Utilisation of Ice Rink Waste Heat by Aid of Heat Pumps

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Abstract. Ice rinks have a simultaneous cooling and heating demand to maintain the ice slab and providing the required heat to different needs in the ice rink facility. This provides a potential for utilising a heat recovery function, which is used in many ice rinks with traditional ammonia (R717) systems, however using carbon dioxide (R744) as a refrigerant in a trans-critical system can provide a fully self-sufficient ice rink in terms of heat. In R744 systems more heat is available at higher temperature levels, whereas in R717 systems the largest heat portion is present at condensing temperature level, which does not fulfill high temperature heating demand. In this study energy saving potential with heat recovery systems in ice rinks is evaluated. A system solution is developed, modelled and evaluated. One objective is to look at using R744 as refrigerant in ice rinks, however, focusing on the heat recovery aspect. In order to check the applicability, a R744 system with heat recovery is compared to traditional R717 refrigeration system with a propane (R290) heat pump. Data from an ice rink in operation is used to map the heating demand during season and to increase credibility. The results show that heat recovery performance in ice rink with R744 direct refrigeration system uses 47 MWh less energy than in indirect R717 systems with R290 heat pump, which constitute to 16%.

Keywords: Natural refrigerants, ice rink, R744, heat recovery, heat pump, heat export.

1 Introduction

1.1 Energy Usage in Ice Rinks

The number of ice rinks in Sweden is about 360 and grows in a rate of 5 to 10 new constructions per year [1]. At the moment, the average annual purchased energy of an ice rink in Sweden is about 1000 MWh/year, where typically about 80% is electricity and 20% is heat [2]. Currently, the total energy usage of indoor ice rinks, in Sweden, reaches a total of 300 GWh/year. Since indoor ice rinks are still increasing in numbers in the country, it is very important to practice a policy of sustainability and search for better energy efficient techniques, given that the amount of energy used to these facilities will continuously to increase.

Results from an investigation in 135 ice rink energy usage in Sweden suggest that the highest energy share is used in the refrigeration system, constituting to around 43%, while the heating system fill almost a third of the whole energy usage [2]. In practice the energy systems are interlinked through different driving forces, without an option of avoiding that completely. However, it is possible to minimize the negative effect by appropriate controls or even benefit from it, which requires a proper design. An obvious possibility is to reclaim waste heat from a refrigeration system to further utilize it for the rink space heating, hot water heating, etc. There are different solutions for partial heating demand coverage by reclaimed heat, while the best practice has proven the ability to cover the whole heating demand.

2 Natural Refrigerant Properties

The most important properties and aspects of the candidate refrigerants will be discussed since that is key to the refrigerant and system selection later on.

The use of natural refrigerants (carbon dioxide – CO2 (R744), hydrocarbons (HCs), and ammonia – NH3 (R717)) has increased significantly in the past years. This trend is predicted to continue in the future, as the impact from legislation such as the F-gas regulation in EU, has an increasing influence in the refrigerant choice. Natural refrigerants have no ozone depleting potential (ODP) and neglectable greenhouse warming potential (GWP). The indirect effect, which is the greenhouse gas emission due to power generation, may be reduced due to favorable thermodynamic properties of these fluids.

Ammonia is a widely used refrigerant, suitable mostly in commercial and industrial size applications, i.e., in relatively large refrigeration plants. Thermodynamically the heat of vaporization for ammonia is high and the heat transfer is favorable. On the negative side comes its toxicity and flammability. Well-designed safety measures are necessary and normally ammonia is not allowed to use inside closed spaces with people present such as supermarkets, ice rinks, etc.

