Energi &
Kylanalys

ICE RINK OF THE FUTURE

- evaluation of energy and system solutions -

(Framtidens ishall – utvärdering av nya energi- och systemlösningar)

15 November 2015

Rev II – 04FEB16

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Summary

Ice rinks consume large amounts of energy, with an average of around 1 000 000 kWh per year. Typically the refrigeration system is the main contributor using about 43% of the total energy. Today, nearly all ice rinks in Sweden use ammonia/brine systems, however, CO2-technology is near ideal in ice rink application due to the combined cooling and heating need. Reduced energy usage, mainly due to heat reclaim, will be the dominating saving factor for the ice rink owner.

The newly renovated ice rink in Gimo, Sweden, was taken into operation in September 2014 with a new energy management system based on transcritical CO2 refrigeration. In order to utilize the heat recovery potential of CO2 fully, the heat reclaim system was designed and adapted to fit the properties of CO_2. A further special feature of this CO_2 application is the geothermal connection which provides a “warm-” as well as a “cold climate” solution.

After the first season of operation the results look very promising. Before the system upgrade, the ice rink’s annual total energy usage was about 950 MWh, which corresponds to about 4 200 kWh/day. After the upgrade the energy usage is down to 1 630 kWh_{el}/day or in total 296 MWh_{el} during the first 6 months. If recalculated to a normal 8 months season it would be 395 MWh which translates to an energy saving of about 600 000 kWh a year, or corresponding to over 60 % energy cost reduction.

The interaction between the different energy systems has worked well where the key is not only a physical integration but also from a control perspective. All energy systems share the same control base which allows them to be synchronized and prioritized if necessary. Although the present winter season was warm the total recovered heat was 466 000 kWh in 6 months which recalculated to an 8 month season would be 621 000 kWh. Even during the coldest days with -15°C ambient temperature the facility manged to fulfil the heating requirements.

The Gimo LED-lighting system has an average light of 600 lux and a total installed power of 9.6 kW. The average monthly energy usage was 2000 to 2 500 kWh with a total of 13 000 kWh for the 6 month season. When comparing with the reference ice rinks on a seasonal basis the saving is about 55 000 kWh which corresponds to a 76% reduction.

The ice rink has a high electrical energy usage related to the ventilation systems. Due to old and poor performing fan-coils the main ventilation unit run at full power which increases the electrical energy demand. This category used over 90 000 kWh during 6 months which account for 30% of the total electricity used. A proposed measure is to replace the fan-coils which should reduce power consumption and lower the liquid return temperature to the heat recovery system. The potential saving is difficult to estimate but a reasonable estimation is an electrical energy reduce of about 50 000 kWh on an annual basis.

Due to the communication of these results from the Gimo ice rink, several projects in Sweden have decided to go for CO2 and we now see a rapid growth in the number of CO_2 ice rinks. It must be emphasised that the key in this concept is the heat recovery system and the integration of all energy systems – both physically and from a control perspective. This experience need to be carried over to other project where the best advice is to think holistic and try to optimise the ice rinks as whole rather than looking at each system individually.

Sammanfattning

Ishallar använder stora mängder energi, med en genomsnittlig energianvändning för en svensk ishall på cirka 1 000 000 kWh per år. Kylsystemet som oftast har en kyleffekt runt 250-350 kW är den största bidragaren med cirka 43% av den totala energianvändningen. I dag använder de flesta isbanor i Sverige ammoniak-kylsystem i kombination med någon köldbärare. CO2-tekniken är potentiellt väl lämpad för ishallar på grund av det kombinerade kyl- och värmebehovet. Den största potentialen till minskad energianvändning i ishallar generellt ligger i användningen av värmeåtervinningssystem. För CO2-tekniken kommer just värmeåtervinning att vara den dominerande faktorn till besparingen vilket tillsammans med lägre servicekostnader kommer gynna anläggningsägarna långsiktigt.

Den nyrenoverade ishallen i Gimo togs i drift i september 2014 med ett nytt energisystem vilket är baserat på CO2-teknik. Detta satte den nya och förbättrade ishallen på kartan som den första i Europa att använda ren CO2-teknik. För att utnyttja värmeåtervinningspotentialen hos CO2 fullt ut så utformades och anpassades värmeåtervinningssystemet för att matcha egenskaperna hos CO2. En ytterligare finess med just denna CO2-anläggning är att den har ett geolager anslutet vilket ger fördelar både i varma och kalla klimat.

Efter första säsongen ser resultaten mycket lovande ut. Innan systemen uppgraderades så var ishallens årliga totala energianvändning cirka 950 MWh, vilket motsvarar cirka 4 200 kWh/dygn. Efter uppgraderingen är energianvändningen nere på 1 630 kWh_{el}/dag eller totalt 296 MWh_{el} under de första 6 månadernas drift. Omräknat till en normal 8 månaders-säsong skulle detta ge 395 MWh_{el} vilket motsvarar en energibesparing på cirka 600 000 kWh per år, eller motsvarande en minskning av energikostnaderna på mer än 60 %.

När det gäller energisystemens samspel så har det generellt fungerat bra. Det viktiga är inte bara en fysisk integrering av dessa system utan också vad gäller styr- och regler av desamma. Alla energisystem delar samma styrsystem vilket gör det möjligt för dem att synkroniseras och/eller prioriteras vid behov.

För att ytterligare minska den totala energianvändningen så krävs en förbättrad styrstrategi för värmeåtervinningssystemet. Det har t ex visat sig att geolagret inte har använts så som förväntat. Styrsekvensen för återvinningsfunktionen inte är fullt utvecklad och högtryckreglering kan optimeras ytterligare. När denna strategi finns på plats, bör integreringen av värmepumpsfunktionen kunna förbättras. Yttre faktorer har också bidragit till att funktionen inte använts såsom att värmebehovet har täckts med värmen som kommer från ispisten, vilket i sin tur också berott på att vintersäsongen som utvärderas var mycket mild, vilket i sig minskat behovet av värme.

Anläggningen har en hög energianvändning kopplad till ventilationssystemen. På grund av gamla och dåligt presterande fläktluftvärmare så har huvudventilationsaggregatet körts på full effekt, vilket ökat el-energibehovet. Kategorin "diverse och ventilation” har stått för 30 % av den el som anläggningen använt vilket betyder över 90 000 kWh under 6 månader - detta lämnar utrymme för förbättringar! En rimlig åtgärd är att ersätta de två gamla fläktkonvektorerna i ishallsutrymmet vilket kommer att minska el-energianvändningen och sänka vätskereturtemperaturerna till värmeåtervinningssystemet. Besparingspotentialen är svår att uppskatta exakt eftersom det berör flera parametrar men en rimlig uppskattning är att det kan minska el-energiförbrukningen med cirka 50 000 kWh på årsbasis.

Foreword and acknowledgement

Thank you all - who contributed to this evaluation and report!

Firstly we would like to express our gratitude to the Swedish Energy Agency who believed in this idea of using CO2 in ice rink applications already back in 2004 when the first piece of puzzle was laid. Back then the CO2 rink floor design was developed which is still used – not only in Sweden but in Canada, Finland, Norway, Japan, Russia, etc.. These systems using CO2 as secondary refrigerant, we today refer to as generation 1.

In the present study we have evaluated a “Generation 2” CO2 ice rink system, which is based on 100% CO2. Sweden was unfortunately not the first country with such systems but our goal is to know them the best! The present study gives a good picture of the performance of CO2-systems and how you can benefit from integration of the other energy systems, which is possible due to the heat recovery characteristics of CO2 as a refrigerant.

To come back to other contributors in the project we want to mention the ice rink owner Östhammars kommun who allowed us to use the Gimo ice rink for these purposes. A number of companies have invested their time and resources in supporting the activity such as: Green & Cool, Industri- & Laboratoriekyl, IWMAC och Cupori.

Thank you!

Älvsjö, 2015-11-15

Jörgen Rogstam och Simon Bolteau

Energi &
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1 INTRODUCTION

1.1 BACKGROUND

1.1.1 ICE RINKS

Ice rink operation requires significant amounts of energy and a typical single sheet ice rink uses about 1000 MWh per year. Sweden has about 360 ice rinks and the growth rate is about 5-10 annually and the number of retrofits is estimated to be in the same range as the new production. A well designed modern ice rink should not use more than 500-600 MWh per year, consequently the potential energy saving by using best possible technology and design is therefore considerable.

Ice rink refrigeration systems based on carbon dioxide as refrigerant suits the ice rink application very well due to the favourable properties for heat recovery. Only a few ice rinks based on CO2-technology have been built and so far limited to Canada. There is, however, no or little public documentation available as to the actual function and energy efficiency of these CO2-systems.

The first CO2 ice rink outside Canada is now in operation in Sweden which makes it very interesting from a demonstration and evaluation point of view. This ice rink is unique – not only because of the CO2 system but also due to the integration of the energy systems – the "big five" (Refrigeration, Heating, Ventilation, Dehumidification and Lighting). To further utilise the advantages of the CO2 process a geothermal storage is connected to the refrigeration system enabling heat pump operation. This will provide the ice rink with external heat in the winter when the internal loads are insufficient, and enable sub-cooling of the CO2 process during warmer periods. Further, the geothermal storage will allow the refrigeration system to be used as heat pump during "off season" to provide hot water and space heating if necessary. To make the heat recovery as efficient as possible the heating system is designed to fit the characteristics of the CO2 heat rejection.

1.1.2 GIMO ICE RINK

In February 2013 the roof of the local Gimo ice rink in the community of Östhammar, Sweden collapsed. It left the community without one of its two ice rinks and the trouble to fit the popular ice hockey activity in to the remaining ice rink. In 2014, the building was restored; complete with a new roof and an innovative upgrade of the energy systems. The heart of the energy management being a transcritical CO2 unit putting the new and improved Gimo ice rink on the map as the first in Europe to use pure CO2 technology.

1.2 PROJECT SCOPE

The overall aim of this work is to evaluate the potential in using CO2 as refrigerant in ice rinks. Further the integration of the energy systems as well as their control should be covered. The different benefits of CO2 and the required design to optimise the efficiency should be identified. The work will be based on field measurements in the Gimo ice rink and combined with comparisons with reference ice rinks. The outcome should show the potential merits of the systems solutions and come up with proposals as to how to further improve the efficiency. This ice rinks installation will potentially be a "good example" for many projects to come!

1.3 PROJECT TARGETS

In essence the targets of the project may be summarised as follows:

- Literature study on the current methods, ideas, designs behind the construction/design of ice rinks with respect to choice of technology and design, etc.
- Evaluation of the Gimo CO2 ice rink using the existing instrumentation enabling monitoring the system parameters.
- Develop methods to calculate and analyse the cooling capacity, recovered heat and analysis of the respective energy system performances.
- Investigate the function of the respective energy system and their interaction.
- The CO2 system is of specific interest with its different subsystems and current design which should be compared with conventional technologies.
- The heat recovery system design, function and control should be analysed.
- The geothermal storage function, control and sizing should be evaluated.

2 TECHNICAL INTRODUCTION TO ICE RINKS

This chapter introduces the technologies normally found in ice rinks and the specifics of those. Typical designs and system solutions are introduced as well as the expected energy usage. This will serve as background when the specific of the Gimo ice rink is presented in the next chapter.

2.1 INTRODUCTION TO THE ICE RINK ENERGY SYSTEMS

In order to operate an ice rink there are five basic energy systems required:

- Refrigeration
- Heating
- Dehumidification
- Lighting
- Ventilation

The systems are often referred to as the "big five" because they normally account for more than 90% of the energy used in the ice rink. In the figure below these energy systems are schematically indicated in the ice rink.

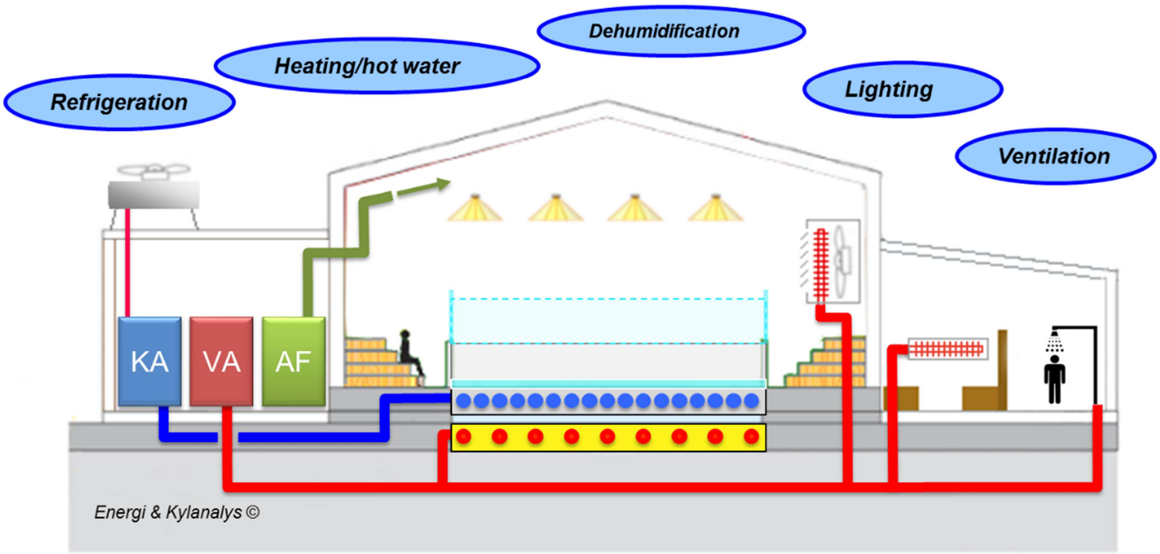


Figure 1 Indoor ice rink energy systems

These systems are present in essentially every ice rink – big or small – and as will be covered many times in this report. Further, these systems interact – regardless if you want it or not! By connecting those systems in a sensible way there are great energy savings to profit from. When looking at the picture above it is evident that the heat supplied in the ice rinks space will affect the ice. In fact an indoor ice rink space is nothing but a thermal short cut with 1800 m2 ice surface which cools the space. At the same time we want to provide thermal comfort for users and spectators by supplying heat by means of warm air, radiators or floor heating. The warmer the air the larger are the "short cut" losses which results in higher demand for cooling on the refrigeration system side. Lighting and dehumidification also affects indoor climate and the heat transfer to the ice which again takes to the conclusion that all systems interact. Interconnecting and controlling these systems together makes a whole lot of sense.

2.1.1 REFRIGERATION SYSTEM

The refrigeration system in ice rinks normally consists of a vapour compression cycle with ammonia as the refrigerant. Ammonia is a natural alternative but other refrigerants such as synthetic alternatives may be used as well i.e. R134a and R404A. CO2 as a refrigerant is relatively new in the business and is winning ground throughout the world but it is not as commonly used as the other refrigerants.

Ammonia is the most common refrigerant in ice rink refrigeration and is used in 85 percent of the Swedish ice rinks. The secondary refrigerant loop typically uses brine which is pumped through pipes in the rink floor by a pump. This configuration is referred to as an indirect system illustrated in Figure 2. The second type of refrigeration system used in ice rinks is referred to as a direct system where only one refrigerant is used. In this configuration the compressor pumps the refrigerant directly through the ice rink which acts as an evaporator eliminating the need for a pump.

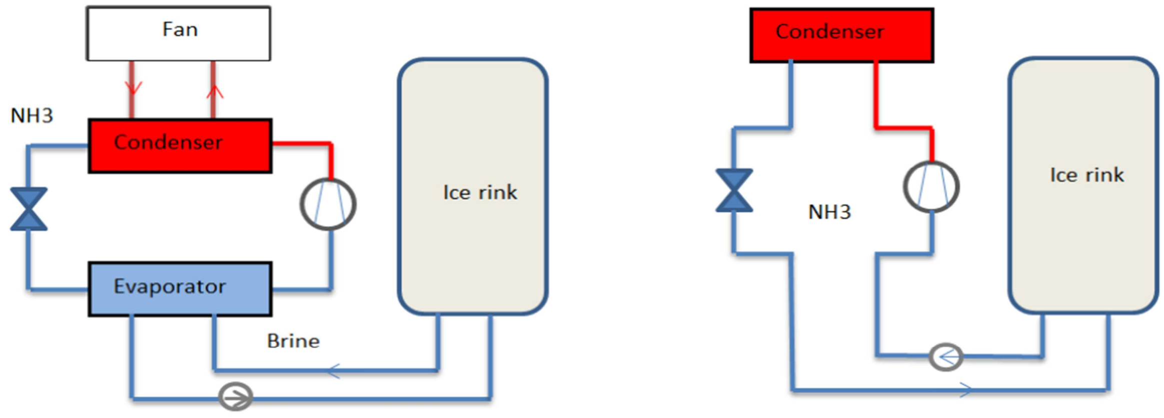


Figure 2 Direct (right) vs indirect system (left) with ice rink installation (Nguyen, 2012)

INDIRECT SYSTEMS

Approximately 97 % of ice rinks in Sweden use an indirect refrigeration system. The main reason for indirect system design being more common is the risk of ammonia leaking from the system. Due to its toxicity and flammability, ammonia in refrigeration systems has a volume charge limit. A way of solving this issue is making the ammonia cycle as small as possible and using a secondary refrigerant and less toxic refrigerant in a separate system with a heat exchanger connecting the two. The secondary refrigerant is normally an aqueous calcium chloride solution.

DIRECT SYSTEMS

In a direct system only one refrigerant is pumped through the whole system directly into the piping under the rink which acts as an evaporator. In a direct system a storage tank can be used to separate the liquid and gas phases of the refrigerant. Liquid refrigerant is pumped through the ice rink while gas refrigerant is sucked out of the top of the storage tank by compressors. Another purpose of the storage tank is to store liquid refrigerant which can be quickly pumped into the ice rink if the load increases, for example when a new ice sheet is being laid, decreasing the response time of the system.

2.1.2 HEATING SYSTEM

Ice rinks have different heating requirements. Space heating is required in order to keep the temperature in public areas and the main hall at a comfortable level. Public areas such as locker rooms and offices require a temperature of around 20°C while the rink space may be kept at essentially any temperature depending on type of arena and type of usage. Domestic hot water in the locker rooms and showers need to be heated to a temperature about 60°C in order to prevent the reproduction of legionella bacteria.

To summarise - an ice rinks uses considerable amounts of heat for its different heat needs such as:

- Space
    - Locker rooms
    - Ice rinks space
- Tap water
- Resurfacing (flood) water
- Etc.

Typically these needs are covered with different independent heating systems such as;

- Gas or oil
- District heating
- Electricity
- Wooden pellets
- Heat recovery
- Heat pumps (more rarely!)

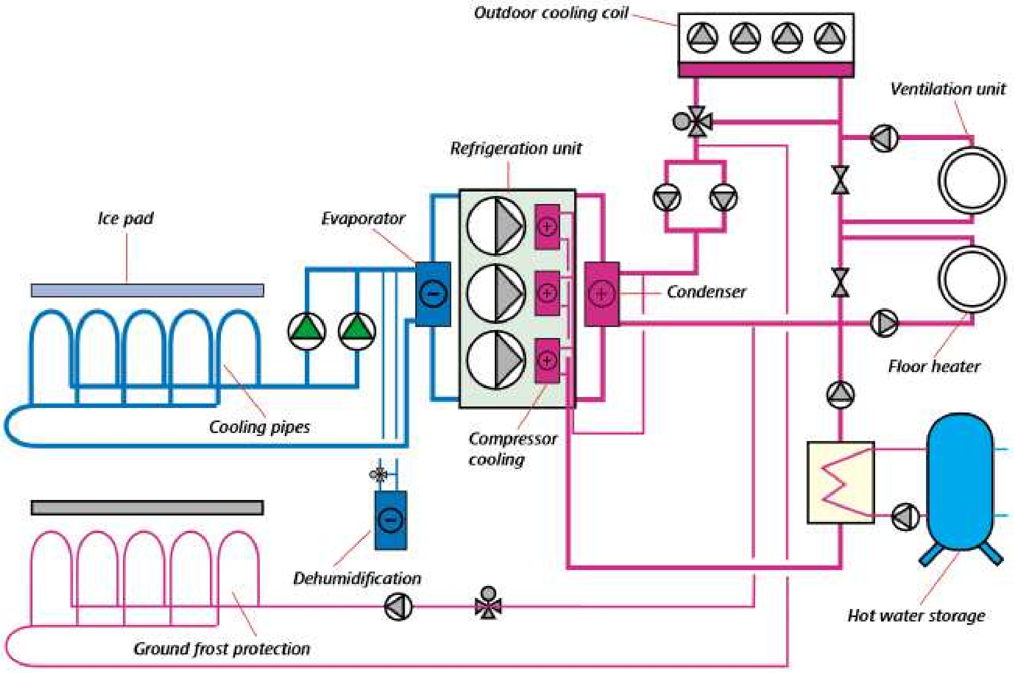


Figure 3 Refrigeration plant with heat recovery: preheating of hot water, floor heating and air heating (IIHF, 2010)

The refrigeration system of an ice rink produces excess heat during ice rink operation. It is therefore vital to address the waste heat utilization properly by implementing energy recovering measures. Instead of wasting excess heat into the outside air, which is a common solution, waste heat can be recovered and utilized within different areas of the building as the example indicates in Figure 3.

