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Field measurements of CO2 refrigeration systems with heat recovery in retrofitted ice rinks

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ABSTRACT

Ice rinks have a high coinciding cooling and heating demand which turns them into ideal heat recovery applications. By using carbon dioxide (CO_2) as a refrigerant in a trans-critical operation, required high temperatures (e.g. for dehumidification, space heating and hot water) can be supplied which in combination with a suitable heating system design can result in very high heat recovery performance. This study compares the measured energy performance and life-cycle cost of five ice rinks in Sweden recently retrofitted from conventional refrigeration systems (HFC and ammonia) to trans-critical carbon dioxide refrigeration systems with heat recovery. The field measurements show that the operational energy use can be cut down by as much as 55% which makes the investment profitable in comparison with the previous conventional systems. Furthermore, in some cases the ice rink also became self-sufficient on its own recovered heat, eliminating the need for an external heating system.

Keywords: CO_2, heat recovery, ice rink, measurement, performance indicators.

1. INTRODUCTION

Ice rinks consume a lot of energy. Statistics from Sweden show that a typical single ice sheet indoor rink with conventional technologies needs about 1 000 MWh purchased energy annually, with the refrigeration system, cooling capacity usually 250-350 kW, accounting for about 43% and space heating with hot water production for about 26%. Due to the regulations set by the EU for greenhouse gases as well as the age of several facilities, many ice rinks are today facing renovations which require sound decision-making to improve the overall performance. Meanwhile, energy monitoring and measurements carried out in ice rinks recently retrofitted with CO_2-based systems are providing actual data on the performance of this modern technology, which if further analyzed may help the decision-making process.

1.1. Technical introduction to ice rinks

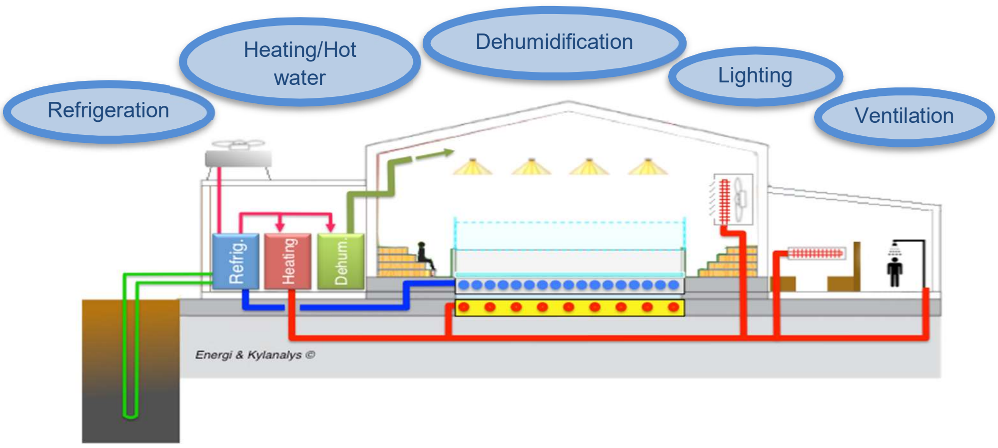


Figure 1. The general energy system layout of an ice rink with optimized heat recovery.

Ice rink operation is mainly focused on the following energy systems: refrigeration, heating, dehumidification, lighting and ventilation. These “big five” systems, seen in Figure 1, normally account for more than 90% of the energy used in an ice rink (Rogstam et al., 2014). The systems interact which can be an advantage when utilized correctly. E.g. space heating, air movement and lighting inside the arena room will cause a heat load on the ice sheet. In order to maintain the desired ice temperature, the refrigeration system must extract this heat load from the ice. The extracted heat together with added heat from compressor work is eventually rejected on the warm side of the refrigeration system, often for the most part to the ambience. Optimizing the heat recovery process, where the rejected heat is instead used to cover the heating demands of the facility, is by far the biggest energy savings measure that can be done in today’s conventional ice rinks. It has been shown that when an ice rink has a well-designed heat recovery system it may even be self-sufficient on its own heat. (Rogstam and Bolteau, 2015)

