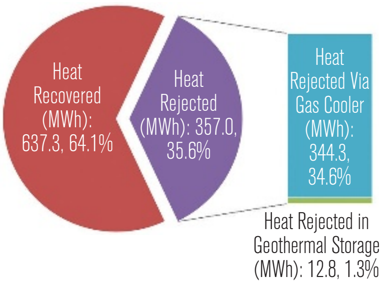
FIGURE 5 Monthly average heat distribution for the 2015 – 2016 season.

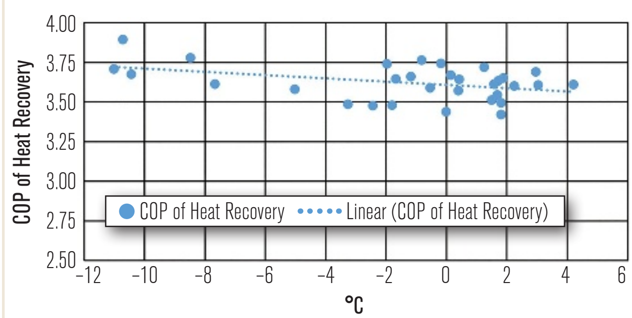


MWh	JUL 2015	AUG 2015	SEP 2015	OCT 2015	NOV 2015	DEC 2015	JAN 2016	FEB 2016	MAR 2016	TOTAL (MWH)	TOTAL (%)
TOTAL HEAT AVAILABLE	67.4	140.5	142.7	121.4	117.6	111.3	118.8	115.6	59.0	994.3	100%
HEAT RECOVERED	24.0	65.7	79.1	83.3	83.2	81.5	91.8	84.2	44.6	637.3	64%
HEAT REJECTED VIA GAS COOLER	43.3	74.7	63.5	37.6	33.5	29.0	24.0	27.7	11.0	344.3	35%
HEAT REJECTED IN GEOTHERMAL STORAGE	0.1	0.2	0.2	0.5	0.9	0.8	3.1	3.7	3.4	12.8	1%

(G) followed by the final step in which the fluid used for the subfloor freeze protection is heated by a heat-exchanger marked as (H). Finally, the water in the primary loop is returned to the initial position (A) at about 25°C (77°F).

The temperature profile is, therefore, tailored to the demands of the facility as well as to the properties of CO_2. The waterfall concept has the inherent advantage that it cools the primary loop to the lowest possible return temperature, resulting in an optimized heat recovery system for the ice rink.

FIGURE 6 COP of heat recovery vs. ambient temperature.



The optimized heat recovery system covers the entire heating demand of the ice rink, even during colder periods, without applying the geothermal storage, eliminating the need for any external heat source. In fact, the system has proven so efficient that it will be used to export heat to a nearby swimming pool facility.

The Control System

In terms of energy system interaction, not only is the physical integration important but also the control strategy and its implementation. The Gimo ice rink uses a programmable logic controller (PLC) control system, which functions as the brain of the facility. In addition to refrigeration, the PLC system also controls the functions of the heating, domestic hot water, dehumidification, geothermal storage, freeze protection, ventilation, and lighting systems. It is, therefore, possible to synchronize and/or prioritize the energy systems when necessary, which basically is a prerequisite for the optimized heat recovery process.

Results on the Electricity Bill

After the two first seasons, the results look very promising. Before the ice rink was upgraded, the energy consumption during an eight-month season was about 900,000 kWh (electricity and heat), which corresponds to about 3,700 kWh/24 hours. After the retrofit, the seasonal energy use has been less than 428,000 kWh, which corresponds to 1,750 kWh/24 hours. This is a 50% to 60% reduction, indicating that about 470,000 kWh energy is saved for an eight-month season. At the same time, by analyzing the refrigeration system during the season, the amount of available heat per month can be calculated.[3]

In *Figure 5* (Page 54) the available heat has been compiled with the recovered and rejected heat. The heat recovery system has recovered 637 MWh (2174×10^6 Btu) heat, which covers the total heating demand of the ice rink. This amount corresponds to about 70% of the total heat available, so there is a fair share that also can be exported. Due to a pump control failure, the geothermal storage was not used much during the second season, which explains the low percentage.

The available heat is relatively constant, an average of 110 MWh (375 × 10^6 Btu) per month throughout the year. The available heat is mainly dependent on the load in the ice rink in the sense that a higher cooling capacity results in a higher amount of heat available on the warm side of the system.

Performance of Heat Recovery

Tazi[3] analyzed the heat recovery function through the COP of heat recovery, COP_{HR}, which is defined as the ratio between the heat recovered, Q_{HR}, and the additional compressor power used to provide that heat, where the latter is the difference between the power used by the refrigeration system in heat recovery mode, E_{comp}, and floating condensing mode, E_{FC}.

$$COP_{HR} = \frac{Q_{HR}}{E_{comp} - E_{FC}}$$

Figure 6 shows the COP_{HR} for the heat recovery system in the Gimo ice rink. This calculated value, between 3.5 and 4, can be compared with any other heating system or heat pump for that matter that would provide heat to ice rinks.

Future Vision

The rapid development of CO_2-based refrigeration systems in supermarkets has allowed for an accelerated reduction of component and system costs. Today, the investment cost for CO_2-based technology is highly competitive when compared to traditional alternatives. There is also a considerable expansion of CO_2-trained service companies, which ensures the availability of skilled technicians offering the required service at a competitive price.

So far, the CO_2-based systems have been very well received in ice rinks, with Gimo serving as the prime example. The most relevant aspects regarding this specific ice rink are evaluated and documented by Rogstam and Bolteau[4] in an English-language public report financed by the Swedish Energy Agency. The results have propelled the interest to invest in CO_2 technology, both in new construction and as a replacement for obsolete systems. At the end of 2016, Sweden had six CO_2 second-generation systems in operation, and the forecast indicates another five to seven systems will be in operation by the end of 2017.

The opportunity to export heat from the simple, yet highly effective, heat recovery systems offered by CO_2 technology has made facility owners connect the ice rinks with nearby indoor swimming pools or other sport-related facilities, maximizing the benefits even further.

In conclusion, we might be witnessing a shift in how ice rinks are cooled and heated. The results already indicate that this most likely is the way forward. Systems based on a natural refrigerant with such competitive advantages are simply the way of the future.

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