Recovered heat can be used to preheat space/ventilation air as well as for water service heating, sub floor heating (freeze protection), under-seat heating, water pre-heating and snow melting. Most arenas could probably save 50 percent or more of the annual heating demand by using a proper heat recovery system.

2.1.3 VENTILATION

The main purpose of the ventilation system is to heat and when needed provide fresh air. Often this function is integrated together with the dehumidifier. The ice rink is normally divided into different parts such as rink space, other public areas, locker rooms, etc.

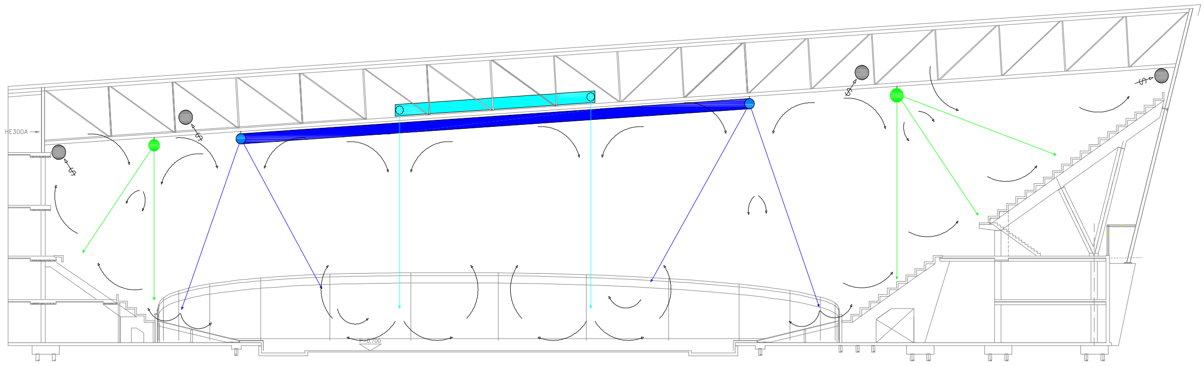


Figure 4 Air supplied to different zones in a larger ice arena.

Normally ice rinks have little or no need for fresh air ventilation since they are large building representing large air volumes it takes long before the air needs to be exchanged. Further, such large buildings typically have considerable air leaks which reduces the need for active ventilation. Generally, the CO2-level should be used to trigger potential fresh air ventilation to avoid bringing outside air into the ice rink. One of the most important reasons for avoiding fresh air is that it brings moisture with it which will increase the dehumidification need.

2.1.4 DEHUMIDIFICATION

Humidity control is an important factor to take account of in ice rinks. To acquire optimum conditions in an ice rink a dehumidifier is required, not only to achieve high ice quality but also to provide a good indoor climate for people as well as the building.

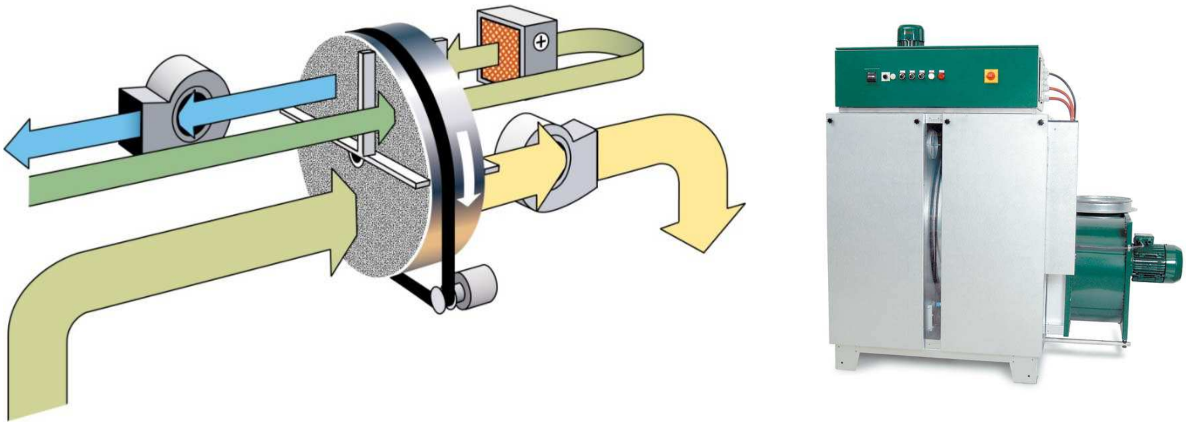


Figure 5 The working principle of a sorption type of dehumidifier (left) and unit (right).

As ice rinks have a large cold surface and condensation may occur if warm and humid air enters the building through doors and other openings. Condensation may form on cold surfaces if they are colder than the so called dew point. Such surfaces are obviously the ice but potentially also the ceiling due to the heat transfer with the ice. If the atmosphere in the ice rink space is too humid, corrosion and mould growth may occur which leads to an unpleasant indoor climate for the occupants.

Sorption type of dehumidifier system are the most common types in Swedish ice rinks and they are designed and controlled to maintain a constant relative humidity or dew point within the building. In Sweden these systems are normally reactivated by means of heat generated from electrical heaters. To produce heat from electricity is practical but necessarily the best way to use electricity – provided you have an alternative! In an ice rink there is plenty of waste heat that may be used for such purposes which will be covered later in the report.

There are other types of dehumidification methods such as refrigeration based which essentially is based on the condensation principle where a cold surface condensates the moisture in the air. These systems use either a separate refrigeration system or the cold secondary refrigerant from the ice rink. The disadvantage with this method is that the air can only be dried to a certain limit – typically to a dew point close to 0°C. For different reasons that will be covered later this may be the desired level in the ice rink bulk air. To provide this on average very large air flows through the dehumidifier will be required which are costly from a fan power energy point of view.

2.1.5 LIGHTING

Lighting typically accounts for around 10 percent of the total energy usage in an ice rink. The radiation from the lighting may contribute to the heat load of the ice as well. Most ice rinks use different types of light tubes such as T5/T8 HF. Other types like halogen and metal halogen still exist but less frequently. The trend is however direction LED which most likely will take over more and more of the ice rinks as the old equipment is being phased out.

Figure 6 Example of an ice rink with a light tube installation.

In figure below the lighting efficiency over time is presented. Halogen lighting have 4000 lighting hours compared to 9000 hours for metal halogen lighting, which is an increase of 125 percent. It is also clear in the figure that the modern types of T5/T8 are not only more efficient than the other two but also lasts much longer.

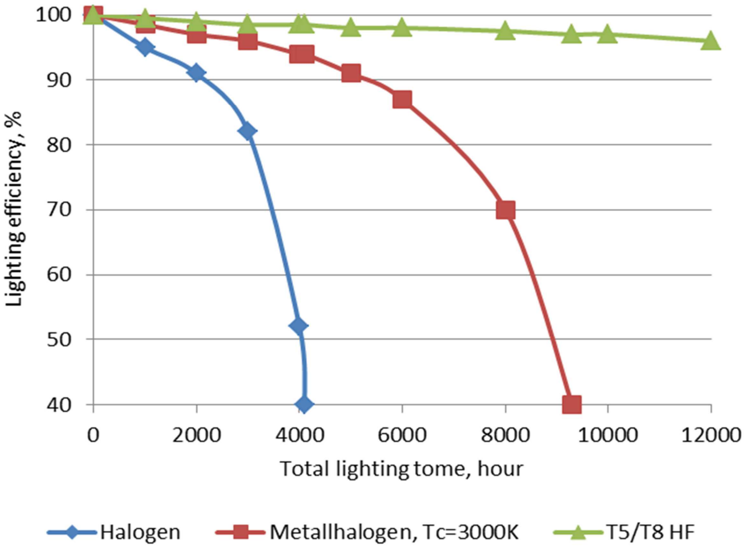


Figure 7 Efficiency of different lighting types during their lifespan.

2.2 HEAT LOADS

To maintain the ice quality it is key to keep the desired ice temperature which typically falls within the range -7 to -2 °C. Since the ice surface normally is the coldest area in the ice rink it will face heat transfer from warmer parts in the surrounding. Figure 8 below indicates the different components.

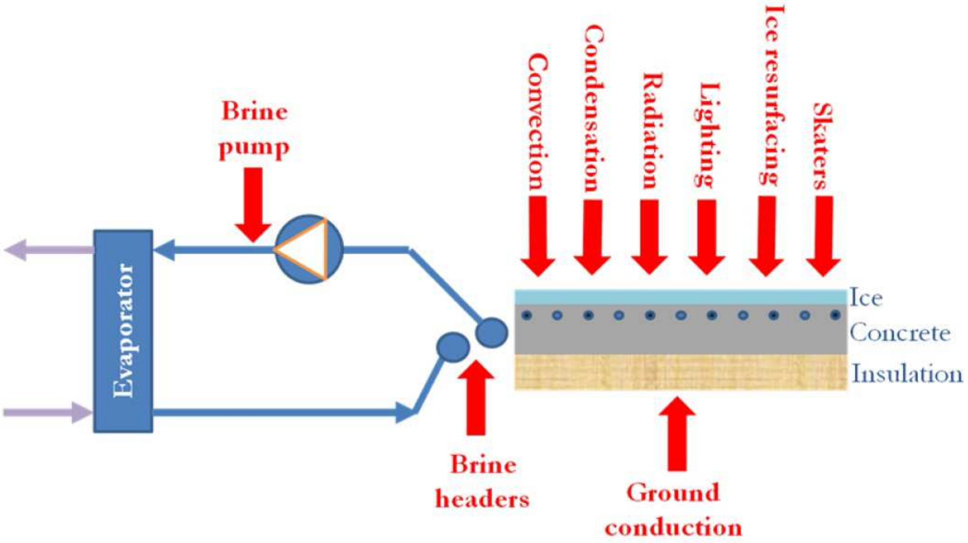


Figure 8 The different ice rink heat load components.

CONVECTIVE LOADS

The air in the ice rinks space will transfer heat to the ice rink since the air temperature is normally maintained in the range 5 to 10°C whereas the ice is about -4°C. High air flows will further increase the heat exchange between the air and the ice surface. In order to minimize this load the ventilation air flows should be reduced as long as the indoor air quality is not compromised.

CONDENSATION LOADS

Due to the moisture in the air diffusion/condensation will occur where the moisture is "attracted" by the cold ice surface. This results in a mass transfer from the moist air to the ice surface which forms frost on the ice. This process contributes with heat load but also deteriorate the quality of the ice. To limit this contribution a dehumidifier functions is important as previously described.

CONDUCTIVE LOADS

The ice rink will absorb heat from the ground and therefore proper insulation is important in order to reduce this load. Another load which falls in this category is the ice resurfacing which replaces the worn ice surface with warm water in order to provide a shiny surface.

RADIANT LOADS

The ice sheet absorbs radiation from the ceiling and walls due to the existing temperature difference. The effect of this mechanism can be reduced through the use of surface materials with low emissivity. Materials such as aluminium foil with a low emissivity coefficient are good alternatives. Other options are painting the ceiling with low emissivity paint or installing a second suspended ceiling acting as a passive additional barrier. The lighting of the rink space yields some additional radiation heat which can be reduced as using energy efficient lighting as possible.

2.3 ICE RINK FLOOR

The ice rink floor is a very important component in the ice rink since it is the base for the ice. From a construction point of view it needs to be in level and from a material perspective it must withstand the stress from low temperatures and high weight loads. In Europe most ice rinks have the measure 60x30 m whereas in North America the typical measure is 62x27 m.

An ice rink floor typically consists of a number of layers illustrated in Figure 9 where the top one is the ice sheet with a thickness of 25-30 mm. The second layer is usually made out of concrete although sand and asphalt may occur due to lower investment costs. In the top part of the concrete the cooling pipes are typically embedded which provides the heat transfer work as the load on the ice needs to be transferred to the refrigeration system. Under the concrete which is normally about 150 mm in total there is an insulation layer. The insulation is there to reduce the heat load from the ground. Below the insulation there is one more important function – the so called freeze protection or sub floor heating. Although the insulation is there with time the ground below the insulation may be cooled down to freezing temperatures which may result in frost heaving. If that occurs there is a risk of damaging the rink floor construction including pipe leakages and loss of surface level.

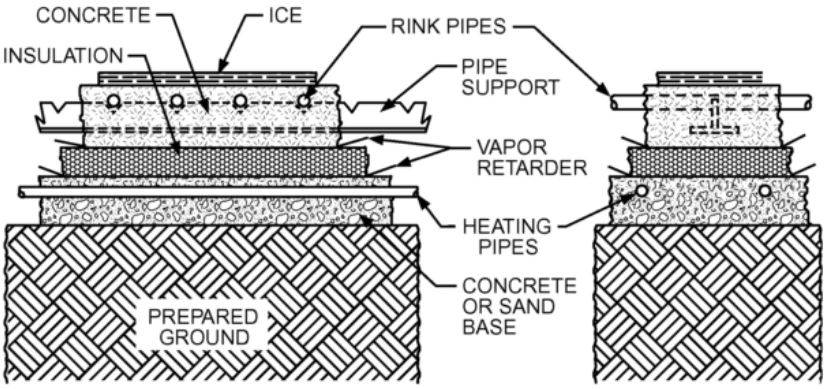


Figure 9 Typical layout of and ice rink floor.

There are mainly three types of materials used for the pipe in the ice rink floor through which the secondary refrigerant flows; plastic, steel and copper. Plastic is the conventional solution used with most aqueous based secondary refrigerants. In CO2 systems plastic pipes cannot be used due to the high working pressure of CO2 which during normal operation is typically in the range of 25 to 30 bar. Steel and copper pipes can handle higher working pressures and have higher thermal conductivity than plastic.

Table 1 Typical ice rink floor and pipe/tube dimensioning

Parameter	**Size**
Ice Thickness	25-30 mm
Concrete thickness	150 mm
Insulation thickness	100 mm
Brine headers diameter	150-200 mm
Brine distribution pipes diameter	25-32 mm
Pipe spacing	75-125 mm (100 mm typically)
Top pipe – bottom ice distance	25-20 mm

Although material costs are higher for copper tubes compared to steel pipes, the installation cost of copper tubes is lower since they can be bought at long lengths and rolled out on site. Steel pipes on the other hand are delivered at fixed lengths and welded together. In an experimental study done at the Royal Institute of Technology in 2006 12.7mm copper pipes with plastic casing show similar heat transfer performance as 21.3 mm steel pipes while plastic pipes at 25 mm are significantly worse. The study concludes that 120 m copper pipes with 12.7 mm diameter and plastic casing are recommended for use with CO2 in ice rinks with regards to heat transfer and pressure loss (Khuram, 2006).

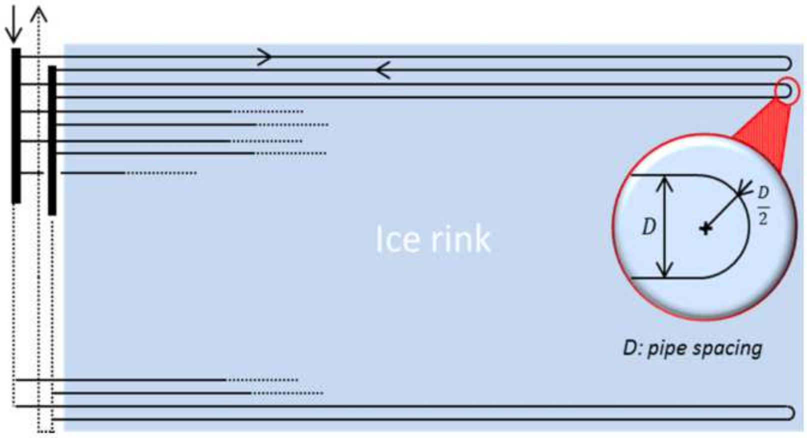


Figure 10 Typical piping layout with headers on the short end side.

The piping layout is normally arranged like indicated above where the feed (forward) and return headers are placed on the short end side. In the rink floor there is normally a two-pass arrangement where the secondary refrigerant is passed to end of the floor and then returned. To allow for effective capacity control of the distribution pumps it is favourable to arrange a so called revered return arrangement on the header side. This is also often referred to as a Tichelmann connection.

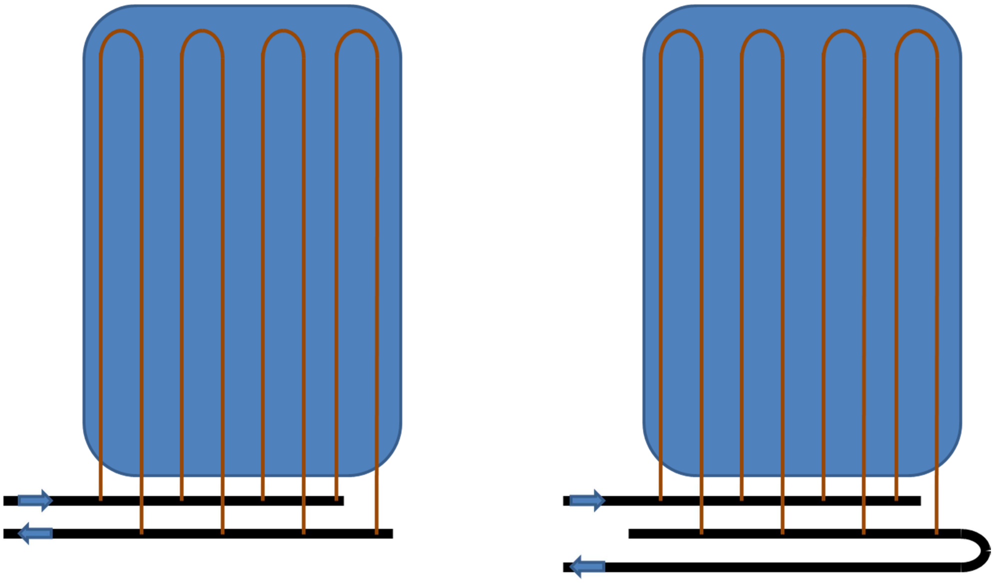


Figure 11 Two different header arrangements; conventional (left) and reversed return (right).

The advantage of the reversed return being that since it is “hydraulically balanced” it will provide an even flow distribution regardless of the total flow. On the contrary a conventional system which normally uses restrictions to control the distribution which increases the pressure drop and it cannot be capacity controlled within a large flow range.

2.4 ENERGY USAGE IN ICE RINKS

Through the Swedish project Stoppsladd, where an inventory of the energy usage in Swedish ice rinks was made, it was concluded that ice rinks use an average of about 1000 MWh of energy per year, which translates to about 4500 kWh/day of operation. In the figure below the daily average purchased energy for about 135 ice rinks is showed. The average purchased energy is not flattering in a national perspective and it was concluded that most ice rinks can save 20-40% of energy with no or little investments. One of the most obvious measures to save energy is training and information which would give the ice rink staff the tools to probably reduce 10-20% with no investment.

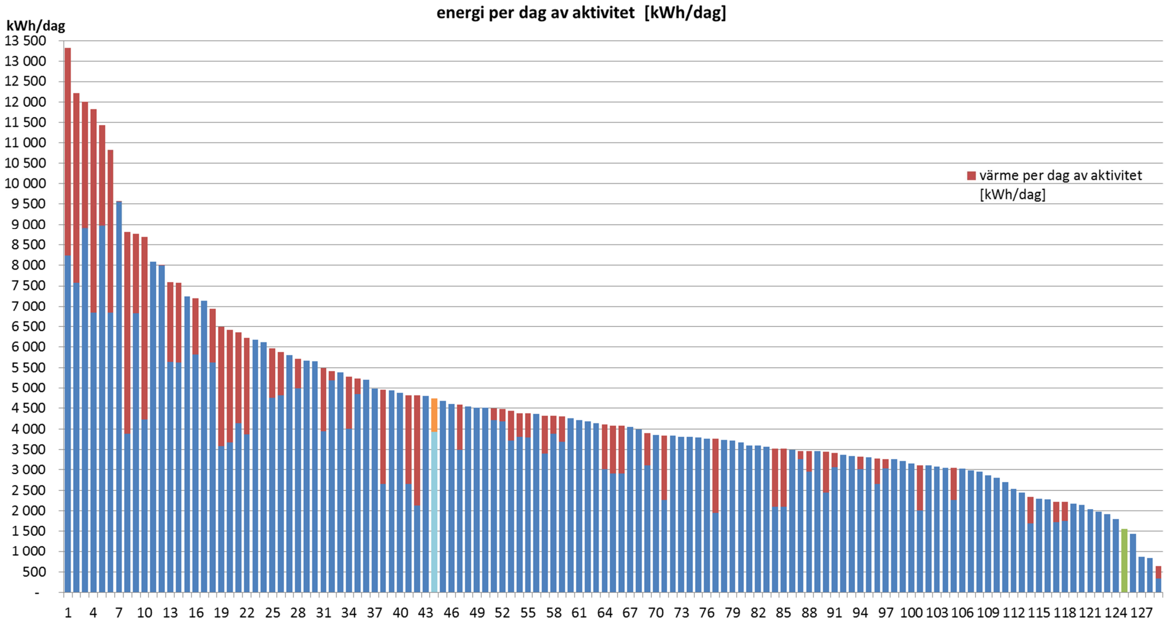


Figure 12 Purchased energy in 135 Swedish ice rinks according to the "Stoppsladd" project.