1.2. Why CO_2 seems to be well-suited for ice rink refrigeration systems

As mentioned before, the greatest source for lower energy consumption in an ice rink lies in the utilization of an optimized heat recovery system. CO_2 has very good properties in terms of heat recovery. Figure 2 shows the share of used available heat on the x-axis at corresponding temperatures on the y-axis. The temperatures of each refrigerant are 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 reaches 35°C, only 19% of the available heat is extracted in the NH_3-case whereas more than 60% of the heat is available above 35°C for the CO_2. This advantage allows the CO_2 heat recovery system to cover all heating demands in a “typical” ice rink, reducing the cost of operation considerably which coupled with competitive investment and service costs, due to the rapid development of CO_2-based refrigeration systems in supermarkets, will yield long-term benefits for the owner.

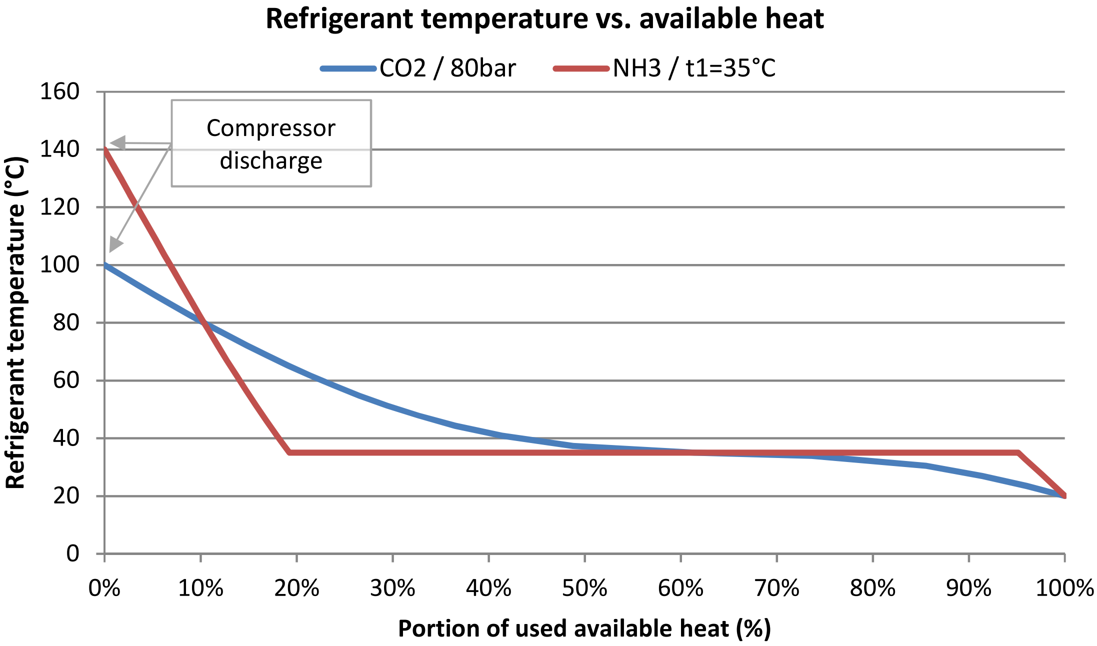


Figure 2. Comparison of the heat available between CO_2 and NH_3. (Rogstam et al., 2017)

Using CO_2 also as the secondary refrigerant in the distribution system brings several advantages over traditional solutions, e.g. calcium chloride and glycol. Perhaps the most prominent ones are that CO_2 utilizes 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 20-25 % of the refrigeration system 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 compared with traditional fluids which require 5-15 kW. Thus, the energy consumption of the auxiliary equipment in a CO_2 direct refrigeration system becomes less than 3 % of the grand total. However, in renovations where the rink floor is left untouched, very good results can also be achieved by installing an indirect CO_2-system which uses for instance aqua ammonia as the secondary refrigerant in the existing plastic pipes.

2. CASE STUDIES – ICE RINKS IN SWEDEN

2.1. Facility A

Facility A is an average size heated ice rink (arena room temperature 8°C) with one ice sheet, which used to be cooled down by having a calcium chloride circuit connected to an ammonia refrigeration unit. The heating demand was mainly covered by district heating. In 2014, a new 250 kW CO_2 system with direct expansion into copper pipes in the rink floor was installed. The one stage heat recovery supplies a constant 60°C forward temperature. In addition, a geothermal storage is used for subcooling or as an alternative heat source, meaning that the refrigeration unit can guarantee heating even during off season.