Propane is a hydrocarbon that has similar thermodynamic characteristics to the synthetic R22 refrigerant, which is phased out. Because of flammability, charge minimization is a major design challenge when using propane. A study suggests that high evaporation temperature, up to 24°C, can be achieved in R290 cycle, which makes it suitable as sanitary hot water heating heat pump, for instance. [3]

Carbon dioxide is unique among natural refrigerants, because of its good safety characteristics – it is non-flammable, non-explosive, and relatively non-toxic, which makes it a beneficial in applications where relatively large refrigerant quantities are needed. Carbon dioxide is a refrigerant that has a relatively low critical temperature (31°C) and high working pressure. As the primary refrigerant it can operate in a transcritical mode, rejecting heat without undergoing a phase change and compared to other common refrigerants the heat recovery can be obtained at relatively high temperatures. [4]

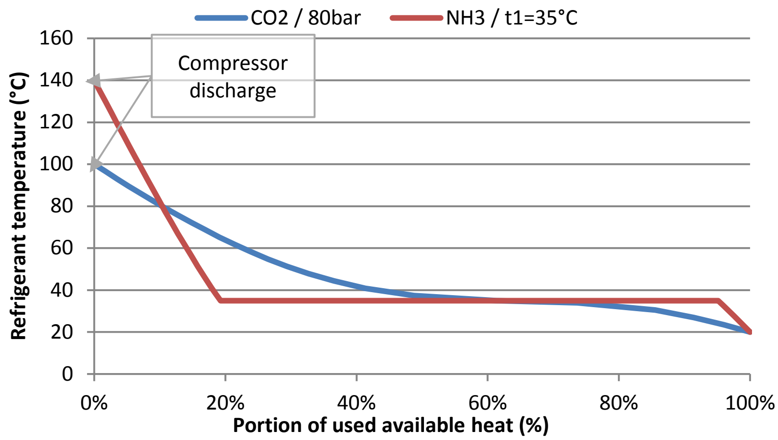

Fig. 1. Comparison between ammonia and carbon dioxide available heat in the temperature range [5]

Historically ammonia has been the most commonly used refrigerant in ice rinks. However, in the past carbon dioxide systems have proved to be an efficient choice, most importantly - due to the heat reclaim function. Both fluids can be compared from a heat recovery perspective using Figure 1, where the share of used available heat at a certain temperature level is plotted. The comparison is made at an NH3 condensing temperature of 35°C and CO2 head pressure of 80 bar. The relation shows that only 19% of heat for NH3 is above 35°C, while for CO2 the corresponding figure is around 60%. This benefit makes it possible to cover more of, or the whole, heating demand in a typical ice rink by using a CO2 heat recovery system. [5]

3 A CO2 Ice Rink –with a Full Heat Recovery Solution

To generate reference data as far as the heating demand is concerned, an ice rink in Sweden comprising a full direct CO2 system is used. It fits in a group with around a third of the national stock of ice rinks that are single sheet, mid-size with 500 to 1000 spectator seats, having a heated arena room (5-10°C). For that reason it can be regarded as typical and further in the text will be referred to as the reference ice rink. Each system/category is measured with “high quality type” (Carlo Gavazzi) energy meters, which are developed and manufactured in full compliance with the most important standard regulations. Measurements are logged in the IWMAC system. It is a permanent measurement/monitoring system, that allows us to analyse the data for the main energy systems as well as the temperature profiles. In this study, data for one season between late July and mid-March, is taken into consideration, to further compare it with the model for an ammonia indirect system, which is discussed more into detail further in this work.

3.1 Refrigeration System

A fully direct CO2 system has one working fluid circulating in the system. The latter consists of an accumulator tank, where the refrigerant is stored and separated, while a pump is used to circulate the fluid from the accumulator tank into the rink tube system.