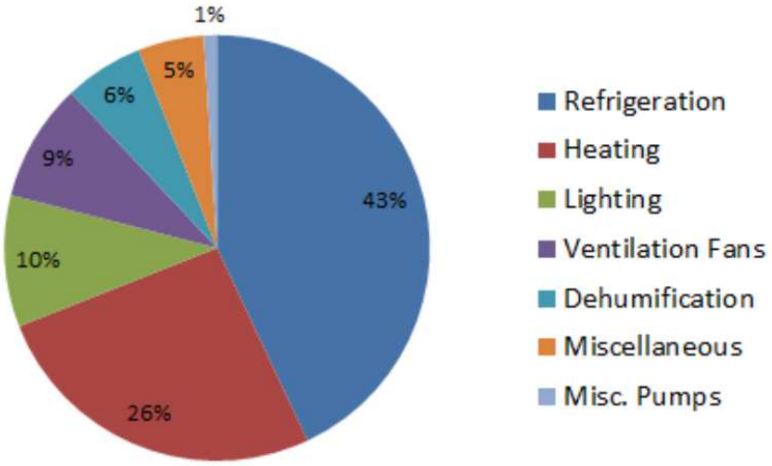


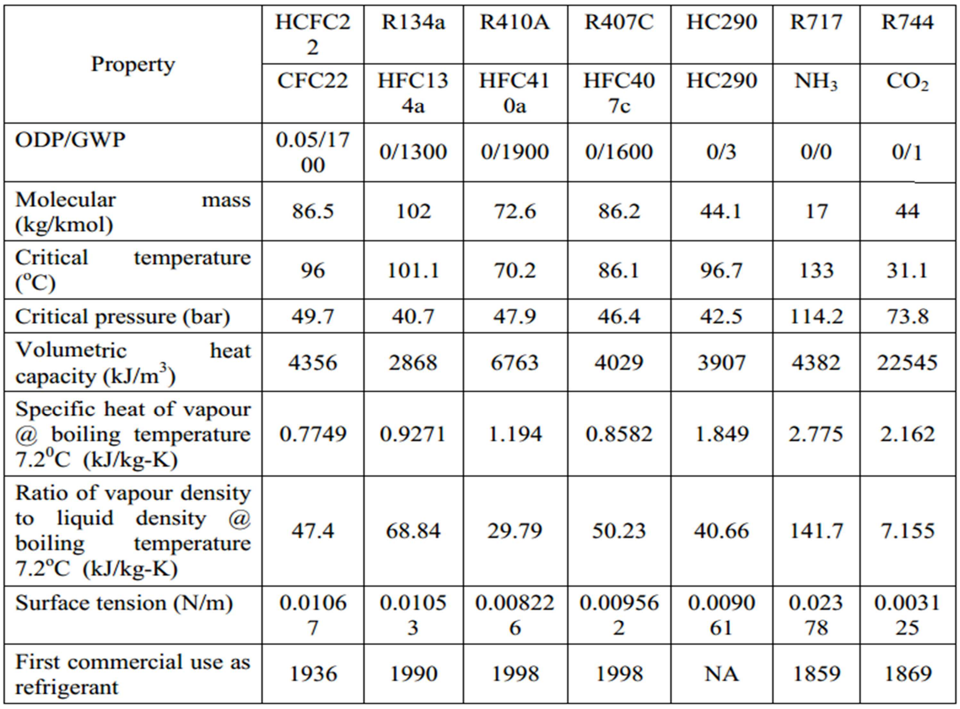
Figure 13 Distribution of used energy in Swedish ice rinks.

As the figure above indicates a conventional ice rink uses most of the energy for refrigeration and heating. The refrigeration accounts for approximately 43 percent and heating demand for 26 percent.

2.5 REFRIGERANTS

As previously stated the most commonly used refrigerant in ice rinks is ammonia. There are, however, a number of alternatives which could be used but for different technical and environmental reasons they are of less interest.

Table 2 Physical properties of different refrigerants.



Property	HCFC22	R134a	R410A	R407C	HC290	R717	R744
	CFC22	HFC134a	HFC410a	HFC407c	HC290	NH_3	CO_2
ODP/GWP	0.05/1700	0/1300	0/1900	0/1600	0/3	0/0	0/1
Molecular mass (kg/kmol)	86.5	102	72.6	86.2	44.1	17	44
Critical temperature (^{o}C)	96	101.1	70.2	86.1	96.7	133	31.1
Critical pressure (bar)	49.7	40.7	47.9	46.4	42.5	114.2	73.8
Volumetric heat capacity (kJ/m^3)	4356	2868	6763	4029	3907	4382	22545
Specific heat of vapour @ boiling temperature 7.2^{o}C (kJ/kg-K)	0.7749	0.9271	1.194	0.8582	1.849	2.775	2.162
Ratio of vapour density to liquid density @ boiling temperature 7.2^{o}C (kJ/kg-K)	47.4	68.84	29.79	50.23	40.66	141.7	7.155
Surface tension (N/m)	0.01067	0.01053	0.008226	0.009562	0.009061	0.02378	0.003125
First commercial use as refrigerant	1936	1990	1998	1998	NA	1859	1869

Many different fluids (media) can be used as refrigerants in refrigeration processes; however, for practical reasons the actual usage is limited to a few candidates. The physical properties of the substance will determine whether it is an interesting candidate or not. Examples of physical properties are for instance the pressure of the substance at a certain temperature which will determine the design pressure of the refrigeration system. Other aspects that are of increasing importance are the safety (flammability, toxicity, etc.) as well as the environmental impact. The latter has in recent years turned the focus in the direction of natural refrigerants. In Table 2, a couple of candidates are listed.

All these substances/fluids have different properties as far as pressures, safety, environmental impact, etc. are concerned. In the beginning of the refrigeration history, which starts in the beginning of the 19th century primarily natural substances were used since they were the only ones available. In the beginning of the 20th century the chemical science learned how to compose substances with suitable properties such as R22 mentioned above. Until this happened the industry used the natural alternatives where some are indicated in Table 2 but there were more in use.

2.5.1 SYNTHETIC REFRIGERANTS

R22 (HCFC-group)

This refrigerant is normally only referred to as R22 and is a synthetic compound belonging to the HCFC-group (CHF2Cl). It was developed during the 40-ies and was widely used until the "ozone debate" started at the end of the 80-ies. Due to its "ozone eating" properties it is subject to phase out in most parts of the world. As a refrigerant it was very appreciated due to relatively high efficiency, non-flammability as well as non-toxicity.

R134a, R410A, R407C, etc. (HFC-group)

This group consists of different alternatives and is normally just referred to as "HFCs" which are a synthetic compounds. When the ozone debate started there was a need for replacement of the traditional refrigerants and since HFCs has no effect on the ozone layer they were widely accepted. Due to their greenhouse effect properties they are not a "final solution" and is therefore also subject to phase out.

2.5.2 NATURAL REFRIGERANTS

R290 (propane)

Propane is a natural compound in the HC-group often referred to as the hydrocarbons. It was early discovered that propane has good properties for refrigeration purposes and therefore it was one of the first refrigerant to be used at the end of the 19th century. One major drawback is the flammability which restricts the use to somewhat smaller charges and when being used there are considerable precautions to be considered.

R717 (Ammonia)

Ammonia is a natural substance with the chemical formula NH3, which has been used as refrigerant since "the beginning". It is environmentally friendly and efficient but also flammable and toxic! The use of ammonia requires well designed safety measures which drive the cost; therefore ammonia is normally only used in larger refrigeration plants. For safety reasons ammonia is normally not allowed to use inside closed spaces with peoples presence such as supermarkets, ice rinks, etc. It can still be used as primary refrigerant (in the machine room) but will require a secondary refrigerant (see next section) which transports "the cold" from the machine room to the cooling object (i.e. ice sheet).

R744 (Carbon dioxide)

Carbon dioxide is also natural substance with the chemical formula CO2. It has a long history as a refrigerant as will be treated later. As primary refrigerant CO2 is generally less efficient than ammonia but the non-flammable and non-toxic properties offers technical advantages which makes it very interesting. Compared to other refrigerants it has high system pressures which together with some other physical properties makes it somewhat challenging. The latter stems from the fact that it has a critical point at a temperature of about 31°C (at a pressure of about 74 bar). At conditions higher than this there is no difference between the liquid and vapour states. Thus no condensation can occur at temperature above 31degrees C. With the proper design it can, however, still offer good efficiency and low cost in many applications.

Summary

There are many more refrigerant alternatives out there but this document limits the discussion to these above since they are relevant to the topic. As a final comment to the primary refrigerants it can be said that due to the focus on environmental issues and sustainability, the industry direction is natural refrigerants and/or newly developed synthetic alternatives. The latter is a hot topic today where intensive research and development takes place.

2.5.3 HISTORY OF CO2 AS A REFRIGERANT

Using carbon dioxide, CO2, in refrigeration applications has a long history stretching back to 1850 when it was first patented. CO2 was one of the natural alternatives at the time where most of the others were toxic and flammable. Therefore CO2 was considered a safe alternative. As the synthetic alternatives evolved the interest in CO2 gradually disappeared.

Since about 25 years the natural refrigerant alternatives are back in business just because they are "natural" and most synthetic alternatives are found to have negative effects on the environment. Particularly CO2 as a natural alternative started developing from "0" back in the late 80s. The first applications to be developed were automotive A/C systems in the 90s. This also when the first components, in the new CO2 era, such as compressors, heat exchangers and valves were developed and adapted to the rather small capacities required at the time.

The next step in the development was the commercial industry (supermarket refrigeration) which adapted systems to CO2 starting at the end of the 90s. Primarily the compressors were challenging to adapt to larger cooling capacities so the first supermarkets to be built used 10-20 compressors, however, the industry was used to work with 2-4 compressors. Using a large number of compressors will inevitably affect the cost of the system in a negative way.

2.5.4 PROPERTIES OF CO2 AS A REFRIGERANT

An important property that makes CO2 stand out as a refrigerant is the high saturation pressure compared to other refrigerants as shown in Figure 14. The operation pressure for CO2 used in an ice rink refrigeration system is approximately 25 bars at the low pressure side and 120 bar at the high pressure side.

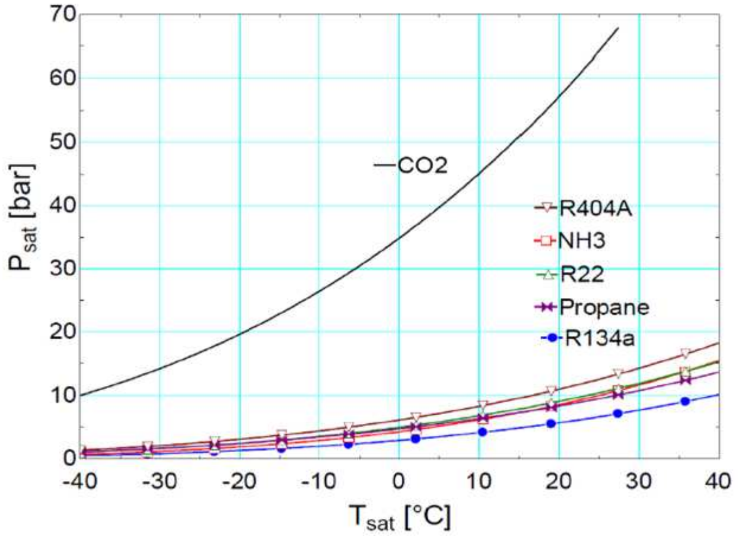


Figure 14 Saturation pressures of common refrigerants.

Due to its higher pressure CO2 has 3-4 times higher volumetric capacity at saturation than most other refrigerants implying less refrigerant volume needs to be circulated thus saving compressor displacement and material cost for compressors and piping.

A disadvantage of CO2 is the low critical temperature resulting in transcritical cycle in high ambient temperatures which has a negative effect on the refrigeration cycle performance.

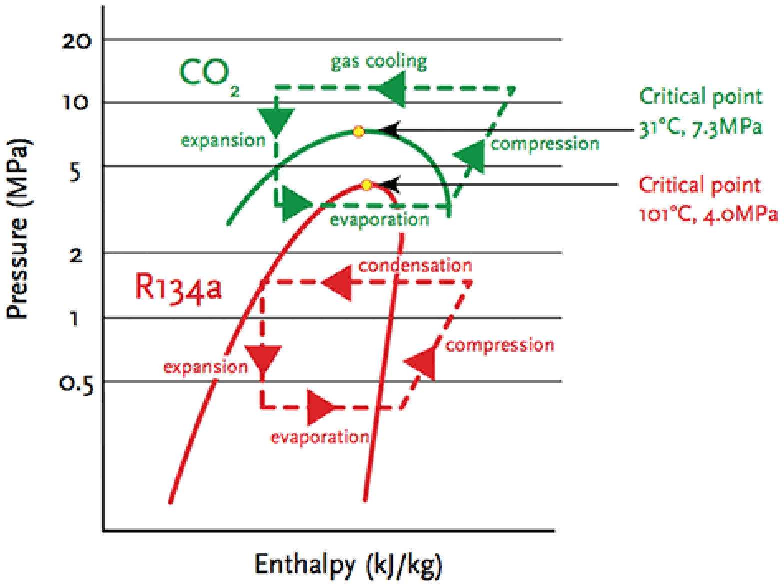


Figure 15 Subcritical (red) vs transcritical (green) cycle (Dwyer, 2012)

A direct CO2 refrigeration cycle has to be able to operate transcritical, meaning the CO2 is surpasses the critical point of 31°C and 74bar and gas and liquid states of the CO2 are no longer distinguishable. Instead the CO2 exists as a supercritical fluid which in the temperature lowering phase is cooled by a gas-cooler illustrated in Figure 15. Other than the fluid not condensing and no latent heat being removed the cycle still works by the same principal as subcritical refrigeration.

2.6 CO2 REFRIGERATION SYSTEMS IN ICE RINK APPLICATIONS

The first ice rinks using CO2 as secondary refrigerant in Europe (Dornbirn 1999, Wil 1999, etc.) all used steel pipes in the ice rink floor. Three out of the first seven installed systems during 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 during the years 1999 to 2004 about 23 ice sheets were built where half of them were new and the rest was retrofitted.

Figure 16 The first generation 1 CO2 ice rink in Dornbirn, Austria 1999.

The inherent challenge with the steel pipe design is the cost of installation, which indeed is the reason why the steel pipe design was abandoned in the 70s in favour of plastic pipes. In order to use CO2, however, there no choice, the system pressure of CO2 requires metal pipes. Although a couple of ice rinks were built with CO2 from 1999 to 2004 the commercial success was not obvious. As indicated above the installation cost was too high to really convince the rink owners.

A first step in the direction of reducing the installation cost was done in Sweden in 2004/2005 where a CO2 rink floor system based on copper tubing was developed. Firstly this offered considerably less labour since the smaller diameter (1/2”) copper tubing could be handled on rolls and soldered to the headers. This implied that the refrigeration contractor could handle all steps of the installation without having to involve external welders.

In the previously built steel pipe based rink floors larger diameter (1”) steel pipes were used which can only be handled on lengths of 10-12 m which eventually will require at least 1500 welds just to get the distribution system completed.

Although the copper tube concept together with CO2 as secondary refrigerant was installed in the new Katrineholm ice rink and proven to be a good technical solution, it was still not enough to make a commercial success. The very same concept was during the years 2005 to 2010 installed in 5-6 new ice rinks in Sweden, Norway, Russia, Japan and Finland – still with CO2 used as secondary refrigerant and in most cases in combination with ammonia.

In the beginning of the 2000s the so called transcritical CO2 systems gained in popularity and the first systems in commercial (supermarket) use were installed in 2003. With the introduction in this sector, which has a significant cost focus, the cost of the components in the systems decreased. Further, it triggered the development of new and better adapted components to allow higher design pressures and make system more practical and safer to handle as well as more energy efficient.

For CO2 to become a generally accepted system solution all components had to be adapted to allow practical designs such as higher allowed pressures, but not the least to lower cost. The compressor is a very vital component in the system as far as performance and cost is concerned. It is therefore a good example to illustrate the development in terms of the number of compressors required to build a single sheet ice rinks. In the first proposal from 2006 (Katrineholm 2006), 12 compressors were required to meet the 300 kW cooling capacity requirement. When the Marcel Dutil Arena, QC, was built in 2010 it used 7 compressors which corresponded to a 317 kW of cooling. A recent CO2 ice rinks project in Sweden uses 4 compressors to meet the specified cooling capacity of 250 kW. These figures show the rapid development on the CO2 component side in the recent years.

2.6.1 GENERATION 1 – CO2 PUMP CIRCULATION SYSTEMS

This configuration refers to the use of CO2 as secondary refrigerant in an indirect systems where the CO2 fluid is used to distribute “the cold”. The primary refrigerant cools the secondary fluid (CO2) which is then pumped to the cooling object, therefore this is often referred to as *pump circulation, PC*.

The Swedish company Stal AB developed and realized the use of carbon dioxide as a volatile secondary refrigerant in supermarket systems for the Swedish market as from 1995. In 2007 more than 100 such systems were in operation in Sweden.

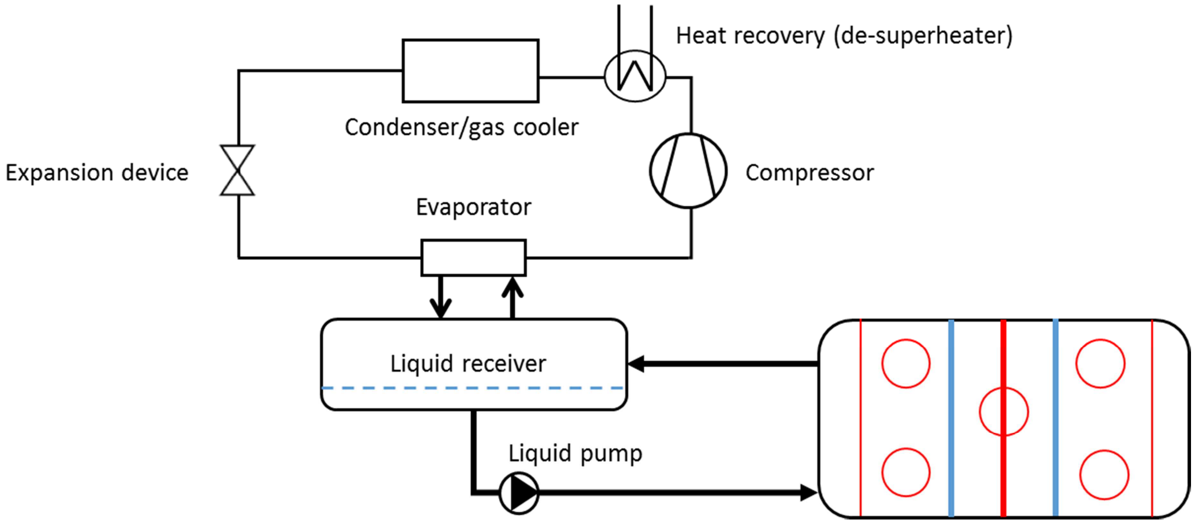


Figure 17 Indirect system with ammonia and CO2.

The system consisting of an indirect refrigeration cycle with ammonia as the primary and CO2 as the secondary refrigerant is usually referred to as generation 1. With this setup shown in Figure 17, less pump work is required than when brine is used in the secondary cycle due to the lower viscosity and latent heat properties of CO2.

2.6.2 GENERATION 2 – 100 % CO2 SYSTEMS

To use CO2 in ice rink applications is a very obvious consequence of what has been described above. The general system solution and associated challenges are the same as with other refrigerants which have been used in ice rinks. It was shown above that the indirect (PC) CO2 systems had evolved from the first Austrian application in 1999. In parallel with this the supermarket business introduced the so called trans-critical (TC) CO2 system solutions in the early 2000s and it was obvious to combine the two systems.

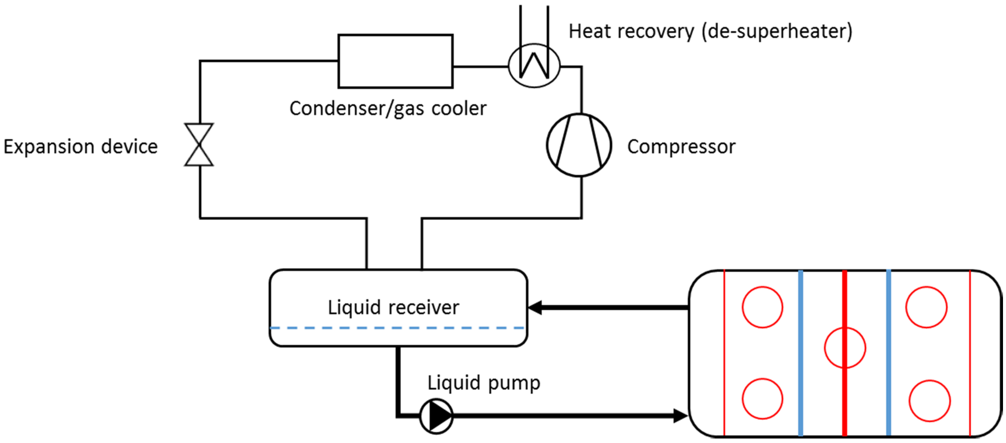


Figure 18 A direct ice rink refrigeration system using a free of choice refrigerant i.e. ammonia, R22, CO2, etc.