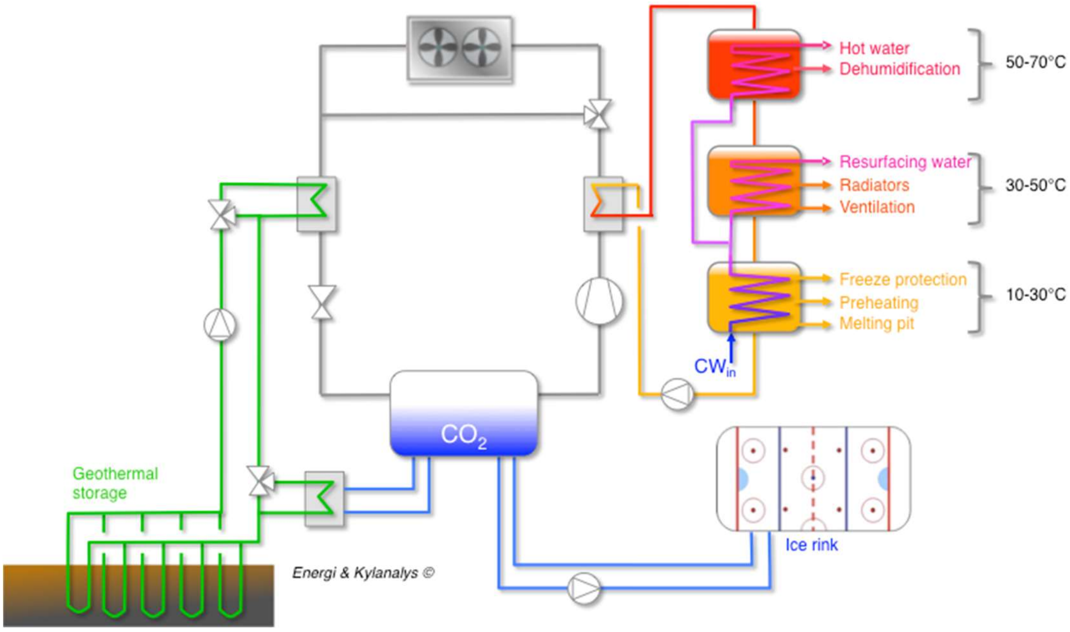
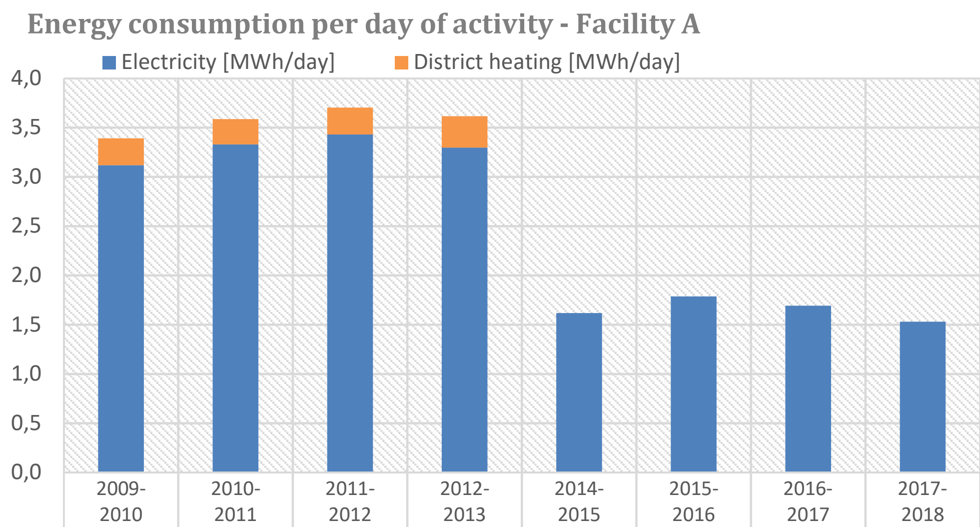


Figure 3. Overview of the system solution in Facility A.