Table 1. Refrigeration system energy usage in the reference ice rink

Refrigeration energy users [MWh]	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	TOTAL
Compressors	16.4	41.2	45.5	31.1	31.1	30.8	34.7	33.2	16.6	280.7
CO2-pump	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.2	4.0
Gas cooler	0.6	0.6	0.2	0.2	0.2	0.1	0.2	0.3	0.0	2.4
TOTAL	17.2	42.4	46.2	31.8	31.8	31.4	35.4	34.0	16.8	**287.0**

The resulting energy usage from Table 1 show that auxiliary refrigeration system equipment has very low relative consumption (CO2 pump – 0,8%; Gas cooler - 1,4%), which can be explained with the high volumetric heat of the fluid, low pressure losses due to the high density, as well as the advantages of the direct system solution. The working pressure on the high pressure side is normally above the critical pressure of CO2, making the system trans-critical.

3.2 Heat Recovery System

The reference ice rink has a heating system that solely utilizes recovered heat to cover the heating demand and the system principle layout is illustrated in figure below.

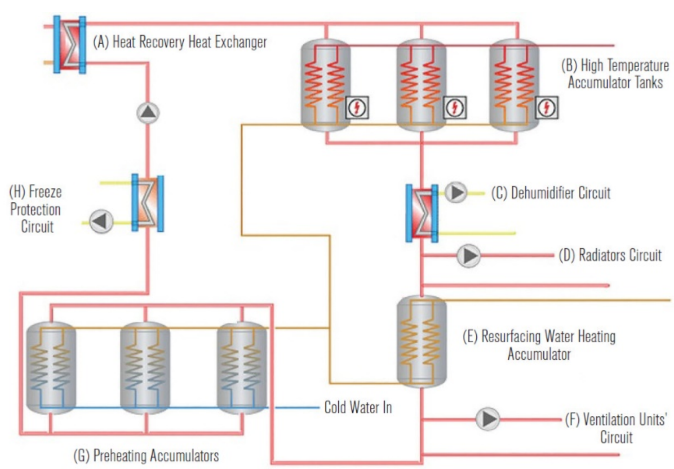

Fig. 2. Reference ice rink heating system principle [5]

In order to illustrate heating demand profile, it is plotted depending on the ambient temperature as shown in Figure 3, using data from the reference ice rink. The profile is slightly corrected, to disregard fluctuations from the reality. The highest heating need is the one for the arena room heat supply, distributed by the ventilation system and requiring a supply temperature of around 35°C. When the ambient temperature drops below 1 °C, the air heating demand becomes constant, which can be explained with insufficient air heating system capacity, resulting in decreased indoor temperature. Nevertheless, this is the real profile and the analysis should be based on reality.

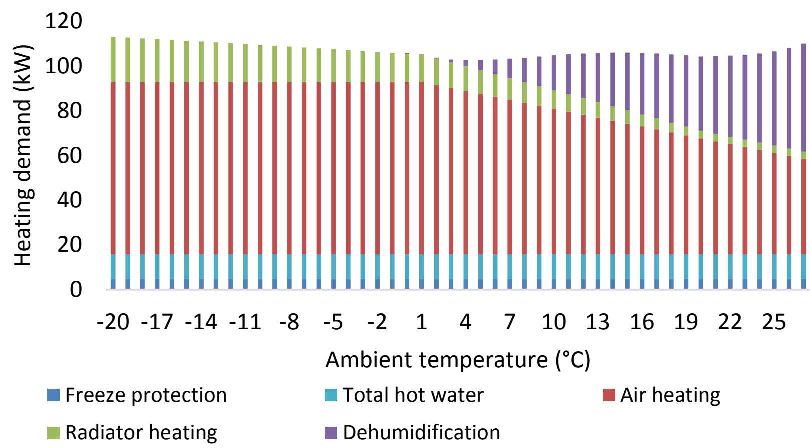

Fig. 3. Heating demand profile in the studied ice rink

The radiator heating demand is linearly depending on the ambient temperature and requires a supply temperature of around 55°C. The outdoor air, which affects the indoor air, becomes more moist with increasing ambient temperature, which results in higher dehumidification needs. In the studied ice rink a desiccant dehumidifier is used and recovered heat is utilized for the reactivation process. The supply temperature, same as for hot water heating is close to 60°C. The freeze protection heating demand as well as the water preheating are performed with a supply temperature below 35°C. Typically the return temperature to the heat recovery is around 25°C.