In a fully CO2 direct system referred to as generation 2 there is no heat exchange between two refrigerants. Liquid CO2 is pumped to the ice rink where it partly evaporates. The vapour/liquid mix is then returned to a storage tank. Vapour is later removed from the storage tank by a compressor and passed through a condenser/gas cooler. The refrigerant is then returned, via the expansion device, to the storage tank and once again pumped through the rink floor. The pump work needed in this configuration is up to 90 percent lower than a conventional indirect refrigeration system with brine.

2.7 GEOTHERMAL STORAGE

Geothermal energy storage means using the ground as a heat source or a heat sink. It is an effective way of heating and cooling objects with large heat and cooling demands. Normally a pump circulates a fluid in a borehole through a heat exchanger to transfer heat to or from the ground. The upper layer of ground surface maintains a near constant temperature of 10 to 15°C depending on latitude. Seasonal variations in the ground temperature disappear at depths of 7 to 12 meters. As ambient air temperature varies greatly with season the geothermal source will be more effective for cooling when ambient temperature exceed the ground temperature and more effective for heating when the ambient temperature is lower than the ground temperature. As heat is transferred to or from the ground the temperature in the bore holes will change depending on the size of the borehole and the load.

In a study done at KTH in 2009 field measurement and simulations where done on a supermarket close to Gothenburg, Sweden with direct CO2 refrigeration, that runs in transcritical state during high ambient temperatures, and a cooling capacity of 250 kW. A heat exchanger with geothermal storage is used for further cooling before the gas expansion and the geothermal storage is also used to heat the supermarket. It was found that subcooling with a ground heat sink had a positive effect on the COP at an ambient temperature over 10°C and gave up to 50 percent increase in COP compared to no subcooling at an ambient temperature between 15 and 35°C.

Seasonal thermal energy storage can be used to store heat or cold for several months taking advantage of seasonal varieties in ambient temperature. Any source of heat or cold can be used and it common that a geothermal storage is used for moving heat between seasons.

2.7.1 GEOTHERMAL STORAGES IN ICE RINKS

Another interesting possibility in ice rink applications is to store larger amounts of heat in the ground in a so called geothermal storage. The storage normally consists of boreholes in the ground where heat can be rejected from the refrigeration system. Potentially the heat is stored to be utilised later or the geothermal well is used solely to dump heat.

Figure 19 A geothermal well in the ice rink North Wentworth Arena, Hamilton, ON.

One example of a geothermal well system installed in 2010 is found in the ice rink North Wentworth Arena, Hamilton, ON, which also comprises a Cimco EcoChill refrigeration system.

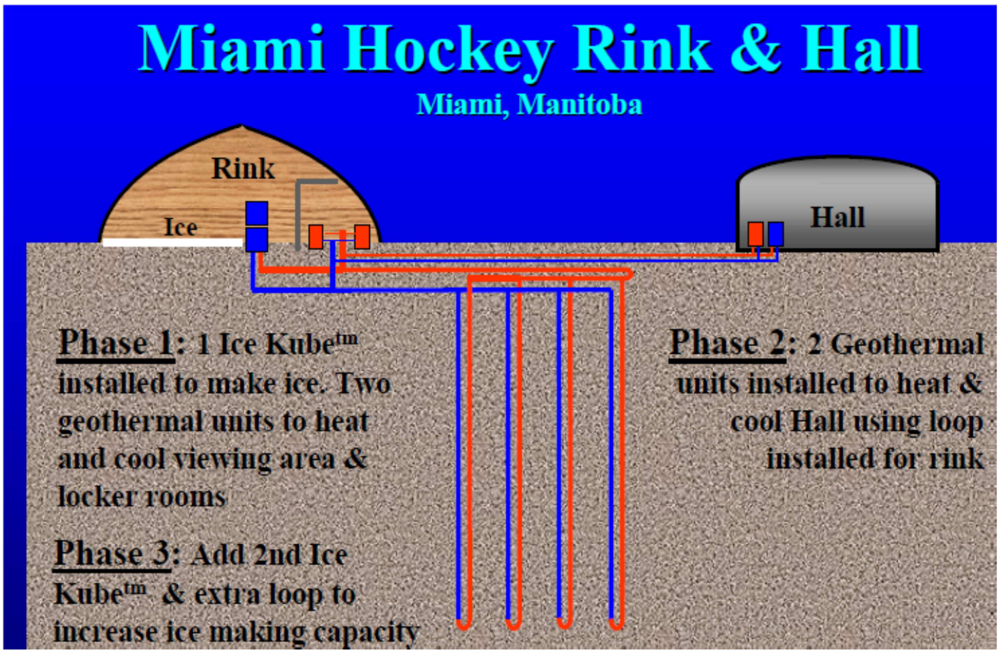


Figure 20 A geothermal storage in the Miami Hockey rink, Manitoba (IceKube, YEAR).

Other examples of geothermal systems in ice rinks are presented by IceKube. They report interesting energy savings from several ice rinks in Canada using their geothermal solutions including vertical and horizontal type of geothermal storages.

3 THE GIMO ICE RINK – CONCEPT AND SYSTEMS DESIGN

This chapter will describe the ideas and consideration that led to the concept applied in the Gimo ice rink as well as the actual design of the respective energy system.

3.1 GENERAL CONSIDERATIONS BEHIND THE CONCEPT

CO2 has become a successful refrigerant in the food retail industry and now has the potential to revolutionise the ice rink industry. A study conducted in Sweden 2012 compared three ice rink refrigeration systems, one fully CO2 system, one using NH3/brine and one using CO2/brine. The results revealed that the application of CO2 transcritical technology is the most efficient system with the lowest energy consumption and the highest COP, and with regard to heat recovery potential, the CO2 transcritical system has the highest energy saving in comparison with other systems.

The “heat recovery potential” so often referred to stems from the fact that the heat rejected in a typical CO2 loop is available on a higher temperature level than most other refrigerants. In the Figure 21 below a comparison is made between ammonia and CO2 which shows the share of the available heat on the x-axis and the corresponding temperature. It can be concluded that although the temperature level on the discharge gas is somewhat lower for CO2 it contains more energy and “lasts longer”. The states to the very right in the diagram reflect the compressor outlet and as the refrigerant is cooled as we move to the left in the diagram. It can be argued what the level for “interesting temperatures” is, but in the current example the ammonia condensing temperature is 35°C. Normally temperatures above 40°C are to be avoided for technical reasons, but the comparison tells us that CO2 has more than 50% of the heat available over 35°C.

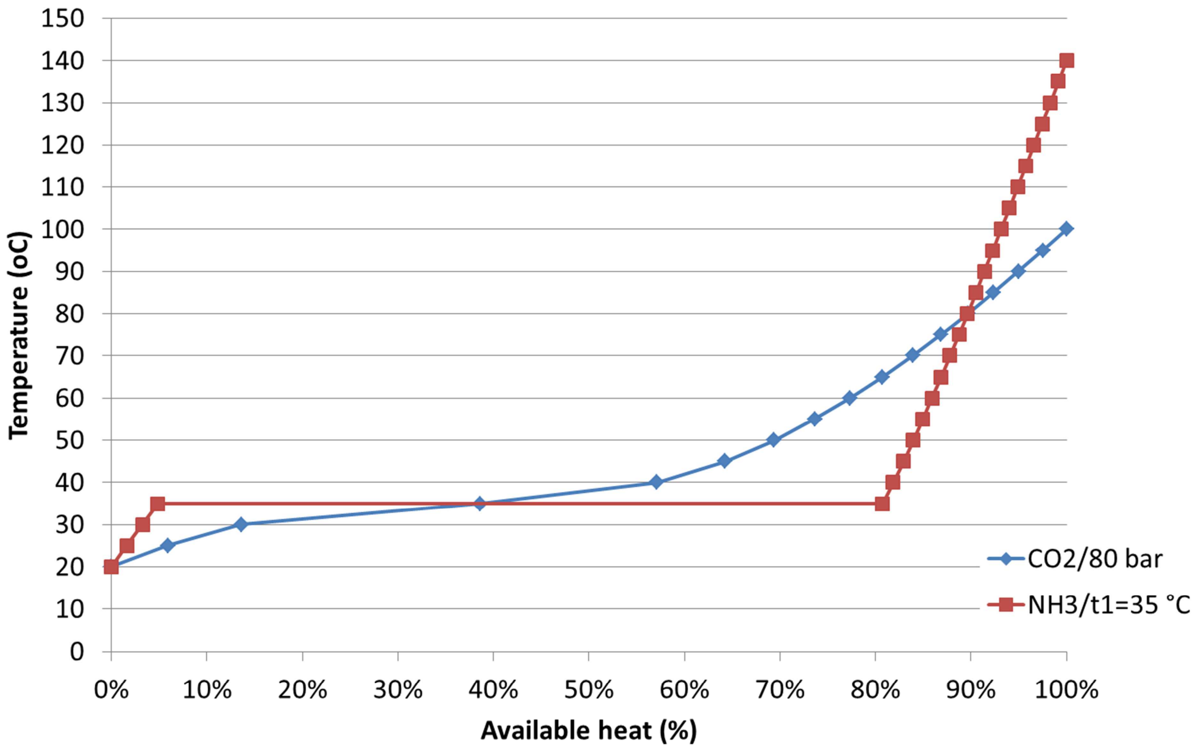


Figure 21 Temperature vs available heat comparing ammonia and CO2.

Given the heat demand in ice rinks and the heat recovery properties of CO2, it seems to be a very good match. In order to benefit from the potential heat recovery it is obvious to try to replace other sources of energy, such as oil, gas, district heating and electricity with recovered heat if possible. Obvious applications are pure heating systems such as space heating, water heating, etc. Next step is to look at energy consumers that may not always use heat in the sense that it comes off a heating system. An interesting example is the dehumidification unit which, in Sweden, very often use electricity for the reactivation process. As mentioned previously the dehumidification need can be taken care of by different means, however, the most commonly applied process is the desiccant wheel (adsorption process). This process uses considerable amount of energy for the reactivation of the desiccant wheel which normally for a single sheet ice rink lies in the interval 60 000 to 200 000 kWh annually. The major part of this, approximately 80%, is heat for reactivation.

Another hidden heat demand is the heat normally coming from the lighting system. It may sound surprising but older generation lighting systems generated significant amounts of heat, not seldom in the range 20-30 kW when in operation and 50 000 kWh to 100 000 kWh on an annual basis. When switching to LED technology more than half of that disappears which will reduce the heat supplied to the ice rink interior. Replacing that with recovered heat will be a saving together with other advantages coming with the LED technology itself.

Provided the considerations outlined above and the potential in of using these it was decided to set up an energy target for the renovated ice rink. In conclusion, realistically this type of ice rink should be able to operate with less than 500 000 kWh per year. To achieve this it was decided to use a CO2 refrigeration system as a base and develop a heat recovery system adapted not only to the requirements of the ice rinks but also to the properties of CO2.

In summary the following list summarises the technical requirements and the actual technology selection for the Gimo ice rink project.

- 100% CO2 system
    - CO2 DX in the rink floor
    - 250 kW cooling capacity
- Full heat recovery
    - No external heat should be needed
    - All heat demands to be covered
- Heat pump function
    - To be used when the heat recovery is not sufficient
    - Off season heating functionality guaranteed
- Geothermal storage
    - Subcooling – in warm periods
    - Heat source – in cold periods
- Dehumidifier with preheating of reactivation air(recovered heat)
    - The existing dehumidifier should be supplemented with preheating
- LED lighting system
    - Should provide 600 lux
    - Maximum installed electrical power 10 kW

3.2 GIMO ICE RINK – ENERGY SYSTEMS DESIGN

The requirements following the general considerations regarding maximised heat recovery and best possible energy system integration required not only the systems should be physically connected when possible but also that they were controlled together. Figure 22 below schematically shows that the different energy systems are interconnected. All of the big five are physically connected expect for the lighting system, but as explained above, an energy efficient lighting system does affect the big energy picture in the way that the heating demand increases when the lighting generates less heat.

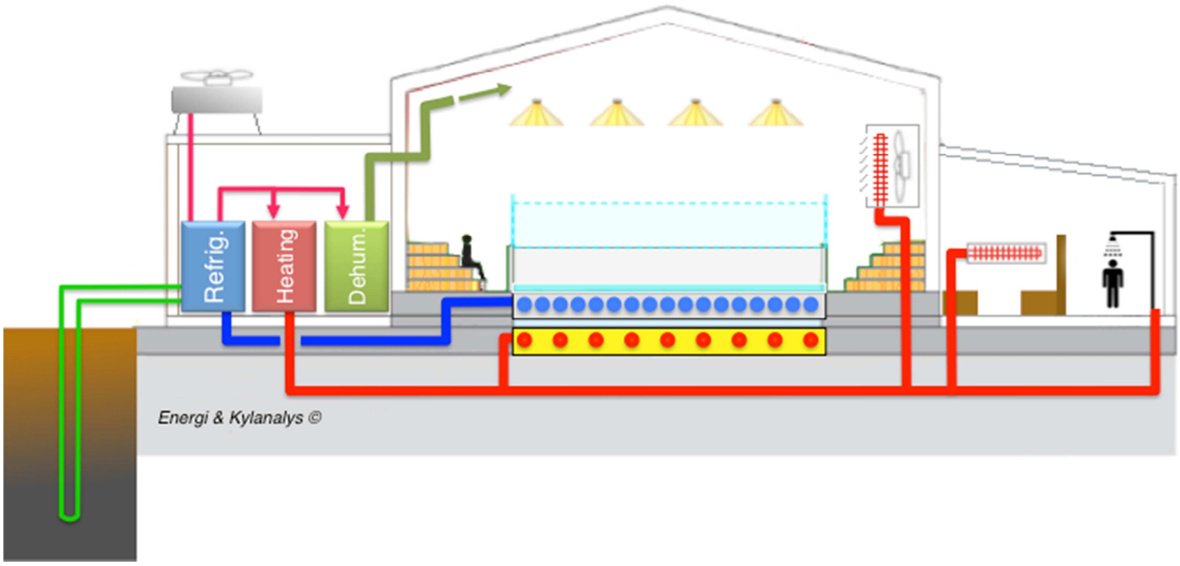


Figure 22 The general ice rink energy system layout of the Gimo ice rink.

3.2.1 "THE ENERGY HUB"

This Gimo ice rink should be independent as far as heat supply is concerned since the CO2 system is combining the refrigeration and heating functions. No supplementary heating such as gas, electricity or district heating should be used. In case of insufficient load on the refrigeration system to satisfy the heat reclaim function, the geothermal storage is activated. This will add some "false load" to the refrigeration system resulting in a boost of the heat rejected.

The "hub" of the energy systems in Gimo should be the CO2 refrigeration system, which is able to recover the waste heat from the cooling process to use for space heating and hot water. Any excess heat is transferred to a geothermal energy storage enabling subcooling of the CO2 process and saving heat for use during colder periods. In order to utilize the heat recovery potential of CO2 fully, the heat reclaim system was designed and adapted to the properties of CO2. A so called "water fall principle" was applied to the heating needs in order to achieve the most advantageous temperature conditions.

As can be seen in the schematic Figure 23 below the direct CO2 system has a liquid separator and accumulator tank to store and separate the CO2 liquid. This CO2 liquid is then pumped to the rink floor to provide the cooling effect of the ice sheet due to its evaporation in the rink floor tube system. The evaporated vapour returns to the tank and is from there evacuated by the compressors. After the compressors the discharge gas continues to the heat recovery heat exchanger where the high grade heat is transferred to a heat transfer fluid which is water in this case. The water loop forms the primary heat recovery loop which feeds the different heat needs in the ice rink in order of required temperature. This step wise utilisation of the available heat is referred to as the water fall principle which has the inherent advantage that it cools the primary loop to the lowest possible return temperature which is key for the heat recovery performance.

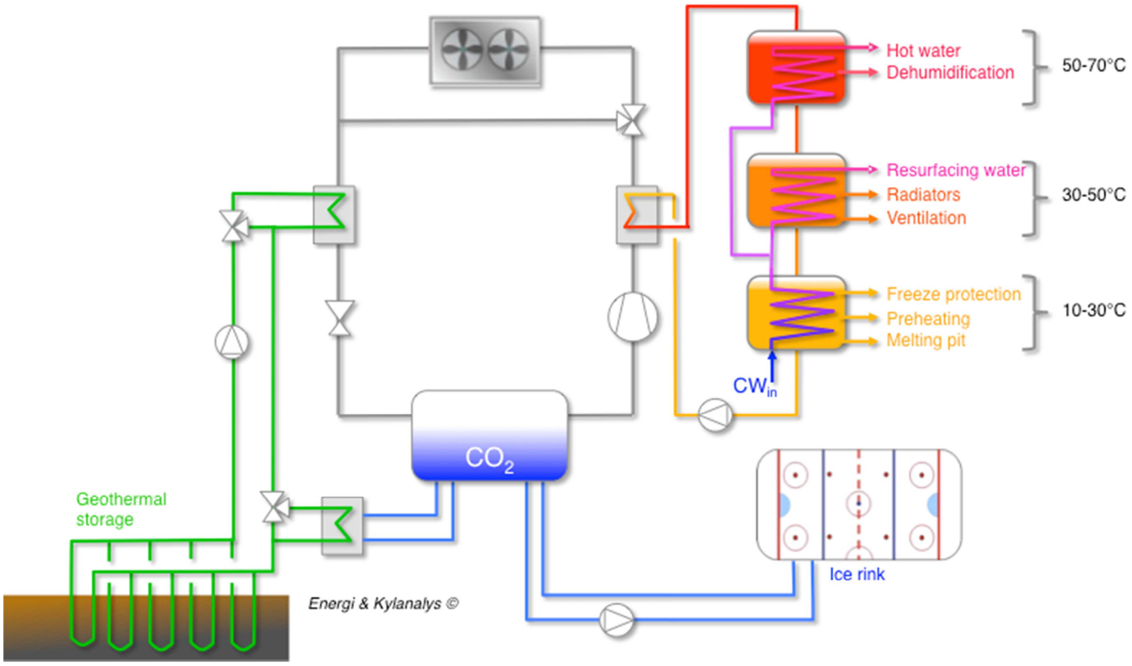


Figure 23 Overview of the refrigeration system in GIMO ice rink.

The primary heat recovery loop is indicated with red in the beginning where the highest temperatures are available and then the heat is utilised in principally three steps from about 60 °C down to approximately 20°C.

3.2.2 REFRIGERATION SYSTEM

The CO2 refrigeration system loop may be described starting with the compressors marked with A in Figure 24 below. These should evacuate the evaporated refrigerant from the tank and circulate the refrigerant in the loop. The working pressure on the high pressure side is mainly above the critical pressure of CO2 making the system trans-critical. After the compressor the refrigerant passes through a heat recovery heat exchanger marked as B. The heat to be recovered is transferred to the primary heat recovery loop. All the recovered heat is used for heating the building including ventilation and dehumidification.

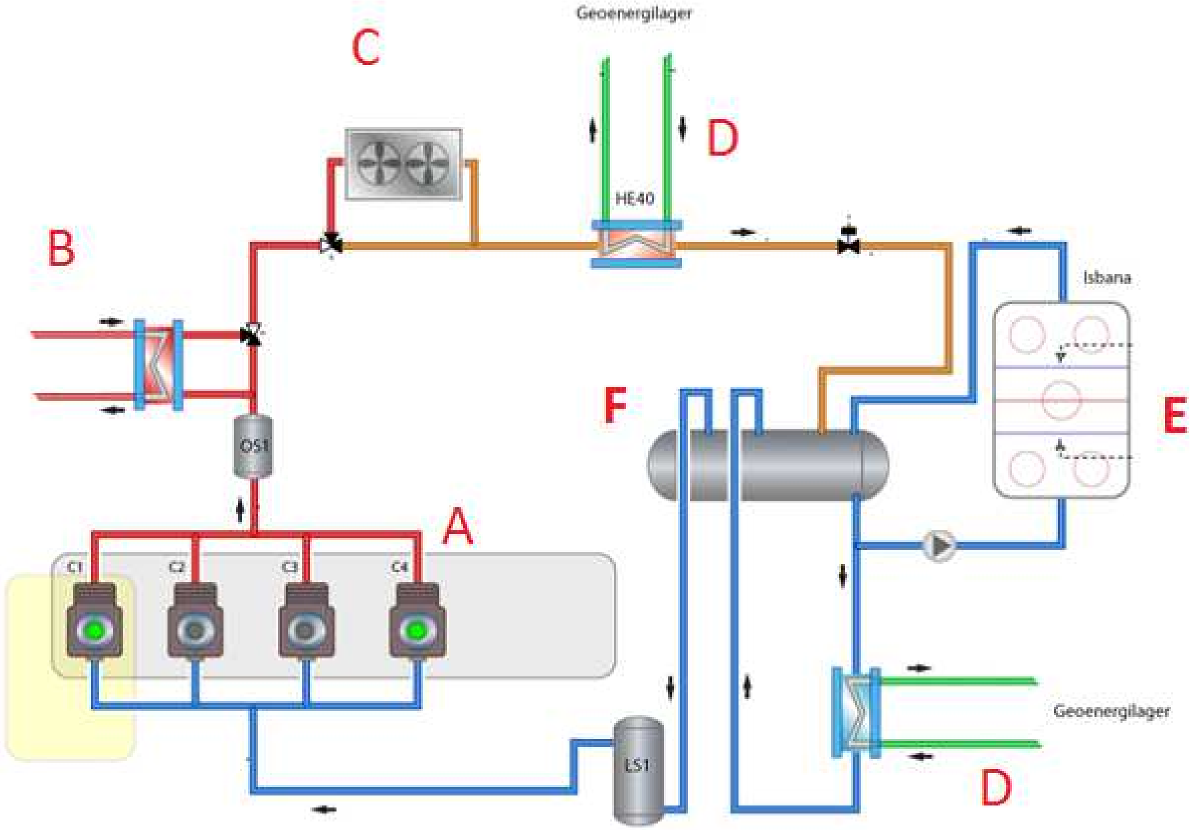


Figure 24 Overview of the refrigeration system in the GIMO ice rink.