	2009-2010	2010-2011	2011-2012	2012-2013	2014-2015	2015-2016	2016-2017	2017-2018
District heating [MWh/day]	0,27	0,26	0,27	0,32	0,00	0,00	0,00	0,00
Electricity [MWh/day]	3,12	3,33	3,43	3,30	1,62	1,79	1,69	1,53

Figure 4. Facility A energy consumption.

After the performed renovation the facility saved up to 55% on its energy consumption on the first year, from 3.62 to 1.62 MWh/day of activity. The ice rink reached its best performance during the 2017/2018 season, with a total use of 326 MWh electricity for a 7 month long period. Furthermore, the heat recovery system covers all the heating demands in the facility, making the ice rink selfsufficient on its own heat and eliminating the need for district heating. In fact there is excess heat still available, and the municipality has recently started to export 80-100 kW heat to the adjacent swimming hall.

2.2. Facility B

Facility B has two ice sheets (ice hockey and curling in separate buildings) and consists also of a sports hall. An R404a refrigeration system with calcium chloride running in the rink and curling floor pipes was used before to cover the cooling demand. The heating demand was mainly covered by district heating. In 2015 an indirect CO_2 refrigeration system replaced the old one. The existing secondary circuits were reused and retrofitted with aqua ammonia, reducing the pumping power demand. The new system provides a new complete one stage heat recovery function with a constant 60°C forward temperature. A new sorption dehumidifier benefits for instance from the recovered heat for reactivation.

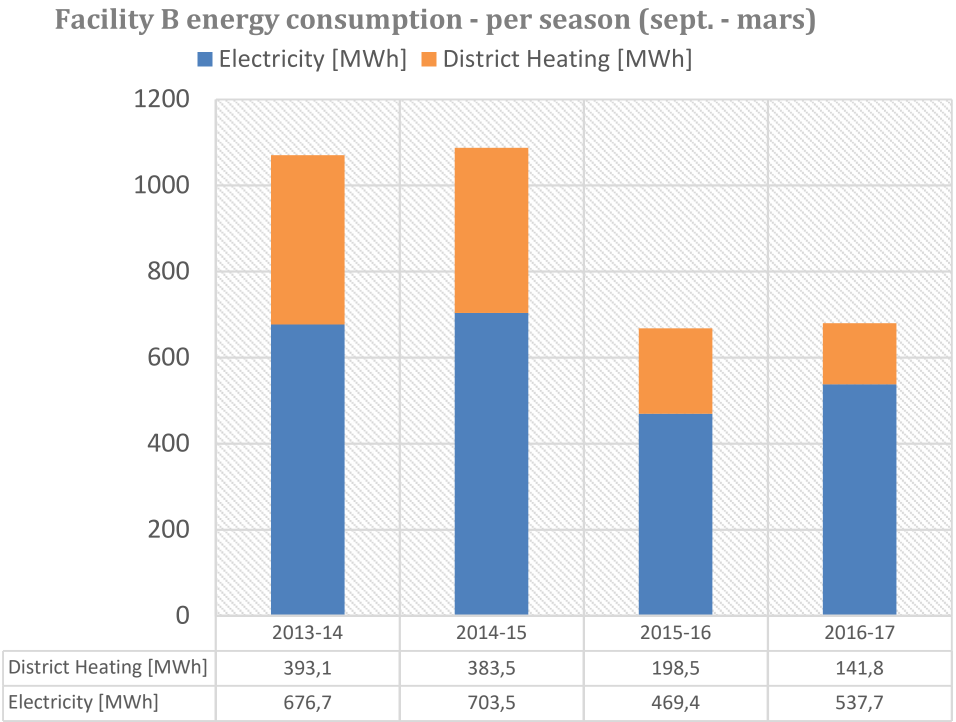
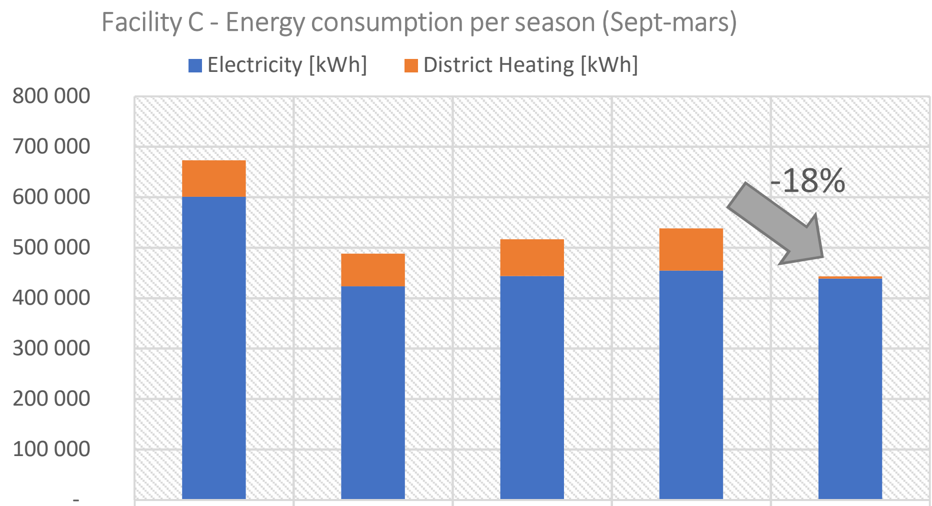