4 Evaluation of Heat Recovery Potential in an Ammonia Indirect System

Using heating and cooling profiles from the reference ice rink, a simulation model of ammonia indirect system is created with the aim to evaluate the potential of full heat demand coverage by connecting a heat pump to the refrigeration system's coolant loop.

There are many existing ice rinks with ammonia indirect system in Sweden as well as in the rest of the world. This case is of particular interest since many existing systems could be retrofitted with heat recovery systems. Although this is an environmentally friendly choice considering the direct impact of the substance, the waste heat is either partly or not at all utilized in a majority of the facilities. It is possible to recover heat directly from the condensing heat, however the temperature level is not necessarily high enough, depending on the heating system design.

4.1 Method of Evaluation

A software "Pack Calculation Pro" is used as the simulation tool for the refrigeration system and heat pump analysis. The software credibility was analysed in a previous study where the same CO2 ice rink, for the same period, has been compared to a CO2 trans-critical system model results, showing an accuracy within 10% [6]. In this case the system is comparable to the model although a different system solution. The output results are further processed and additional calculations are made in a spreadsheet application based on "Microsoft Excel".

4.2 Refrigeration System

A fully indirect NH3 system with brine as the secondary fluid is a chosen. As regards to the cooling profile, it is identical to reference ice rink, however, the evaporation temperature profile is deduced from a well monitored indirect NH3 ice rink system, resulting in lower temperatures than in the reference system for the same capacity, which is mainly due to temperature losses in the heat exchanger.

4.3 Heat Recovery by Aid of a Coolant Heat Pump

As can be seen in the Figure 4 below, the heat from the refrigeration process is first recovered through the desuperheater. The rest of the heat will pass through the condenser and via the coolant to the accumulator tank. This tank is necessary in practice as a buffer when heat rejection is not simultaneous with heating demand. The remaining heat is rejected to the ambient by means of the dry cooler. The heat pump extracts part of the available heat from the refrigeration system and boosts it to a higher temperature level, and ideally covering the heating demand.

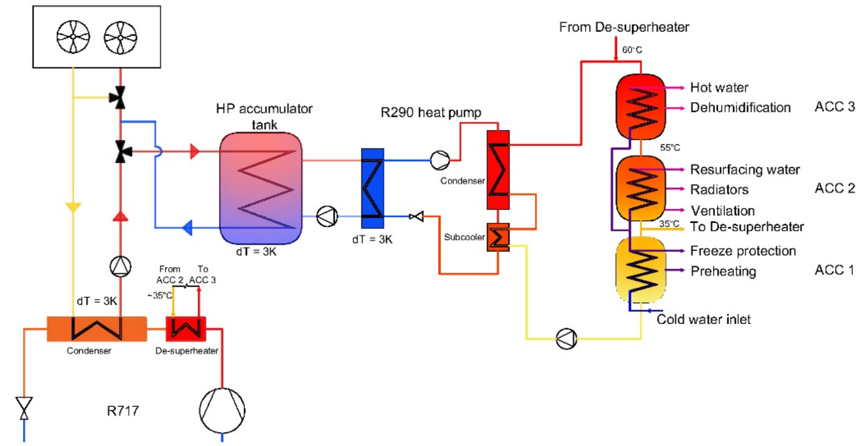

Fig. 4. Schematic for the model case

Temperature levels for the heating system are divided in to three ranges by aid of accumulator tanks, following the same principle as it is in the reference system. Several studies suggest that a propane cycle efficiency can be increased by implementation of subcooling, which coincides with the heating need of low temperature level and is set to 30K in the present model.

For the heat pump evaluation heating demand profile, input data is necessary, and it is deduced according to a relation between the ambient temperature and capacity from Figure 3. The resulting difference in total supplied heating energy between reference system and the model turn out to be only 3,3%.