The refrigerant is then cooled further using a gas cooler marked as C and/or a geothermal heat storage marked as D. After expanding the refrigerant back into the tank it can be passed through the ice rink tube system which is the evaporator, marked as E. There is as well as another heat-exchanger connected to the geothermal storage where additional heat can be provided when the cooling demand is low. The refrigerant is stored and separated in the accumulator tank marked as F.

In practice the system can be seen in the pictures below and consists of a “standard CO2 pack” which could be found in any modern supermarket. The pack includes four compressors where one is capacity controlled. Additional major components on the pack side are the electrical panel, oil separators, and heat recovery heat exchanger.

Docked to the compressor pack there is a pump module which contains an accumulator tank of about 3000 litres as well as the CO2-pump. In the present case this module also includes the geothermal evaporator.

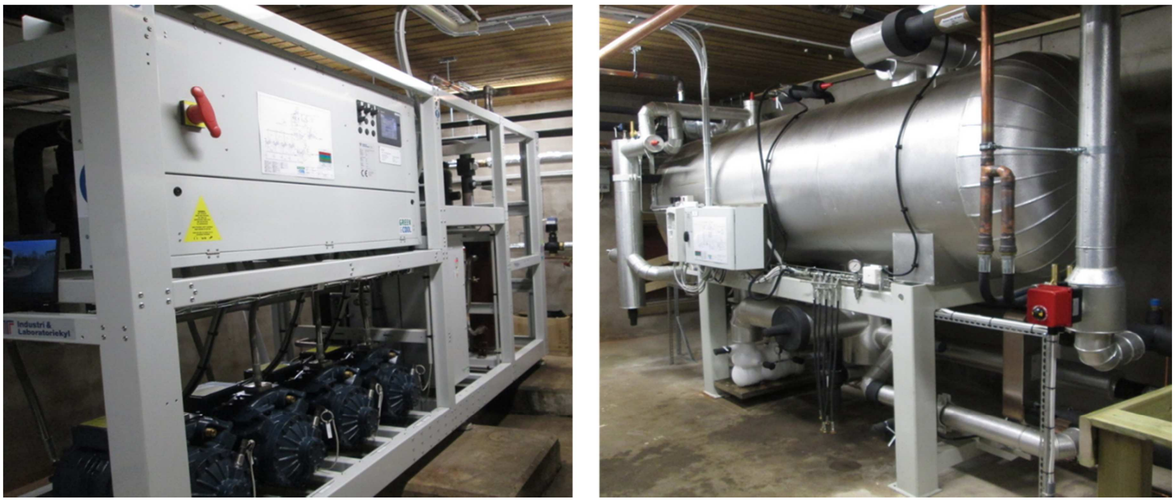


Figure 25 Overview of the refrigeration system in the GIMO ice rink.

3.2.3 HEATING SYSTEM

The heating system connects to the refrigeration system through a heat-exchanger marked as B in Figure 26. The primary circuit water first passes through high temperature accumulator tanks in A where hot water is heated 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 form position D. In the following section marked as E the resurfacing water is heated.

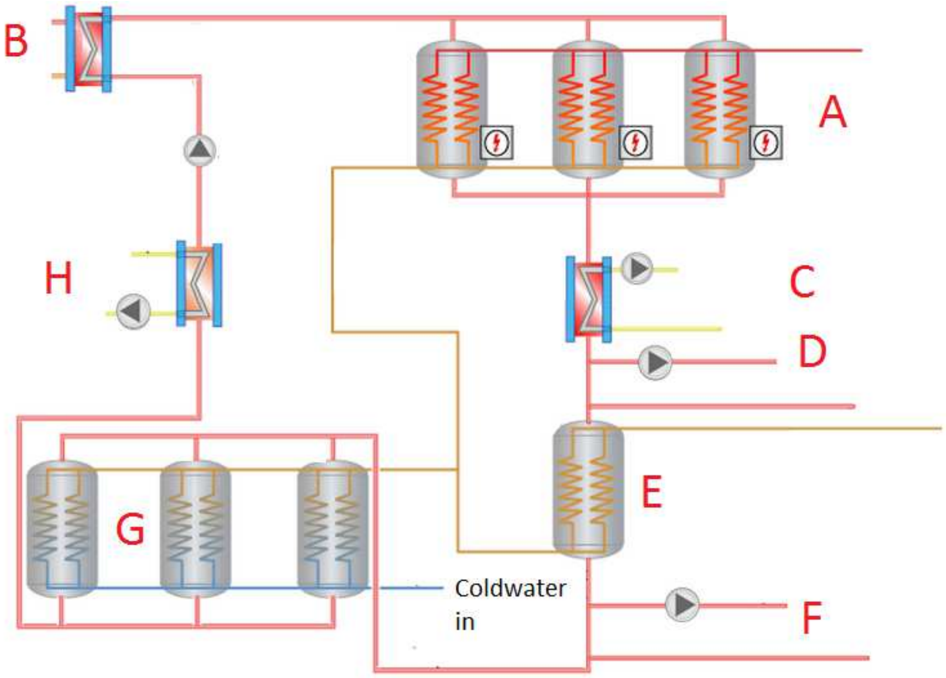


Figure 26 Schematical view of the heat recovery system.

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 accumulators in section G leading followed by the final step where the water used for subfloor freeze protection is heated by a heat-exchanger marked as H before the water in the heating system is returned to the initial position B.

In practice the tank and primary heat recovery loop can be seen on the picture below, Figure 27. Each temperature stage consists of three tanks except for the medium temperature stage which is one tank only. The volumes of the tanks in each stage should be designed to meet the capacity peak needs of the water taps regardless if it is resurfacing water or normal warm water.

Figure 27 A view of the technical room containing the heat recovery system.

3.2.4 VENTILATION SYSTEM

Essentially the ventilation systems remained from before the renovation of the ice rink. Some upgrades were done to adapt them to the new energy management system. The adaptation consisted of equipping fans with capacity control and instrumenting the units with temperature sensors. Two fans-coils were also included in this upgrade for the ventilation system.

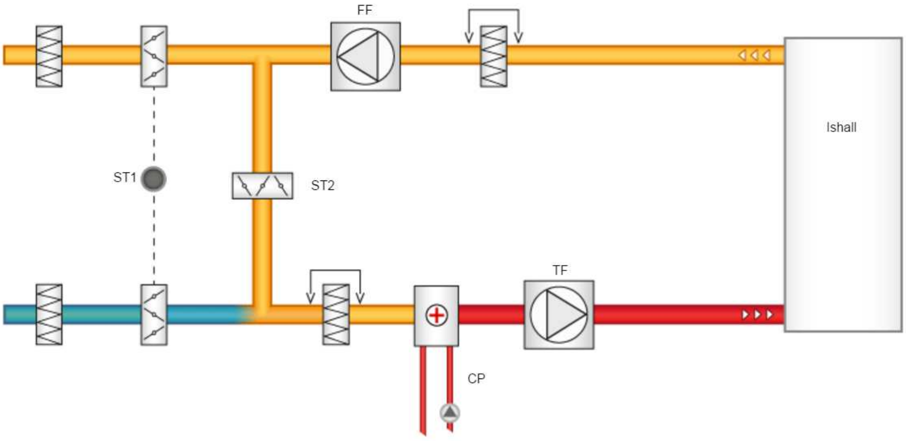


Figure 28 Principle sketch of the ventilation unit for the rink space Gimo ice rink.

The ice rink will be supplied by air from the ventilation system that is connected with a frequency controller which can be controlled both automatically and manually. The ventilation system is designed for an occupancy of 1000 people, which is controlled by various flow rates in order not to over ventilate the ice rink. A CO2-sensor controls the flow rate with respect to the occupancy. The sensors are placed in the stands surrounding the ice rink. If there is no or very low occupancy, the ventilation will be turned off and the air will be naturally ventilated through leakage in the building. When the occupancy is high, an exhaust fan will start and the corresponding dampers will be opened.

Figure 29 The original ventilation unit in the ice rink from 1985.

The previous picture, Figure 29, which is taken during the construction work shows the original ventilation unit from 1985. Another part of the original equipment were the two fan-coils heating the rink space – see picture below, Figure 30.

These were upgraded with more sophisticated temperature control but for the rest they remained in their original state. Unfortunately these were in worse condition than expected performance wise and did not deliver the capacity anticipated. Further, the poor coil layout requires a very high fluid flow to distribute reasonably, which at the end of day results in a much higher return temperature than expected.

Figure 30 The original fan-coils in the ice rink from 1985.

Lastly there were some new parts of the system installed which were the ice resurfacer as well as the technical rooms. These got a new fan coils units to maintain the temperature at a target temperature of 20 °C. The latter surfaces are rather small and especially the technical rooms, refrigeration and heating, will be heated by heat losses from the equipment in there anyway.

In summary the "ventilation system" can be summarised as two larger ventilation units – one for the rink space and one for the locker rooms as well as the fan coils for the rink space and the technical rooms. The heating demand in this system is almost solely related to the rink space.

3.2.5 DEHUMIDIFICATION

As was concluded previously the humidity control is an important function to consider in ice rinks. It is not only important from a functional perspective but also from an energy usage perspective! This device may use 50 000 to 150 000 kWh per year and typically this is all electricity. There is, however, a great potential in saving by using other means of heat for the reactivation energy than electricity.

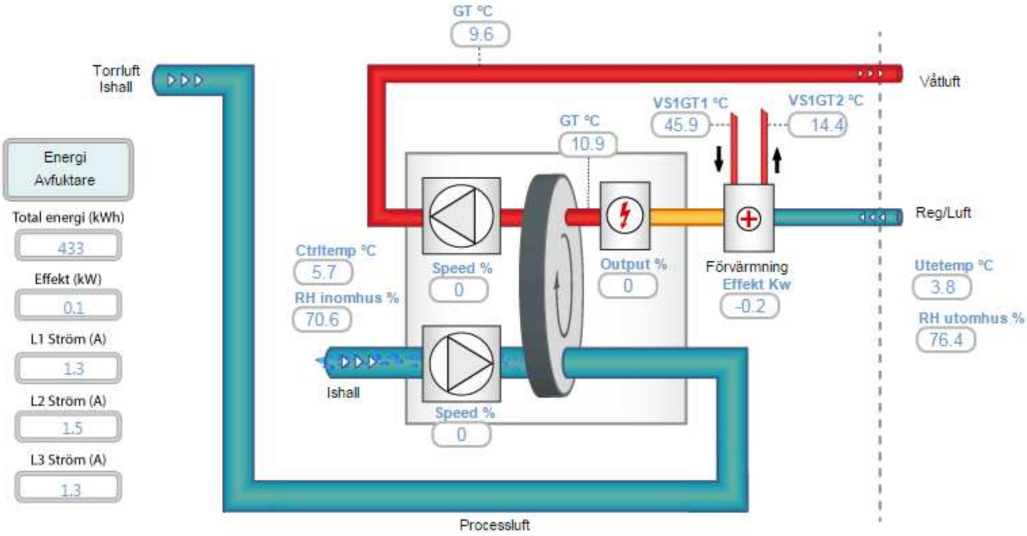


Figure 31 Principle layout of the dehumidification unit including the preheating function.

In the Gimo ice rink the preheating is provided via the heat recovery system, which is connected to a liquid to air heat exchanger in the reactivation air flow connected to the Munters dehumidifier.

Figure 32 The dehumidifier (left) and the preheating function (right).

Through the preheating of a portion of the reactivation air energy can be saved. How much can be saved is determined by the temperature level of the liquid from the heat recovery system, the ambient air temperature as well as the dehumidification capacity required. To preheat is good but today there are products on the market offering 100% reactivation with heat on a 60°C level, which means recovered heat can do the job. Since the largest dehumidification need coincides with the largest heat surplus in summer - autumn time this is an interesting option.

3.2.6 LIGHTING

According to the specification of Gimo ice rink, the total allowed installed power for the lighting system was 9.6 kW. There were a total number of 80 light fixtures with the rated power of 120 W installed. The installed LED luminaires consists of two different models from Easy LED, 32 of which are L2 80DEG and 48 are L1 150DEG. The lighting fixtures are evenly distributed above the ice surface and the lighting performance fulfils the uniformity requirement according to the Swedish ice hockey association.

Figure 33 LED lighting system of Gimo ice hall.

The lighting can be controlled either by a dimmer alternatively with three fixed steps adjusted for game, practice and for ice maintenance. The lighting requirements for this type of arena is at least 600 lux evenly distributed over the rink.

3.2.7 GEOTHERMAL STORAGE

The refrigeration system of Gimo ice rink includes a geothermal energy storage consisting of five vertical boreholes illustrated in Figure 34. The geothermal storage is connected to the refrigeration system at two points via heat-exchangers seen in Figure 24 marked as D. The purpose of the geothermal energy storage is to act as a heat sink in refrigeration mode as well as a heat source in heat pump mode.

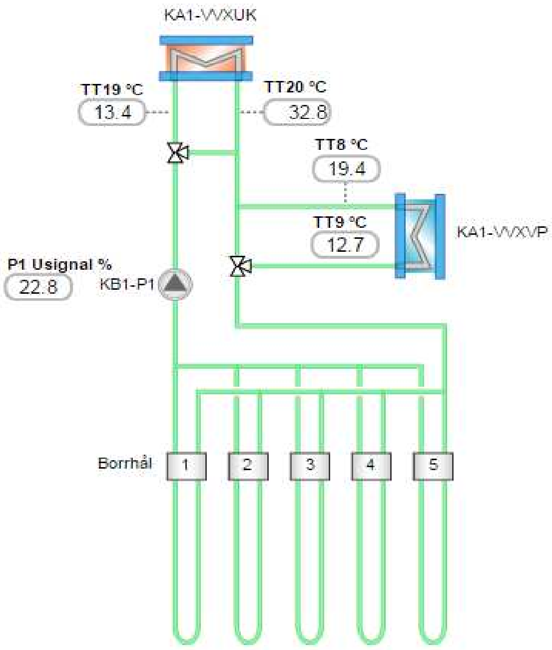


Figure 34 Principal design of the geothermal storage in the ice rink.

The primary idea is to use the storage for short to medium term energy storage, which implies balancing daily heat rejection and source needs as well as on a monthly basis. The latter may be storing the heat from the start up and the warm part of the season, i.e. July to September, and store it until the coldest period – normally January to March.

Figure 35 Collection point for the geothermal wells outside the machine room.

4 RESULTS

The current chapter will present the result mainly from the first season of operation. In order to give best possible perspective a top sown approach is applied where the general energy usage in ice rinks is described. This data is predominately based on the Swedish national perspective. Next step is to look into ice rinks on an individual level where the average energy usage for the different energy systems is shown. Having these background data presented the reporting of the achieved results in the Gimo ice rinks will follow with a similar logic starting from over all energy usage down to the details of each and energy system.

4.1 ENERGY USAGE

In order to put the energy usage of the Gimo ice rink into perspective the global results are first compared in a national perspective and with a couple of similar ice rinks in particular. Secondly the individual energy systems are studied to monitor and analyse their respective performance. These are not all necessarily all comparable with others depending on the design or availability of reference data. The reference data origins from the so called “Stoppsladd” project which during the years 2009 to 2014 compiled data from a large number of Swedish ice rinks.

4.1.1 GENERAL ICE RINK PERSPECTIVE

In the Stoppsladd project a checklist was given to more than 200 of the approximately 365 ice rinks throughout Sweden. The checklist contained questions on the general usage such as time of operation, size of the facility as well as the purchased energy. Far from all checklists generated complete data but more than 130 could present figures on the annual energy purchased. The term “purchased” is used because due to internal processes such as heat recovery and heat pumps the actual energy usage and for what may be difficult to distinguish. The general conclusion was, however, that the average purchased energy is about 1 000 000 kWh for a “normal” single sheet ice rink. There are considerable differences between similar facilities since the time of operation, type activity and in general how they are maintained will differ.

To at least eliminate the season length a key figure was defined as the purchased energy per day of operation. The time factor is the strongest so to keep the comparison reasonably simple this is one way to go. To get to the Gimo ice rink and the situation before the collapse and renovation, the annual energy usage consisting of electricity and district heating was about 950 000 kWh. This translates to a daily energy usage of about 4200 kWh during the “ice season” which is from mid-August to end of March, which used to be the “normal” season.

The first season after the renovation with the new energy systems was slightly shorter than normal but the real operation can be considered from beginning of October 2014 and stretched until the beginning of April 2015. As will be further discussed below the only energy being used is electricity and the total amount was 296 000 kWh during this period. This translates into about 1630 kWh per day which and as can be seen in the graph below where the Swedish ice rinks are lined up from highest to lowest energy user as far as the daily energy usage is concerned it put Gimo almost at the end.

It should be emphasised that not all ice rinks can or are able to report their complete used or purchased energy. Having that said it implies that some figures may be over or underestimated depending on if it is possible to separate the energy being distributes inside the facilities. Sometimes the ice rink shares locker rooms with a sports hall or a football facility – and in that case who supplies/pays for the energy? In other cases the full heat bill is reported on the ice rink although it is shared with other facilities and vice versa.

For the Gimo ice rink owner these figures are in any case pleasant reading since the daily energy usage is reduced by approximately 2500 kWh per day corresponding to about 60% reduction. In an absolute energy perspective considering a normal 8 month season the saving for the municipality is about 600 000 kWh per year.

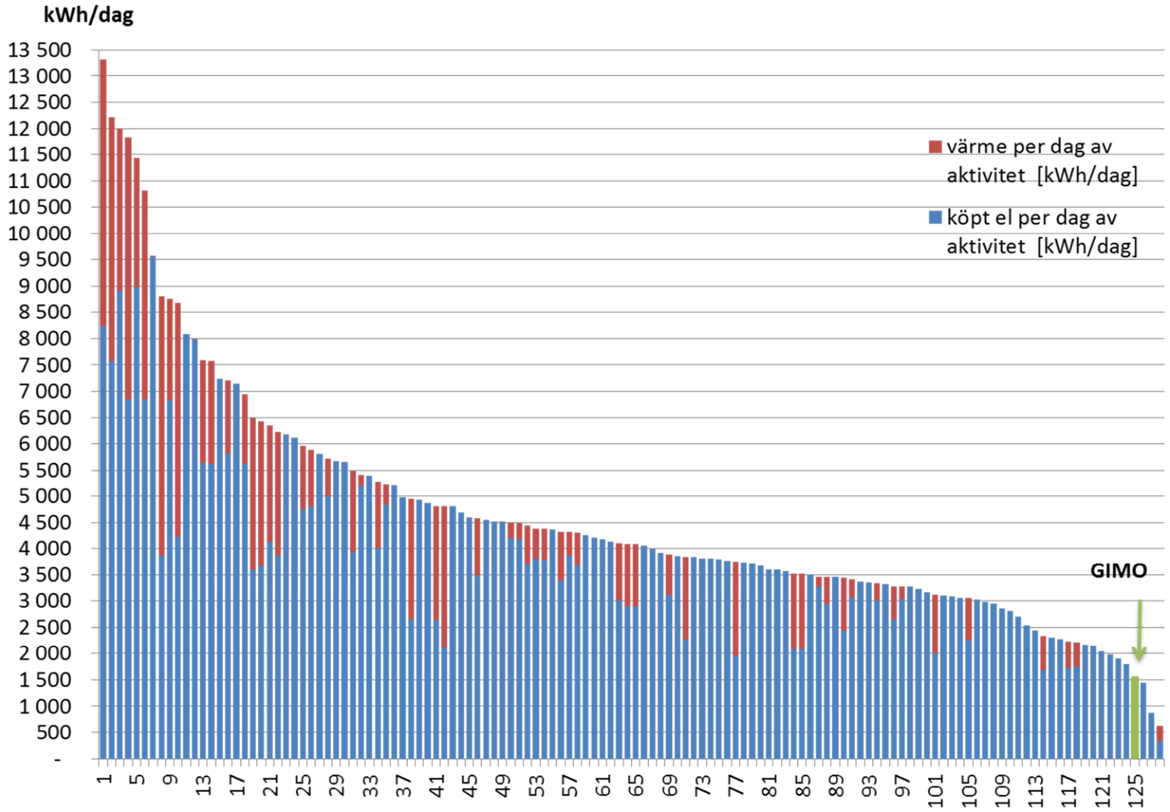


Figure 36 The average daily purchased energy as electricity and heat for 130 Swedish single ice sheet ice rinks.

In the representation above it shows that the Gimo ice rink is among the ice rinks with the lowest purchased energy in the country. The figures above contain many unknown factors such as indoor air temperature in a specific ice rink which is one of the stronger parameters when it comes to the energy usage. As also mentioned above there is some uncertainty as to if the actual energy usage is included depending on the instrumentation available in many facilities when it comes to separation of energy used and for what.