Figure 5. Facility B energy consumption.

Facility B has reduced its energy use by 39% after the refrigeration system renovation, from 5.1 to 3.1 MWh/day of activity, and Figure 5 shows the energy savings on a seasonal level. The control was improved even further for the season 2016-2017, leading to further reduction in district heating.

2.3. Facility C

Facility C is an average sized ice rink, which used to have an ammonia system covering the cooling demand in the heated arena (8°C). In 2014 the rink floor was replaced by a new one with new piping for the secondary refrigeration system, based on aqua ammonia. In 2017 the old ammonia compressors were replaced by a new CO_2 indirect system that was connected to the existing aqua ammonia circuit and equipped with a state of the art two stage heat recovery function that the new sorption dehumidifier can benefit for reactivation.

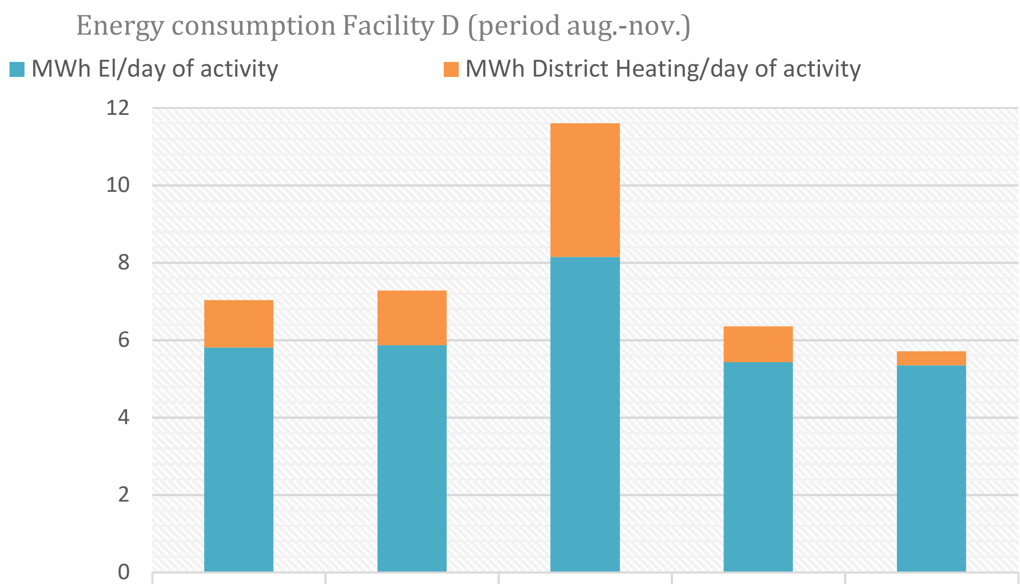


	2013-2014 Old ice rink	2014-2015 Old ice rink	2015-2016 Old ice rink	2016-2017 Old ice rink	2017-2018 New ice rink
District Heating [kWh]	72 672	64 516	72 922	84 014	4 444
Electricity [kWh]	600 470	423 031	443 205	453 925	438 380

Figure 6. Facility C energy consumption.