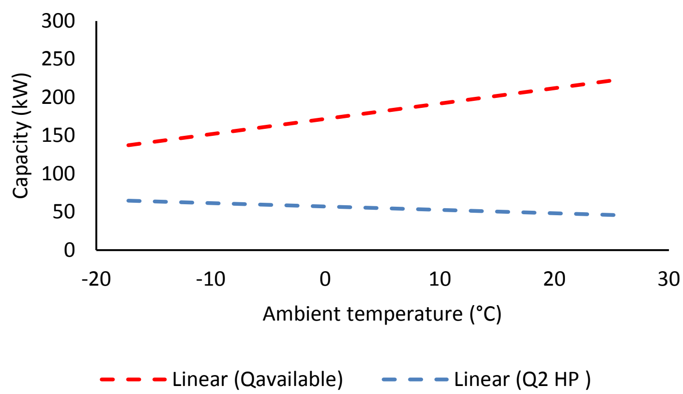

Fig. 5. Available heat from the refrigeration system and heat pump source demand capacity

To understand if the heat pump actually has enough source energy, Figure 5 is produced, revealing that there is a large portion of excess heat that has to be rejected to the ambient, even after the heat pump has extracted energy.

4.4 Global COP

To compare the CO2 direct system to an NH3 indirect system with R290 heat pump in terms of system performance efficiency, a Global COP is calculated.

For a CO2 direct system, the calculation includes sum of cooling and heat recovery capacities, and this is divided with the refrigeration system compressor and auxiliary equipment power:

$$COP_{Global\_CO2} = \frac{Q_{cooling}+Q_{HR}}{E_{comp}+E_{aux}} \quad (1)$$

In an NH3 indirect system - cooling, desuperheater heating and heat pump heating capacities are as the delivered values, while refrigeration and heat pump compressor and auxiliary equipment power is used as necessary input:

$$COP_{Global\_NH3} = \frac{Q_{cooling}+Q_{HR\_ref\_sys\_desup}+Q_{heating\_HP}}{E_{comp\_ref\_sys}+E_{aux\_ref\_sys}+E_{comp\_hp}+E_{aux\_hp}} \quad (2)$$

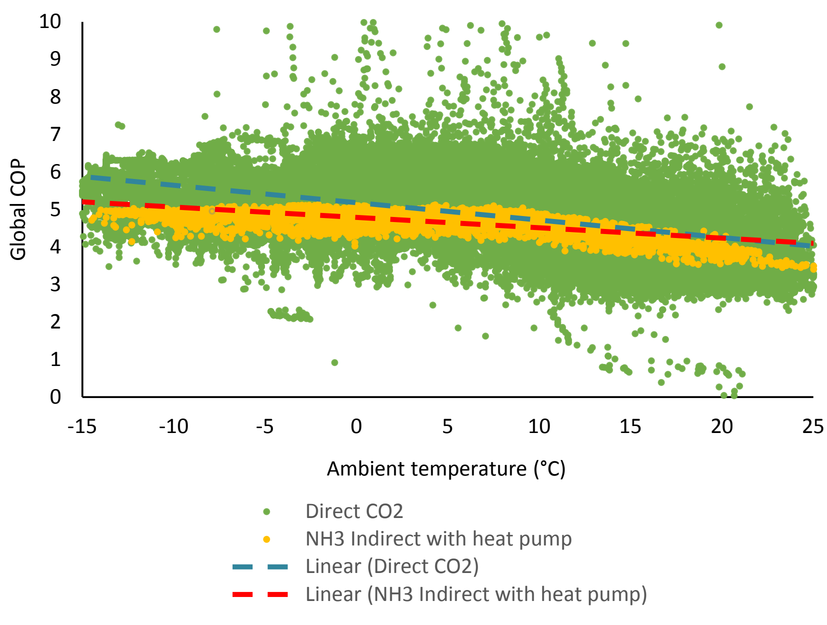

Fig. 6. Global COP depending on ambient temperature

In Figure 6 the results of the Global COP for both systems are compiled and plotted versus the ambient temperature. Both systems have the same trend - decrease in Global