4.1.2 ELECTRICAL ENERGY USAGE PER CATEGORY

As was previously presented and defined the dominating energy systems in an ice rink are the so called “big five”; refrigeration heating, dehumidification, lighting and ventilation. These typically account for about 90 % of the total energy used in an ice rink. When studying the Gimo ice rink the situation is a bit different since some of the systems are interconnected such as refrigeration and heating. The heat recovery system, which later will be treated in detail, covers the full heating demand and therefore the “heating” portion is included in the refrigeration part. Further, the ventilation units are not measured separately but included under miscellaneous.

Table 3 Energy usage by measured category and month during the season.

	Oct 2014	Nov 2014	Dec 2014	Jan 2015	Feb 2015	Mar 2015	TOTAL [MWh]	
Refrigeration [MWh]	31.3	28.2	33.2	33.8	30.2	32.7	189.4	64.0%
Lighting [MWh]	2.2	1.9	2.4	2.2	2.1	2.0	12.8	4.3%
Dehumidification [MWh]	0.1	0.2	0.1	0.1	0.1	0.5	1.1	0.4%
Misc. Ventilation [MWh]	15.2	14.5	17.5	16.7	13.8	14.9	92.7	31.3%
TOTAL [MWh]	48.8	44.9	53.3	52.8	46.2	50.0	**296.0**	**100%**

If the measured electrical energy is presented per month as in Table 3 it can be concluded that the refrigeration system is dominating with 64% of the total energy used, which is expected as commented above. This category is also quite constant per month which is explained by essentially two factors – one being relatively constant cooling demand since the ice rinks building envelope is in a good state, i.e. well insulated. The latter implying that the heat load is quite constant given that the temperature and activity levels are kept reasonably constant. The second being that the heat recovery function maintains the warm side of the refrigeration system at a rather high temperature/pressure level regardless if the ambient is warm or cold. The specifics of the heat recovery system will be treated later in the report.

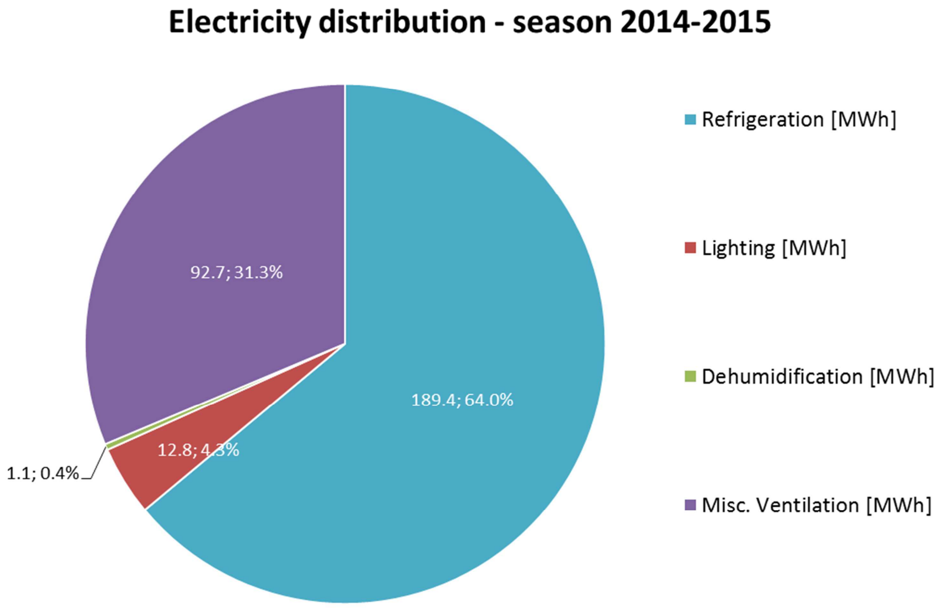


Figure 37 Energy usage distribution during the season 2014/15.

The lighting system account for a very small fraction of the energy usage which is due to the LED technology as well as the control system which is set adapt in steps to the needs of the activity.

The dehumidification system was essentially not in operation during the studied part of the systems and has therefore hardly used any energy at all. The dehumidifier uses both electricity and heat which will be further analysed in the dehumidifier section.

Under the category “miscellaneous” the rest of the users fall which in this case include two ventilation units, all pumps related to the heating functions as well as remaining lights in the building together with charging of ice resurfacer.

In conclusion to the electrical energy used by the facility it can be concluded that the amount of energy being used is much lower than the average Swedish ice rink, however, the average is not very flattering, but to really compare such facilities one need to consider the main driving factors such as indoor temperature and length of the season. The indoor temperature has been around 8 °C which normal to high when looking at this category of ice rink. Secondly the length of the season was shorter than normal but if the key figure kWh/day is used one can still see significantly lower usage than most other ice rinks.

4.1.3 HEAT USAGE PER SYSTEM/FUNCTION

As described when explaining the heating system function this concept is based on a primary heat recovery loop which provides each heating demand with the required heat and temperature level. With this layout one can conveniently measure, calculate and display the heat being used by each subsystem. This data has been extracted per month and displayed in the table below where it can be seen that the total recovered heat during only six months account for as much as 466 000 kWh. As will be treated later the there is a cost associated with this recovered heat, however, it is low and more importantly this ice rink is self-sufficient with heat i.e. no other source of heating is required. This will account for a cost saving beyond the actual energy saving since no alternative heating systems need to be installed and no associated fixed cost which goes with high electrical current abonnement or district heating connection/capacity costs.

Table 4 The distribution between the heat users vs month in the Gimo ice rinks.

Heat recovery	**Oct '14**	**Nov '14**	**Dec '14**	**Jan '15**	**Feb '15**	**Mar '15**	**TOTAL (MWh)**	**TOTAL [%]**
Dehumidification [MWh]	0.2	0.2	0.2	0.2	0.2	0.5	1.7	0.4%
Radiators [MWh]	7.6	8.2	10.4	10.7	9.7	10.2	56.9	12.2%
Water heating [MWh]	7.3	8.6	9.4	10.4	9.6	9.3	54.5	11.7%
Ventilation [MWh]	50.5	44.2	65.6	63.7	52.7	55.1	331.9	71.2%
Freeze protection [MWh]	3.2	3.8	3.2	4.0	3.3	4.0	21.5	4.6%
TOTAL [MWh]	68.8	65.0	88.9	89.0	75.5	79.1	**466.4**	**100.0%**

The dehumidification system heat usage is close to zero and looks like the electrical corresponding table for the same reason – the system was hardly used during the studied period.

As one part of the building heating distribution system a radiator system was used. This primarily provides locker rooms, bathrooms and some common spaces with heating. It accounted for 12% of the total heat used during the season.

Another important heat usage category is the warm water supply which provides the ice resurfacer as well as all warm tap water in the building including showers. It also accounted for about 12% of the total heat used during the season.

The major heating demand is the ventilation system since it heats the ice rinks space. When looking at the figures throughout the season it can be seen that the heat usage has changed a bit which is to some extent due to ambient temperature but also tuning of the systems.

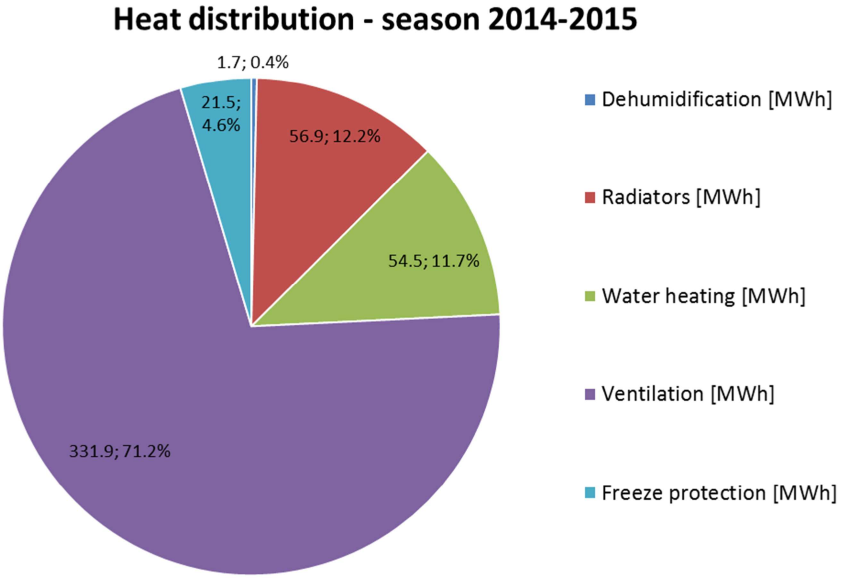


Figure 38 Heat distribution during the season 2014/15.

That the ventilation system has a rather constant and high energy usage is due to the fact that this is the major contributor to balance the cooling effect of the ice. As was described previously the heat transfer to the ice comes from four dominating mechanisms which are convection (temperature of the air), condensation (moisture in the air), radiation from the building interior and resurfacing. The convective part is the dominating share and to maintain the air temperature on the desired level the air needs to be heated with close to same convective heat as what is transferred to the ice. There are some other systems contributing to the heating of the air in the ice rink such as the dehumidification and the losses from the lighting. Other sources may be spectators, players and other equipment which rejects heat in the ice rink space.

A small heat user in this context is the freeze protection which supplies heat under the rink slab insulation in order to avoid freezing of the ground. Essentially it compensates for the heat losses from the ground through the insulation to the rink floor piping. On average this heat need correspond to only a few kilowatts.

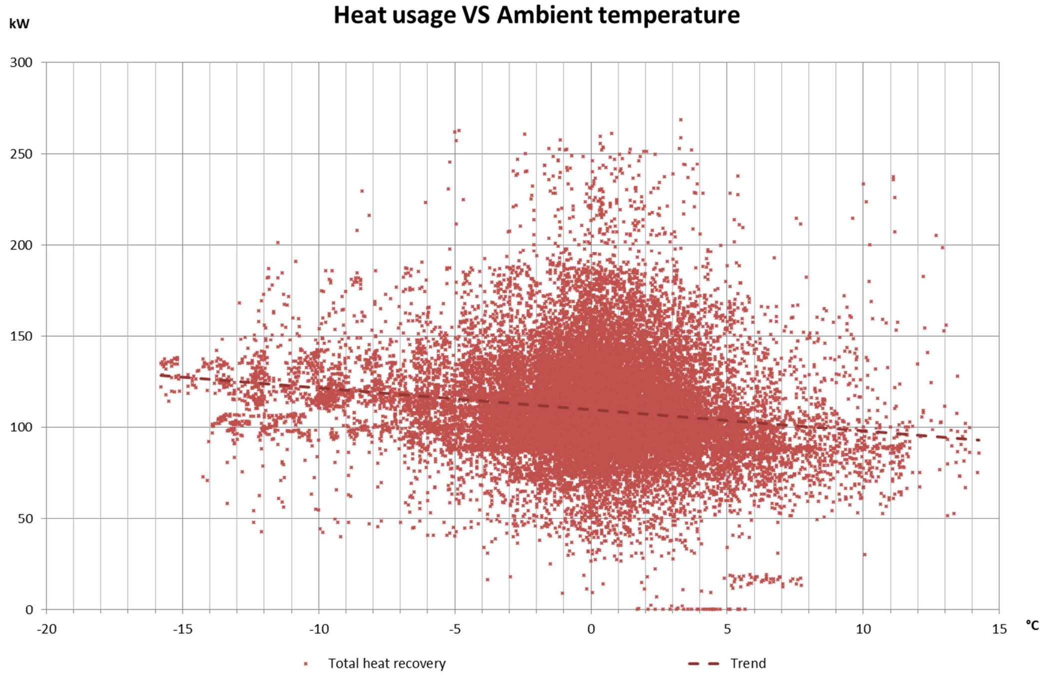


Figure 39 Total heat usage vs ambient temperature during the season 2014/15.

An interesting parameter when designing heating systems for ice rinks is the total heat power demand of the facility. This will obviously vary with the building size and design as well as the climatic conditions. Often the design heat power is overestimated due to superimposed needs for worst case scenarios. With system solutions including accumulation and preheating sequences the peak demand can be reduced. The heating system concept in the Gimo ice rink is an example of where this design is applied.

If the heat power for the facility is studied during the season a wide range of data is obtained according to Figure 39. The scatter stems from the fact that the heat is measured on the heat recovery side and depending on the refrigeration system operation large amounts of heat may be available. Further, due to the accumulation built into the system large amount may be absorbed as well, however, for a limited time, which is the whole idea with accumulation.

The heating system will be further discussed later in the report but it can already be concluded that a well-designed accumulation function reduces or eliminates the need for supplementary heating, since it also on the user side absorbs the peak loads. An obvious example of the latter is the warm water consumption for showers and resurfacer.

4.2 ENERGY SYSTEM PERFORMANCE

The aim with this chapter is to treat every energy system and study the individual performances from different aspects. The refrigeration and heating system are closely interlinked and sometimes difficult to separate.

4.2.1 REFRIGERATION SYSTEM

When studying the refrigeration system it is important to keep in mind that this is not only a refrigeration function but also heat pump which implies that the energy used by this system is used for both cooling and heating. Primarily the system is there to keep the rink floor and ice at the desired temperature but the added heat recovery function as well as geothermal connection provides a reliable heating function as well. To refresh how the system layout looks and the concept works Figure 40 is shown below.

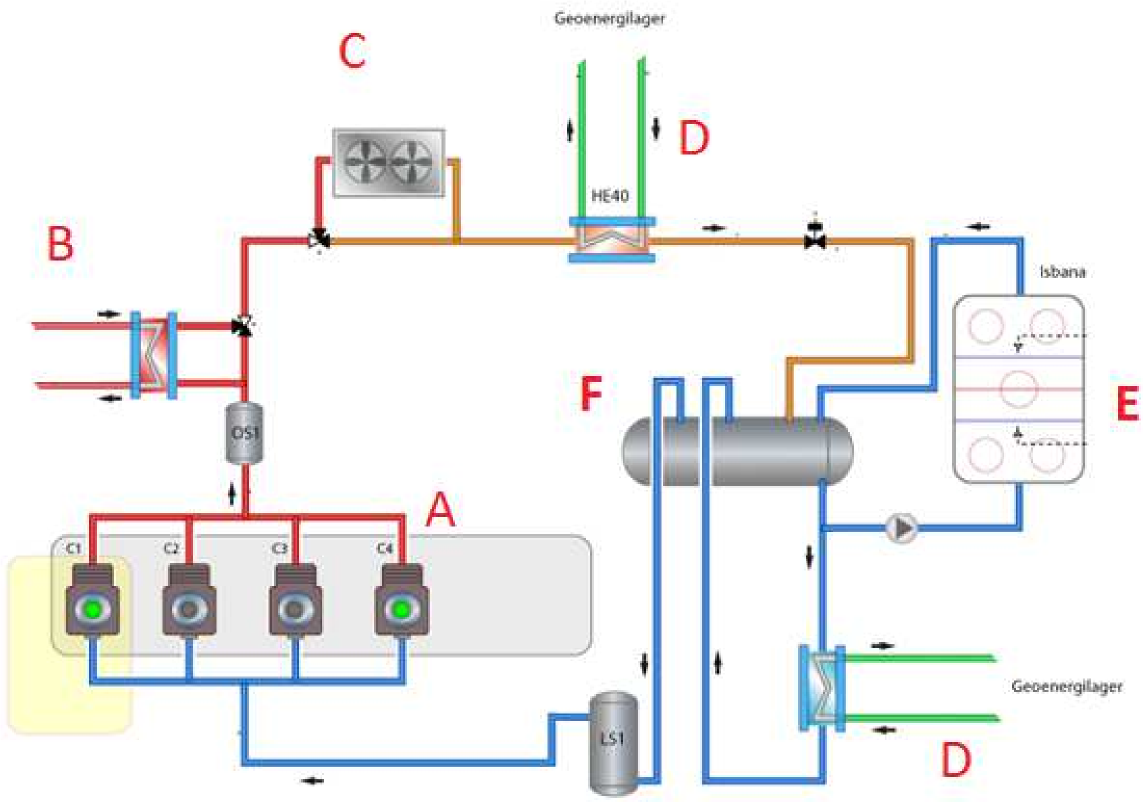


Figure 40 CO2 refrigeration system including heat recovery, geothermal and rink floor.

<u>Energy usage by function</u>

One of the advantages of CO2–systems as oppose to the conventional indirect systems for these applications is that the energy usage of the supplementary equipment is low. In the latter category one normally place pumps for secondary fluids as well as dry cooler fans which for many conventional systems may account for 10 to 25% or more for older systems. This share will depend on the type of pumps and fans as well as if they are capacity controlled or not. Another important factor is whether the refrigeration system has a heat recovery function or not, since a larger share heat recovery will reduce the need for the dry cooler fans to operate.

Table 5 The electrical energy distribution in the refrigeration system vs month in the Gimo ice rink.

Refrigeration energy users	Oct '14	Nov '14	Dec '14	Jan '15	Feb '15	Mar '15	TOTAL (MWh)	TOTAL (%)
Compressors [MWh]	30.8	27.8	32.8	33.4	29.8	30.8	185.5	98.1%
CO2-pump [MWh]	0.4	0.4	0.4	0.4	0.4	0.4	2.3	1.2%
Gas cooler [MWh]	0.3	0.4	0.3	0.1	0.1	0.1	1.4	0.7%
TOTAL [MWh]	31.6	28.6	33.5	33.9	30.3	31.3	**189.2**	**100.0%**

In Table 5 as well as in the pie chart

Figure 41, the respective contribution for the compressors, CO2-pump and gas cooler fans can be seen. The share of the auxiliaries for the Gimo CO2-system is below 2% which is very low and as stated above – one of reasons why CO2 becomes as efficient as it does.

Figure 41 shows the total electrical energy usage for the 6 months of operation.

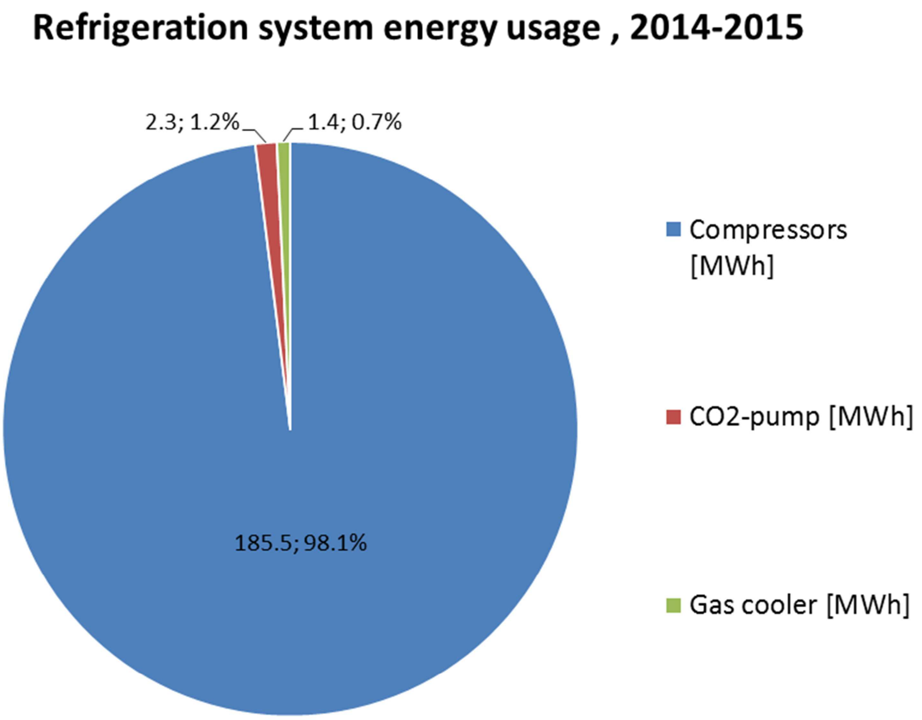


Figure 41 The electrical energy distribution of the refrigeration system in the Gimo ice rinks.

Cooling capacity

The cooling capacity is close to the "total heat load" of the ice rink. What technically may differ between these terms are the potential heat losses to header and distribution pipes on the secondary fluid side, other than that it is correct to consider the calculated cooling capacity to equal the ice sheet load. There is, however, a thermal lag (inertia) in the response from the refrigeration system since the heat loads need to be transferred through the ice and rink floor to the refrigeration tubing and further to the refrigeration system before it sensed by the system.