Facility C reduced its energy consumption by 18% with the refrigeration system renovation from 2.52 to 2.07 MWh/day of activity, eliminating the need for district heating – only a residual 4 MWh consumption was left which can be fully eliminated by further optimizing the control of the heat recovery function. This means that the two stage heat recovery function meets the heating demand. Furthermore, like in the case of Facility A, Facility C is considering exporting excess heat to a swimming hall that potentially may be built next to it.

2.4. Facility D



	2014-15	2015-16	2016-17	2017-18	2018-19
MWh District Heating/day of activity	1,2	1,4	3,5	0,9	0,4
MWh El/day of activity	5,8	5,9	8,1	5,4	5,3

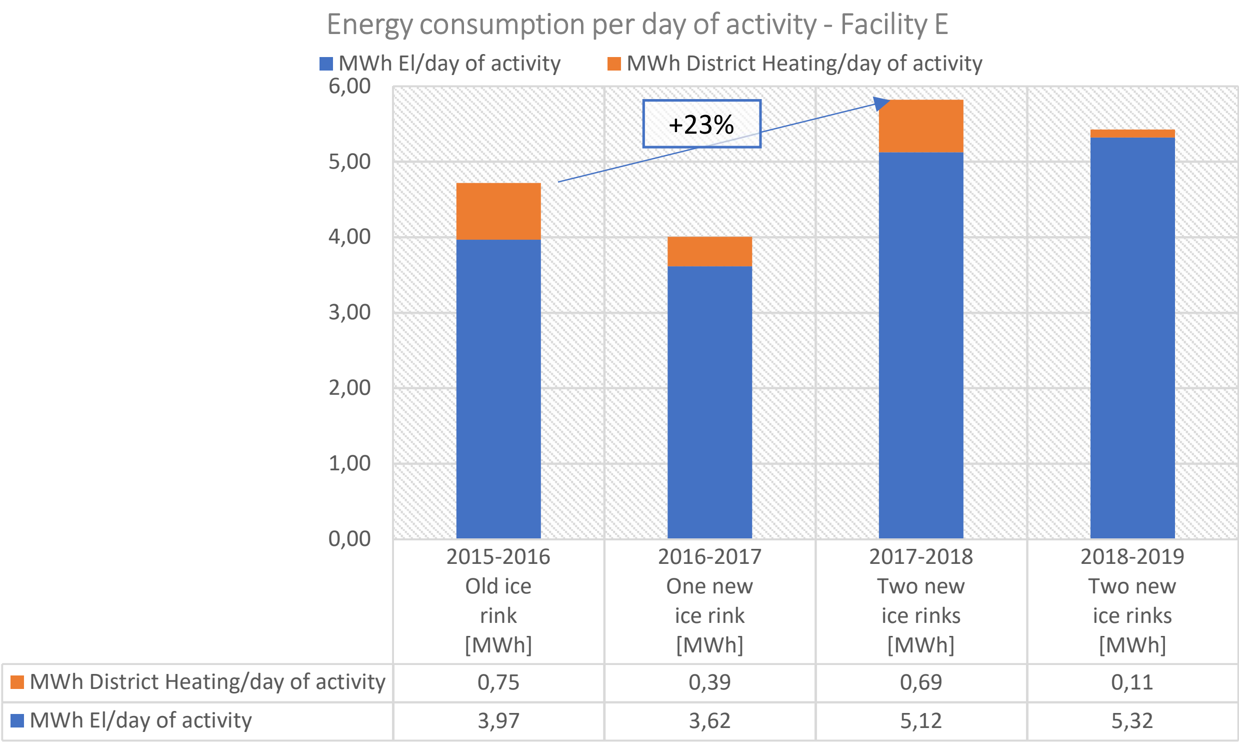
Figure 7. Facility D energy consumption.

Facility D has two ice sheets: one located in a 5800-spectator capacity arena (heated to 15°C) and the other one in a training hall. Before the renovation, the cooling demands were covered by an indirect ammonia refrigeration system providing its 600kW cooling capacity through a calcium chloride circuit. A heat recovery function also existed: a heat pump on the coolant circuit which covered a part of the heating demand. In 2017 a CO_2 indirect refrigeration unit replaced the ammonia one, and aqua ammonia replaced calcium chloride as the secondary refrigerant. The system is equipped with a two stage heat recovery function, from which e.g. a new sorption dehumidifier benefits by applying recovered heat.