COP with ambient temperature increase. The trendlines in high ambient temperature conditions are in the same level, whereas during low temperatures NH3 system is showing lower values. The explanation for this is that in the NH3 system condensing temperature is kept at minimum 19°C and below 9°C ambient temperature the COP2 of the refrigeration system becomes stable. The reason why the real data is more fluctuating is that the model assumptions are based on ideal conditions, while in practice the conditions are influenced by many external factors. However, the trendline represents the major data distribution, therefore attention should be concentrated to it.

4.5 Energy usage

The resulting energy usage for the whole season in both systems is shown in Figure 7, and it suggests that the NH3 indirect system model predicts a 47 MWh (16%) higher energy consumption than in the existing CO2 direct system. The reason, why the model results are divided into two parts is that these are separate systems, but providing both cooling and heating functions in the same amount of energy as it is in the reference ice rink using a single system – the CO2-system.

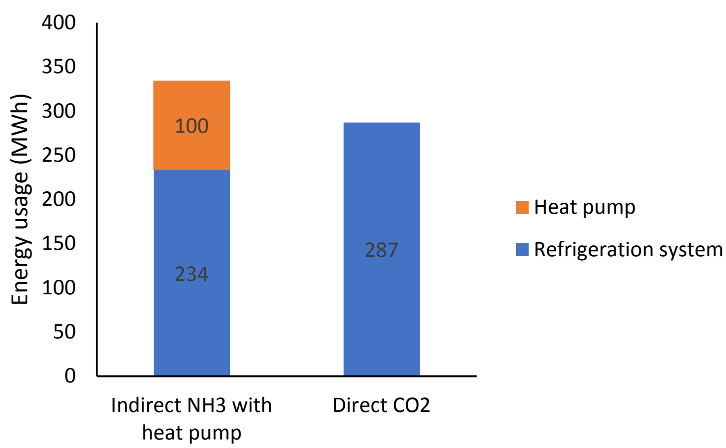

Fig. 7. The total energy consumption providing the same output functions and energy

5 Conclusions

- In this specific study results between simulation model of indirect NH3 system in junction with propane heat pump and data from existing ice rink with CO2 direct system suggest that the total energy usage for providing the same function and energy output would lead to 16% lower energy usage in favor to the CO2 system.
- The general conclusion is that indirect system with a heat pump is also less attractive in terms of more components, more complicated controls and serious safety measures needed due to use of NH3 and propane. On the contrary CO2 with one

refrigeration system works as a heat pump at the same time and has no hazardous effect on people's health.

- The specific study shows that NH3 indirect system with a heat pump has a Global COP between 4,1 and 5,3, while the direct CO2 system shows values in range between 4,0 and 6,0. These results show even better performance than many commercial heat pumps.
- Generally the modelled solution is most likely an attractive solution, when retrofitting an old NH3 refrigeration system with a heat recovery function.

5.1 Limitations and Future Work

The simulation model in this study is compared to an ice rink in operation with a different system solution. To increase the credibility of the results, a same system arrangement with same refrigerants should be compared to a model.

The auxiliary equipment energy consumption may be calculated using a more sophisticated analysis, which in this study is calculated manually using linear correlations from practice.

The minimum condensation temperature for the refrigeration system in the simulation model was set to 19°C. Different control strategy, i.e., lowering the heat pump evaporation temperature, thus allowing the refrigeration system to work with lower condensing temperature, might be more energy efficient solution. This possibility should be further evaluated in the future.

It should be also valuable to evaluate a heat pump with CO2 as refrigerant, as it has proved to be a good solution for sanitary hot water heating in several studies and practical experiences.

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