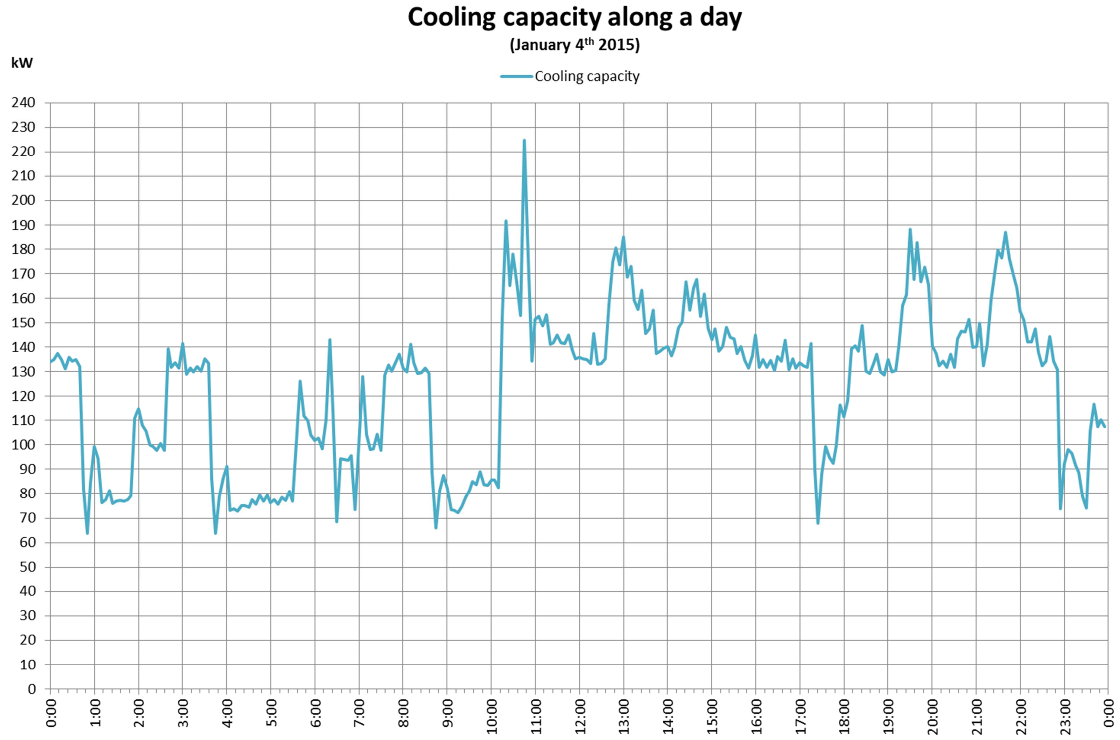


Figure 42 Cooling capacity of refrigeration system for a 24 hour period.

In Figure 42 the cooling capacity during 24 hours is plotted to show the level and the dynamic. The actual load does not very like the graph suggests but is rather a control issue of the refrigeration systems since it happens to be switching between one and two compressors way too frequently. The load corresponds to a cooling capacity which is right between the capacities of one and two compressors. It can however, be seen that the night time load is around 100 kW and when the activity takes off in the morning it increases to 140-150 kW. Normally the “activity load” is related to an increased turbulence on the ice sheet due to the skaters, contribution from the light and the major part which is the resurfacing load.

Another interesting perspective is to look at the influence of the ambient temperature, however, the ambient temperature in itself does not affect the load but normally a high ambient temperature will contribute to a higher indoor temperature. There are other driving forces such as the state of the building which will determine the heat leakage and the subsequent ceiling and wall temperature. These surfaces radiate heat to the ice surface and if the building envelope is poorly insulated the radiation contribution may become significant. In Figure 43 it can be seen that the influence of the ambient temperature is not particularly strong. In this case the indoor temperature is relatively constant and the building envelope, especially the roof construction which is new, is in a good state i.e. well insulated.

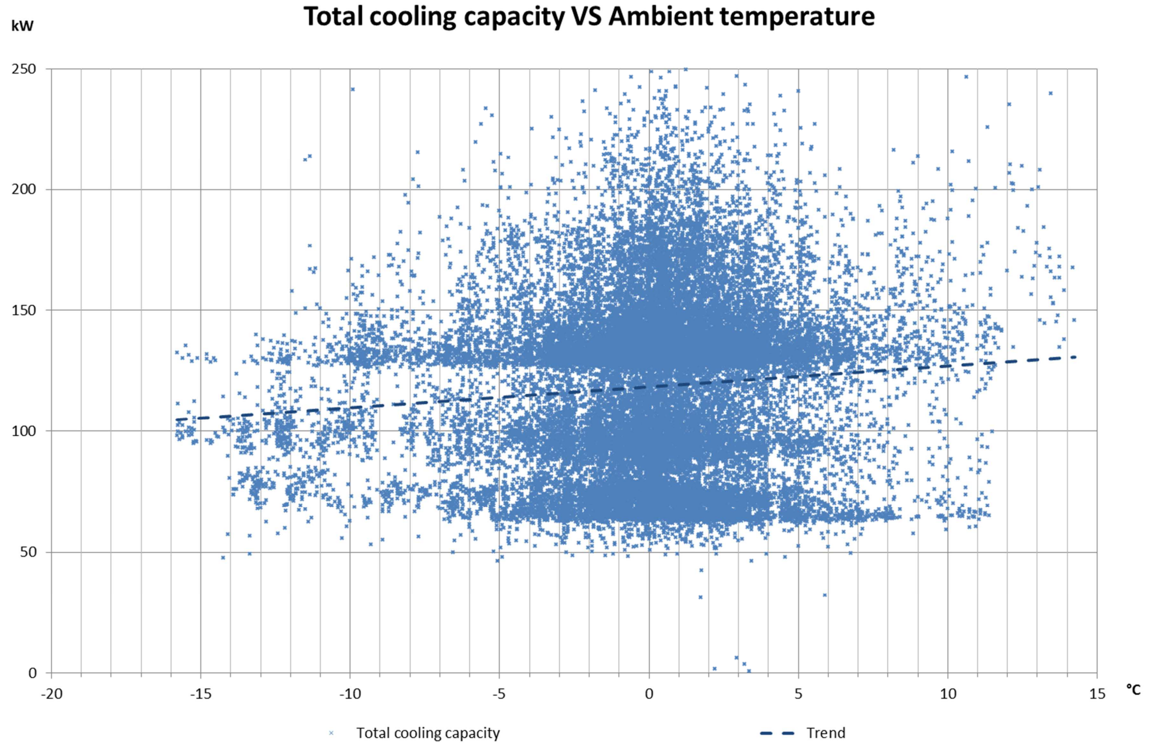


Figure 43 Cooling capacity of the refrigeration system vs ambient temperature.

As indicated above the actual indoor temperature is the strongest driving force when it comes to the total heat load and the subsequent cooling capacity demand. It turns out when studying the influence of the indoor air temperature that is drives not only the convective part as one may intuitively think, but also radiation and diffusion (condensation). The walls and ceilings interact with the ice due to radiation which cools the surfaces of those. To stay in heat balance the surface temperature drops and a heat transfer from the air and/or the outside of the construction occur. Since indoor air does transfer heat to the interior surfaces it will contribute to the radiation.

Most ice rinks control their dehumidifiers based on relative humidity which implies that a higher indoor temperature will lead to a higher moisture content in the air. The latter implies a larger impact from diffusion i.e. water from the air condensing on the ice surface. Having this said it is clear that the indoor temperature is a dominating contributor to the heat load on the ice, although far from everything comes from the convective part.

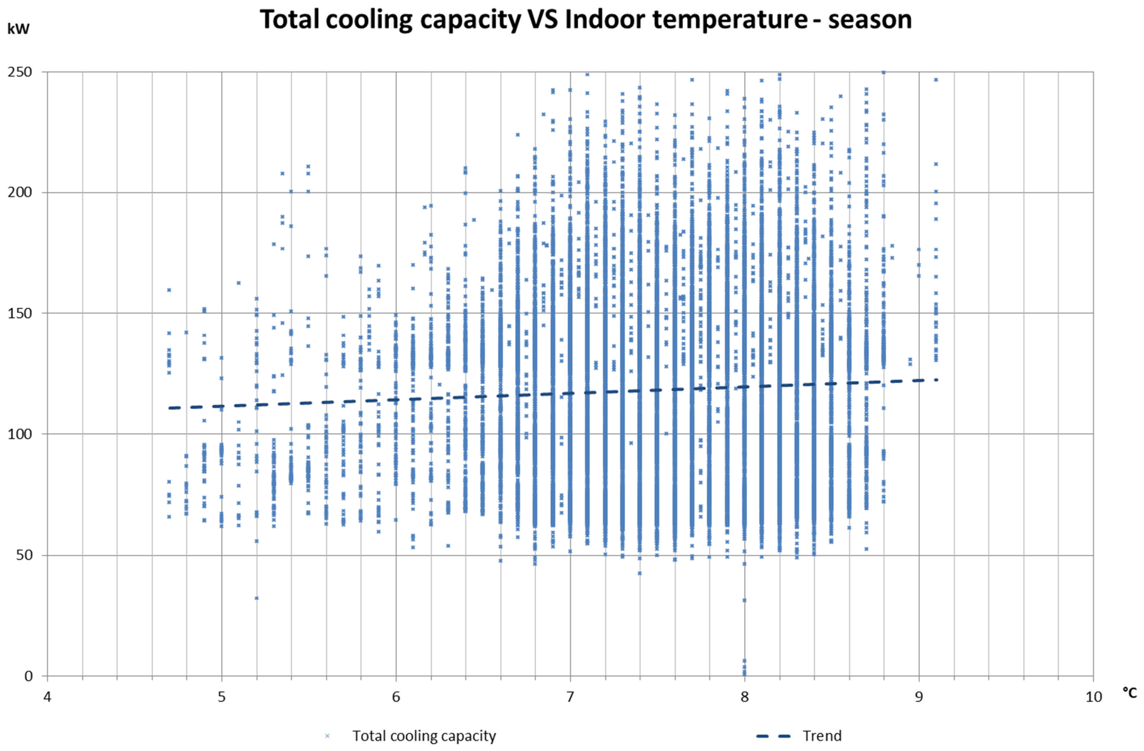


Figure 44 Cooling capacity of the refrigeration system vs indoor temperature.

In the dependency from the indoor air temperature on the cooling capacity is shown. Since the temperature is controlled in a rather narrow band, around 7-8 °C the effect of the temperature does not appear to be pronounced, however, a wider available range of temperatures may have illustrated the effect better.

Coefficient of Performance, COP

Coefficient of Performance is defined as the delivered useful cooling capacity in relation to the absorbed electrical power of the system. There are different boundaries for COP which can be defined for the compressors only or including the auxiliary equipment such as pumps and fans as well. In this case the latter is displayed although the difference is small for this specific system since the auxiliary equipment consumes so little energy (power). Another thing one must remember when looking at these COPs is that the system is almost permanently in heat recovery mode since we have a significant heat demand to cover. This drives the head pressure to higher levels than normally necessary which reduces the COP_2 (cooling) but increases the corresponding COP_{HR} for heating. The latter will be covered later when the heat recovery system is discussed.

In Figure 45 the COP vs ambient temperature is plotted and the general trend is with a first glance surprising since it decreases with decreasing ambient temperature. Normally we would expect it to be the other way around, however, this is explained by what was just discussed above namely the increasing need for heat recovery as the ambient temperature drops. Further, a closer look reveals two levels of COPs along the temperature scale and the explanation to this is also to be found in the heat recovery demand and control. When the cooling capacity is low the heat available to be recovered becomes low as well. In order to compensate for this the control system elevates the head pressure and consequently the COP2 decreases.

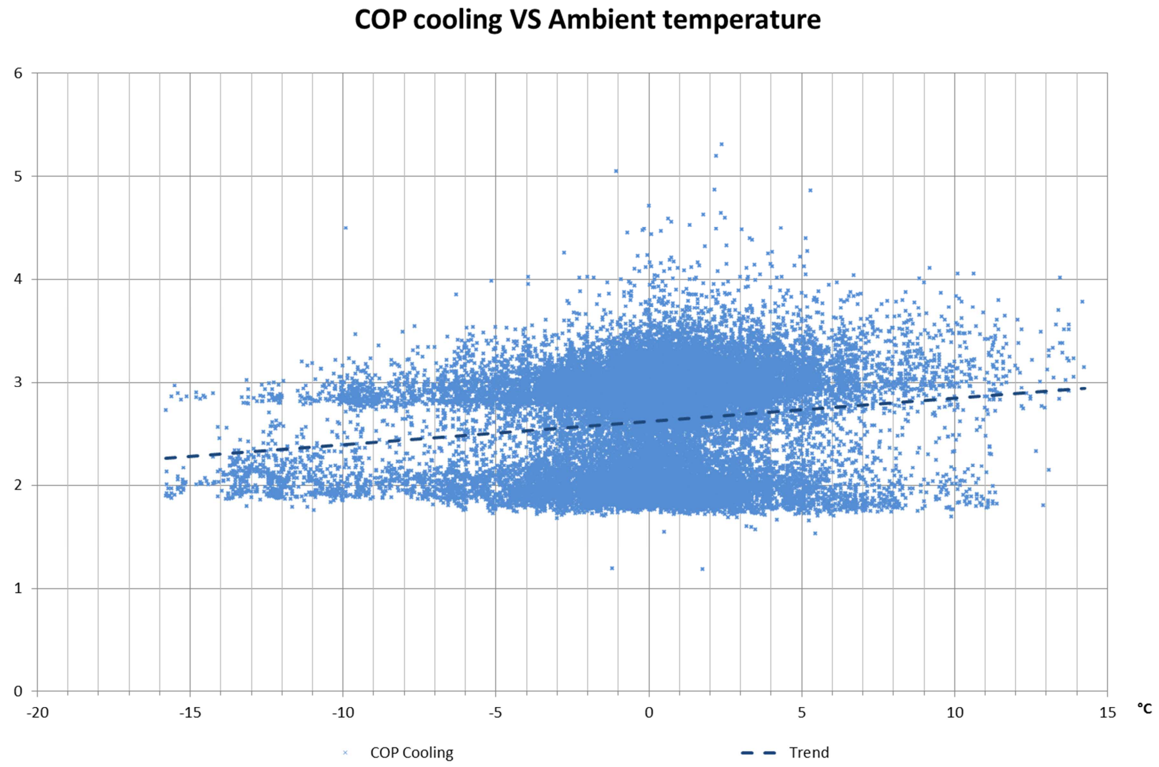


Figure 45 COP of the refrigeration system vs ambient temperature.

To further illustrate the correlation between the cooling capacity control and the COP_2 a 24 hour period is selected in Figure 46 where these two parameters are plotted. A clear shift in COP_2 is seen when the cooling capacity decreases, which is explained by the pressure increase as mentioned above. To improve this situation the compressor control would need to be smoothened out to avoid the drop in cooling capacity.

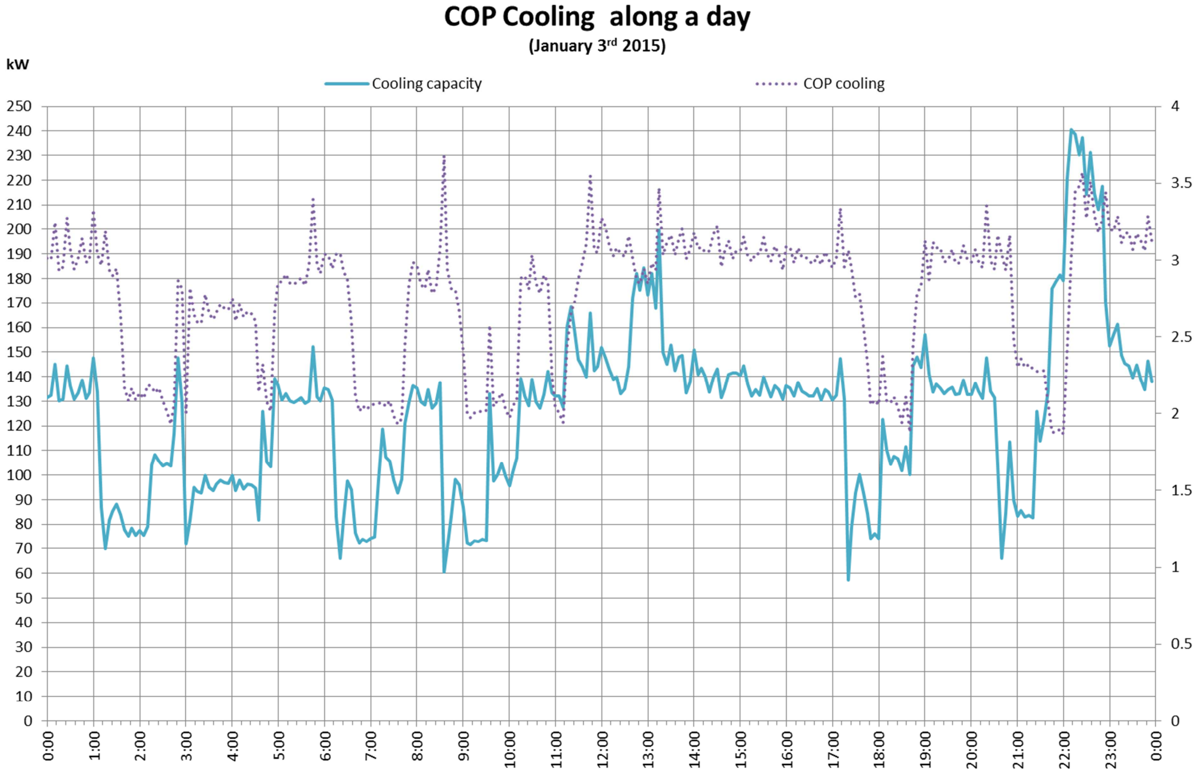


Figure 46 COP and cooling capacity of the refrigeration system vs a 24 hour period.

During night time load is very stable and normally the capacity control should stable as well. The current situation is explained by an unfortunate match of the compressor sizes and perhaps with the applied control strategy. Further, the head pressure control which adapts the heat recovery to the demand is a bit rough and overreacts in that it perhaps elevates the pressure too much and drops it too quickly when the need is covered.

The upside of resolving this control issue is considerable since the difference in COP2 between the low and high band in this example is 2.0 vs. 3.0, which corresponds to a 30% difference. Since so much heat is recovered the “loss” is limited but it is still of great interest to improve the control and not the least it may extend the lifetime of the system and components as well.

4.2.2 HEATING SYSTEM

The heat recovery function design is key with the use of CO2 as refrigerant. Not only is the heat recovery potential a potential asset of CO2 but also one of the main technical arguments to the use of CO2. When comparing CO2 with for instance ammonia (NH3) the heat recovery potential is a factor that makes a difference.

Figure 47 indicates how the different functions are oriented starting with the heat recovery heat exchanger (B), followed by the tap water heating (A), dehumidifier circuit (C), radiator circuit (D), resurfacer water heating (E), ventilation circuit (F), water preheating (G) and the subfloor heating (H).

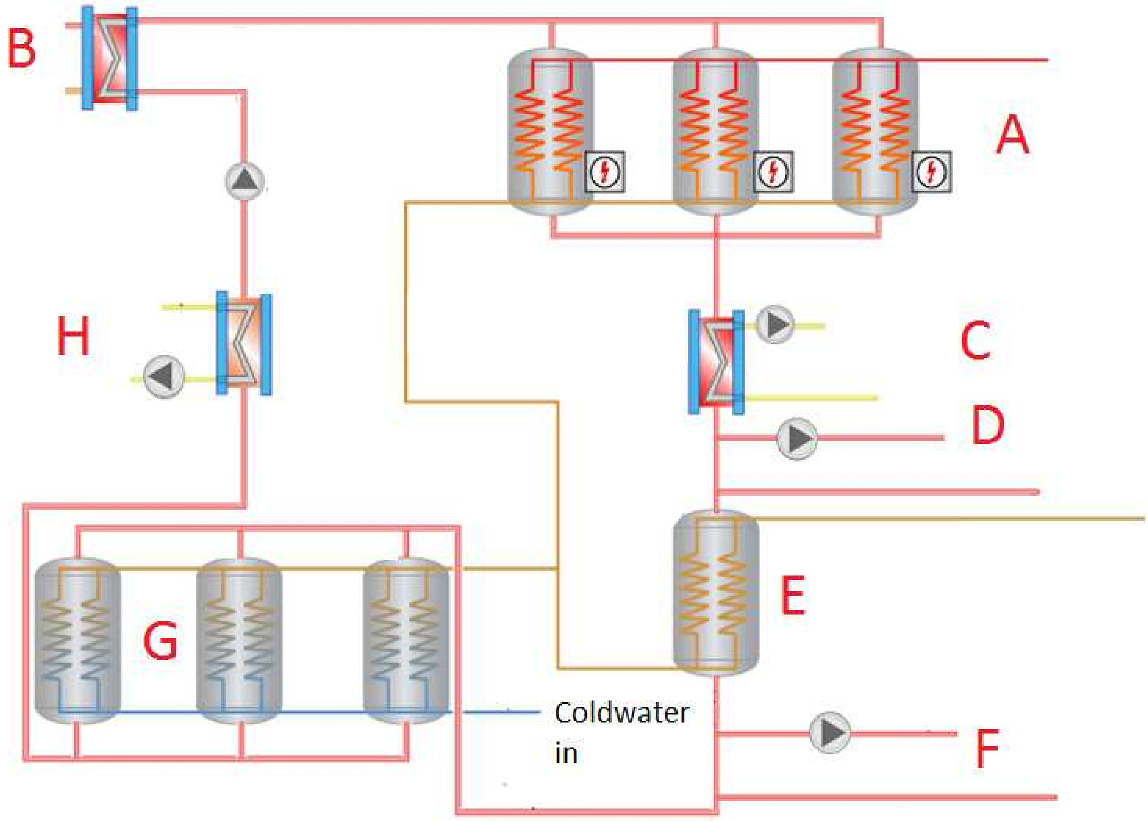


Figure 47 Heat recovery system including water, space and subfloor heating.

To illustrate the dynamics of the heating system a “normal” day is chosen to show how the heating need vary with time, Figure 48. This day is a Sunday and telling from the water consumption there is apparently activity in the ice rink from the morning to the evening at 21.00. It should be noted that no set back temperatures are applied on the heating systems which was originally the idea. This is due to the fact that the existing heating equipment in the ice rink space has very limited capacity and consequently the time to recover the temperature was unacceptable, therefore the temperature is left practically constant.