During the season 2016-2017 the heat recovery function of the former refrigeration system was not in operation, which explains the energy consumption peak. The heating demand was during that season fully covered by the district heating. This allows for the calculation of the total heating demand that's covered by the new refrigeration unit's heat recovery function. Based on the most recent data, the two stage heat recovery function covers 88% of the heating demand in Facility D. If compared with a normal season of activity (2015-2016), the facility has reduced its energy consumption by 22% – from 7.3 to 5.7 MWh/day of activity.

2.5. Facility E

Facility E used to be a typical single sheet ice rink, with a heated arena room (around 8°C). An ammonia refrigeration unit was connected to a brine circuit in the rink floor. A heat recovery function provided up to 28°C for the preheating in the air handling unit. In 2016 a new CO_2 system was installed to replace ammonia, with direct expansion into new copper pipes that were laid in a layer of concrete above the existing rink floor. Furthermore, an additional ice sheet in a heated arena room (around 10°C) located in a brand-new building adjacent to the existing ice rink completes the facility in the 2017/2018 season. An optimized heat recovery system connected to the CO_2 system is designed to cover a large part of the heating demands in both ice rinks.



	2015-2016 Old ice rink [MWh]	2016-2017 One new ice rink [MWh]	2017-2018 Two new ice rinks [MWh]	2018-2019 Two new ice rinks [MWh]
MWh District Heating/day of activity	0,75	0,39	0,69	0,11
MWh El/day of activity	3,97	3,62	5,12	5,32

Figure 8. Facility E energy consumption.

When Facility E still had only one ice sheet in operation the energy savings could easily be noticed from season 2015-2016 to 2016-2017, where the new refrigeration unit and its heat recovery function had reduced the energy consumption by 15% - from 4.72 to 4.00 MWh/day of activity. At this moment the heat recovery function was not used at its full capacity yet. When the new ice sheet was connected to the unit for the season 2017-2018 the energy savings potential of the new system solution became more clearly visible. The CO_2 system is now able to run two ice sheets with an energy consumption that is only 23% higher than what the previous ammonia system needed when running one ice sheet. Moreover, season 2018-2019 looks even more promising since the controls have been improved, resulting in almost no district heating demand and only 15% higher consumption than the old system with only one ice sheet. Finally, plans are in the making to build a swimming hall in the vicinity of Facility E which opens up for the possibility of exporting excess heat from the heat recovery system.

2.6. Summary of all cases – Life-cycle cost analysis

The financial performances of the new CO_2-based system solutions were evaluated in order to give a broad understanding of their benefits for the ice rink owner, which in all the studied cases were municipalities in Sweden. This was done through a life-cycle cost (LCC) analysis, where the old system was compared with the new one in each case study. Furthermore, the calculations have gone through a sensitivity and scenario analysis in order to test the robustness of the results and see how changes in e.g. economic outlook would affect the financial performance of each system. The economic lifespan of the LCC analysis has been set to 20 years, which is a reasonable timescale for these kinds of applications. The results presented in Figure 9 mainly reflect a normal economic outlook, where the nominal interest rate is set as 1,5% per year and the discount rate used by the municipalities in their investment decision-making is 2,5%. Investment (material & installation) and operating cost input are based on real data gathered from each case study, while the service related inputs for the different system solutions are based on a mix of data gathered from the case ice rinks, reports, and experts in the field in order to produce service cost estimations that can be used in the LCC analysis.

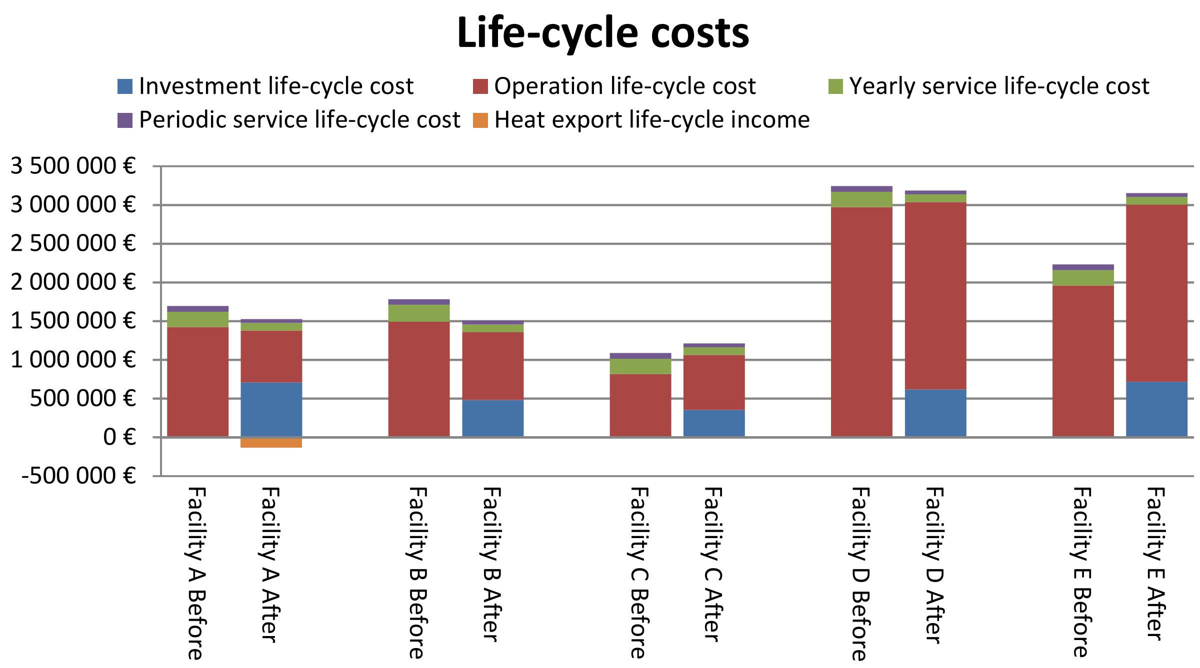


Figure 9. Life-cycle cost before/after analysis of all facilities.

From Figure 9 it can generally be concluded that the savings achieved in performance already at this stage are having a profitable effect on the investments in the studied facilities (it should be repeated here that Facility E increased in size from one to two ice rinks). The only facility not showing clear financial benefit yet is Facility C. The reason for this is most likely related to the combination of lower heating demands in the facility as well as a shorter ice season (7 months) in comparison with the other studied facilities (8-9 months). However, as mentioned before, Facility C is considering exporting excess heat to a swimming hall that potentially may be built next to it. This would turn the tables and make the new system profitable compared to the old solution. The generated “income” from exporting excess heat calculated in the case of Facility A is at this moment a highly conservative value, since it is based on data from the previous season when only halfway into it the export function was taken into use, with 90 MWh heat exported. It does, however, give an indication that the operational savings in ice rinks could be further maximized with a well utilized heat export strategy.

3. CONCLUSION

The aim of the study was to compare the measured energy performances and calculated life-cycle costs of five ice rinks in Sweden recently retrofitted from conventional refrigeration systems (HFC and ammonia) to trans-critical carbon dioxide refrigeration systems with optimized heat recovery. The field measurements of those five ice rinks in Sweden show that the operational energy use could be cut down by 18 to 55%. Furthermore, in some cases the ice rink also became self-sufficient on its own recovered heat, eliminating the need for an external heating system and opening up for the possibility to even export excess heat to a nearby facility.

As previously mentioned, the retrofits were also investigated in the form of a 20-year life-cycle cost analysis for each ice rink owner, where it was concluded that the savings gained in performance makes the investment in CO_2-based systems profitable in comparison with the previous conventional systems. The savings in performance could also be further maximized if coupled with a well utilized heat export strategy.

Finally, it should be commented that measured and gathered data from case studies like the ones presented in this paper play an important role in the development of estimation tools, where generated results regarding energy (Bolteau et al., 2018) and financial (Grönqvist and Rogstam, 2018) performance of modern refrigeration systems in ice rinks can be deemed reliable. This, as a result, should greatly aid the decision-making process in future ice rink renovation projects as well as in new construction projects.

NOMENCLATURE

CO_2	Carbon dioxide	NH_3	Ammonia
HFC	Hydrofluorocarbon	*LCC*	Life-cycle cost

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