From the graph is can be seen, as previously concluded, that the dominating heat demand is the ventilation system with a night time capacity of about 80 to 90 kW. The peaks and drops in the curve are generated by the low load compressor control which is somewhat jumpy since the cooling capacity need happened to correspond to just between one and two compressors. During the rest of the day the demand seems to be rather constant which may be due to the fact that the air heaters and ventilation unit run on full capacity. It is not much of controllability left as far as the air temperature is concerned, which is however maintained at 7-8 °C throughout the season.

The water heating displayed is a sum of pre-, resurfacer- and tap water heating which indicates the high heating capacity required for water heating and how that can be handled by this system. The radiator circuit represents a rather constant heat demand but will vary with the ambient temperature since it account for most of the space heating when it comes to locker and bathrooms as well as common spaces heated to about 20 °C. Another small and rather constant load is the freeze protection which only account for about 5-10 kW. The last line which is hardly visible is the dehumidification which, as commented previously, has hardly been used and therefore shows essentially no contribution.

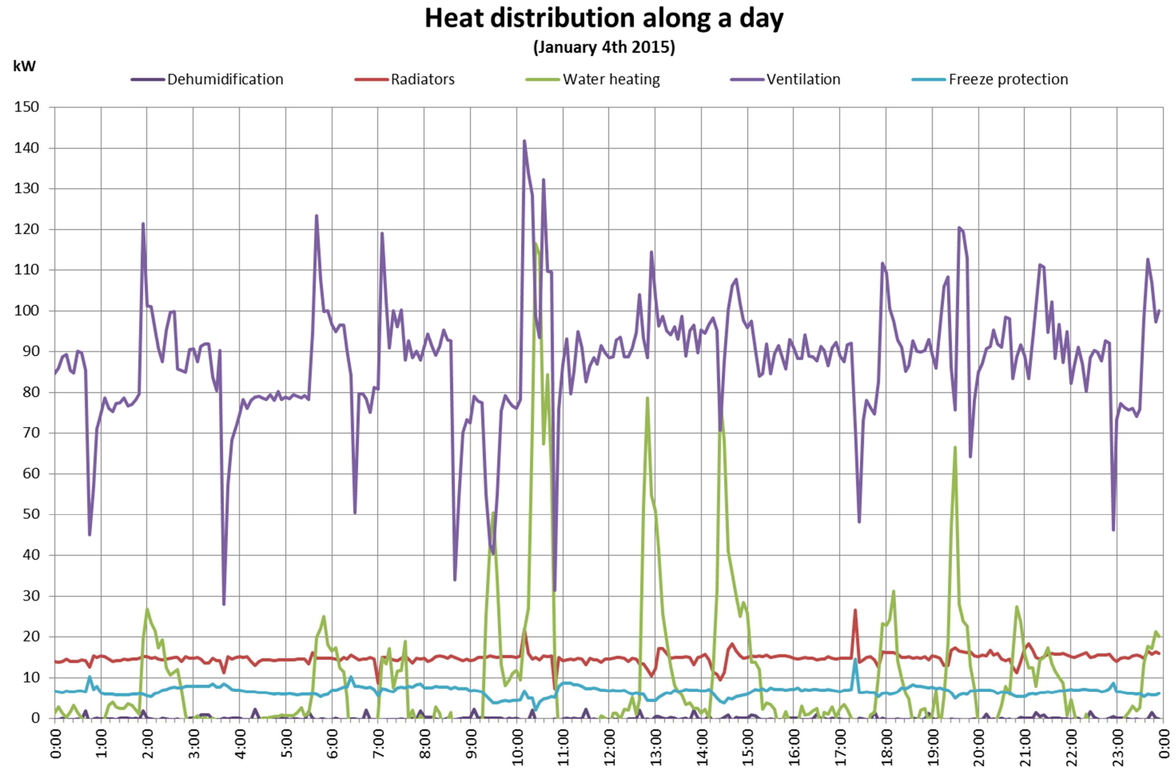


Figure 48 The respective heat demands and their dynamics during Sunday 4th of January.

In order to show the dynamics of the major heat loads together with the most relevant parameters the ventilation as well as the radiator heating systems are plotted vs the ambient temperature in the graphs that follows.

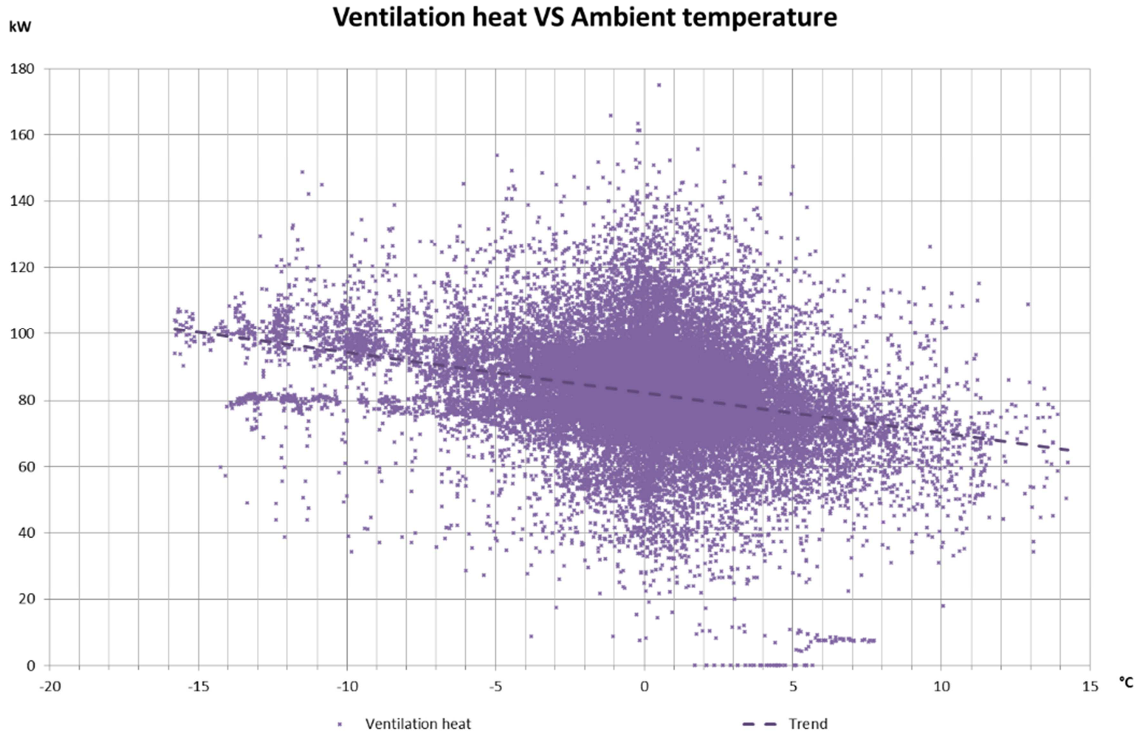


Figure 49 The ventilation system heat demand vs the ambient temperature during the 14/15 season.

In the ventilation system heat demand, the ice rink space dominates the need, but it also supplies the machine room as well as the resurfacer garage. Most of the time the heat demand is around 80-90 kW and increases for this specific ice rink up to and above 100 kW at temperatures below -15 °C.

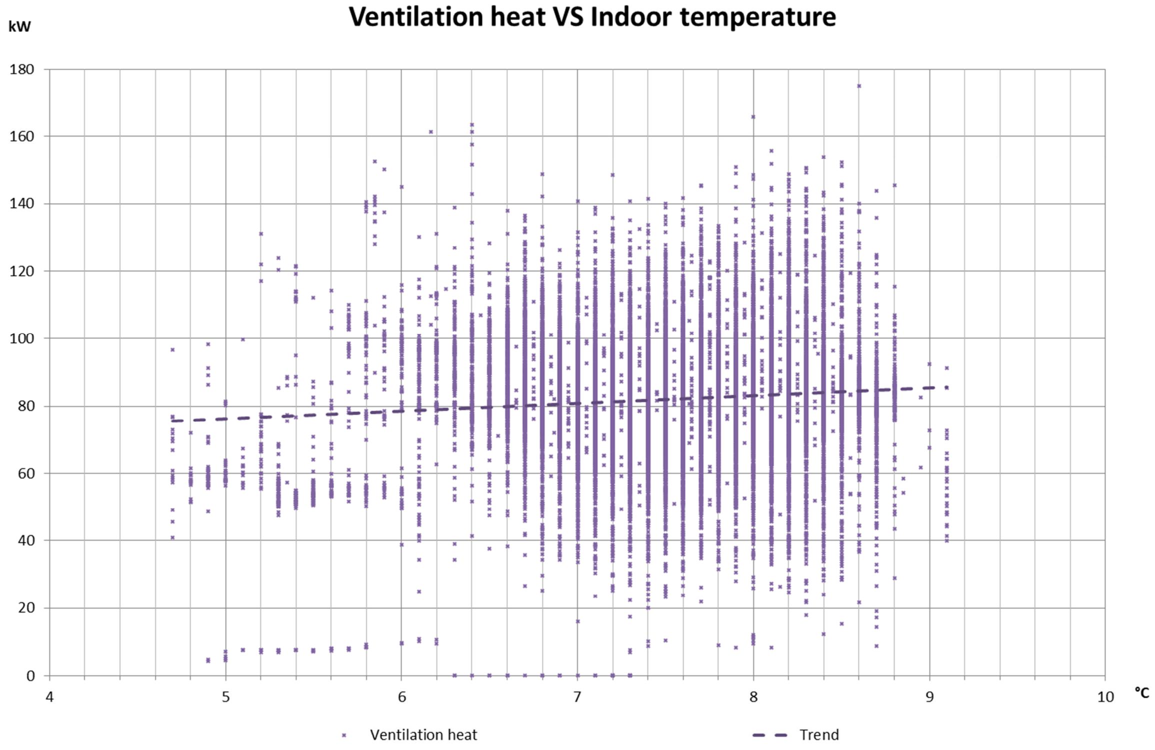


Figure 50 The ventilation system heat demand vs the indoor temperature during the 14/15 season.

Another way to look at the heat demand in the ice rink is to plot it vs the indoor air temperature. As expected the heat demand increases with increasing temperature, however, this data does not tell at what ambient temperature this condition is.

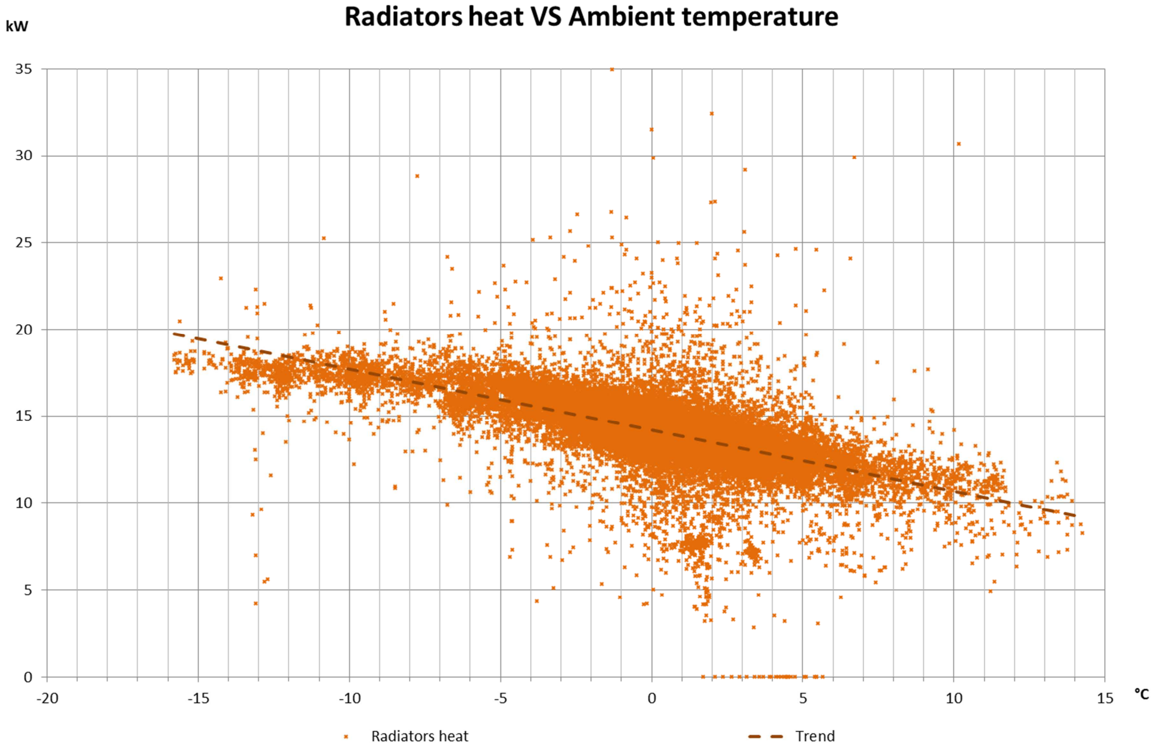


Figure 51 The radiator system heat demand vs the ambient temperature during the 14/15 season.

In Figure 51 the radiator system heat demand is analysed vs the ambient temperature and quite logically it follows the ambient temperature nicely. As mentioned above this system provides spaces heated to about 20 °C and these are mainly located on the outside of the ice rink with outer walls facing the ambient. The radiator heated building surface is around 600 m^2 which gives about 35 W/m^2 at design temperature (-20°C) which is reasonable.

4.2.3 HEAT RECOVERY SYSTEM

The function of the heat recovery system is very essential considering the potential using CO_2 and secondly this ice rinks no other heating system so it has to work! The aim in this section is to show how much is heat is available, recovered and what is the “price” for the recovered heat.

Heat available

By analysing the refrigeration system during the season the amount of heat per month can be calculated. In the table below the available heat has been compiled together with the recovered and rejected heat. The latter is divided into whet goes to the geothermal storage and what is released to the ambient air.

Table 6 The heat available, recovered and rejected from the refrigeration system vs month.

	Oct '14	Nov '14	Dec '14	Jan '15	Feb '15	Mar '15	TOTAL [MWh]	TOTAL [%]
Total heat available [MWh]	120.3	109.0	119.4	121.3	108.0	117.2	**695.3**	**100%**
Heat recovered [MWh]	75.8	70.2	93.2	93.6	80.5	86.3	499.6	72%
Heat rejected via gas cooler [MWh]	37.7	34.1	21.1	22.2	23.7	25.8	164.7	24%
Heat rejected in geothermal storage [MWh]	6.8	4.8	5.0	5.5	3.9	5.0	31.0	4%

As the Table 6 above shows the available heat is relatively constant around 100 MWh per month throughout the year. The available heat is mainly dependent on the load situation in the ice rink in the sense that the more cooling capacity the more heat is available on the warm side of the system. In general a large portion of the available heat is used which is good. During the first season although there are still some tuning and improvement to do the monthly average is around 70 MWh corresponding to above 70% of the available heat.

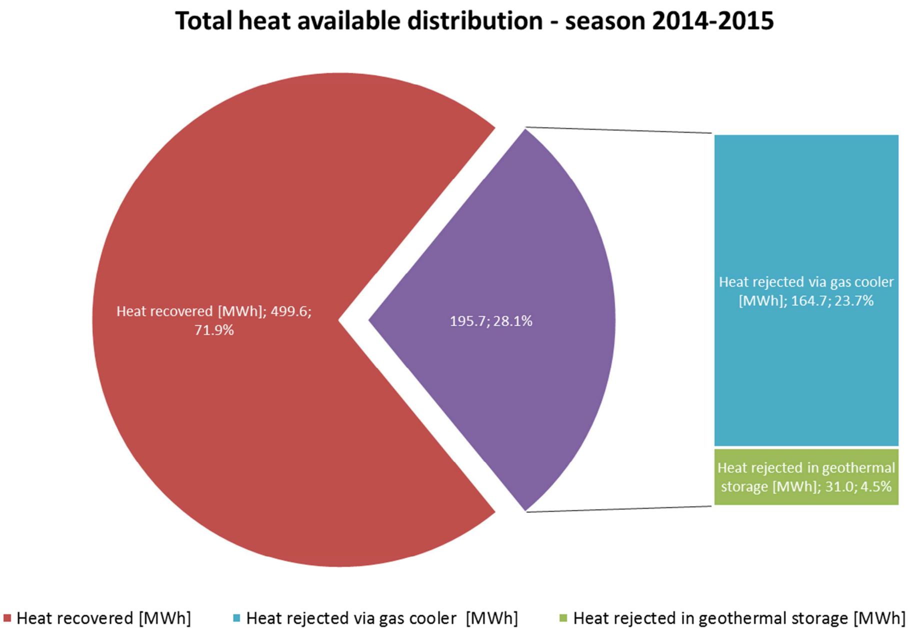


Figure 52 The total available heat and how it was used during the ‘14/’15 season.

Since the Gimo ice rinks has a geothermal storage the surplus heat may be rejected to the storage or the ambient air. The Table 6 and the pie chart Figure 52 show the amount rejected heat which is distributed as 22% to the ambient air and 6% to the geothermal storage. This may seem surprising but can be explained by the fact that the geothermal storage and the subcooling function should primarily be used during warm conditions and the ice rinks was taken into operation in October so the conditions were not ideal for evaluation of the geothermal storage.

It can be concluded that the control of such a heat recovery system is a rather complex task which requires further evaluation and development.

Performance of the heat recovery

One way to get an idea as to the total performance of the system is to form a so called global COP which includes both the useful cooling capacity and the heat recovered. Below it can be seen that the global COP scatters significantly but seem to have an average around 5 during a season.

$$COP_{Global} = \frac{Q_{cooling} + Q_{HR}}{E_{comp}}$$

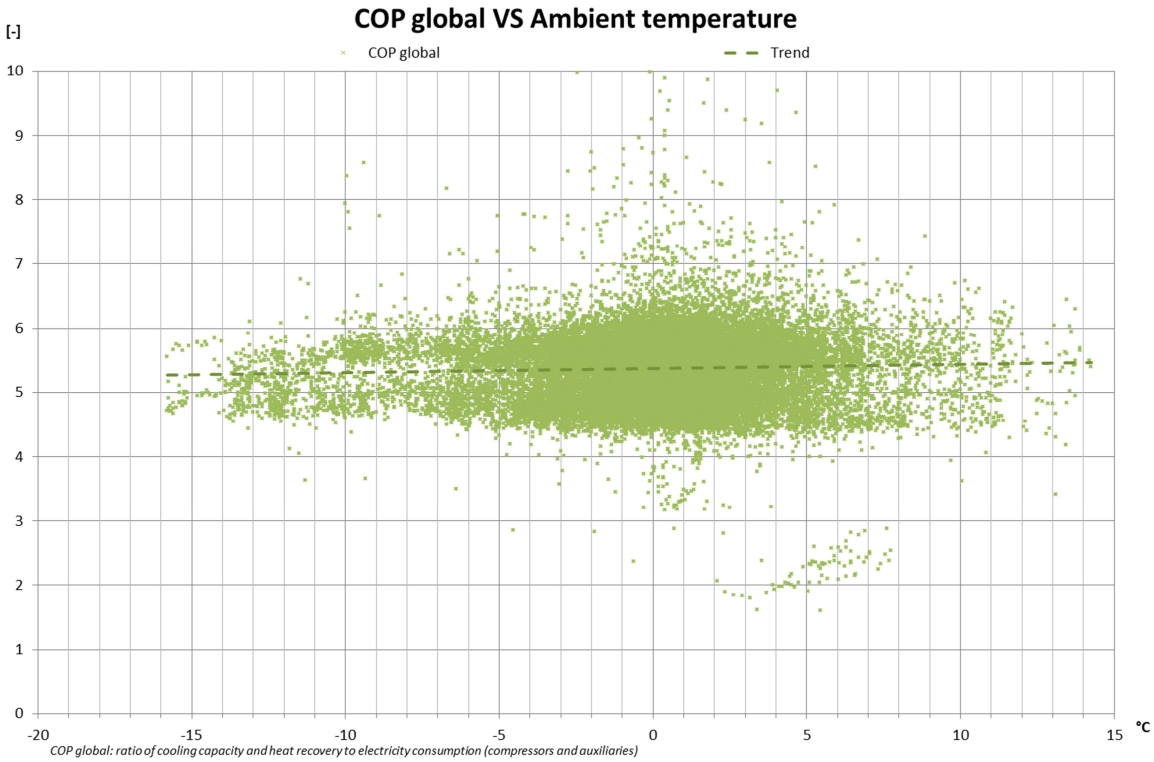


Figure 53 The global COP including cooling and recovered heat vs the ambient temperature.

In order to take the performance analysis of the heat recovery function one step further another COP is defined which is referred to as heat recovery COP, COP_{HR}, and defined according to the equation below where Q_{HR} is the recovered heat, E_{comp} is the actual compressor power input and E_{FC} is the compressor power in floating condensing.

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

The compressor energy of floating condensing E_{FC} is calculated as if the system was operated without heat recovery, in this case the condensing temperature is controlled by the ambient temperature. If the ambient temperature is lower than 5 °C the condensing temperature in floating condensing mode is fixed at 10°C. Otherwise, when the ambient temperature is higher than 5°C the condensing temperature is equal to the ambient temperature plus 5 K. It should be pointed out that the compressors in practice can be operated at lower condensing temperatures than 10°C which in this analysis would somewhat reduce the COP_{HR}.

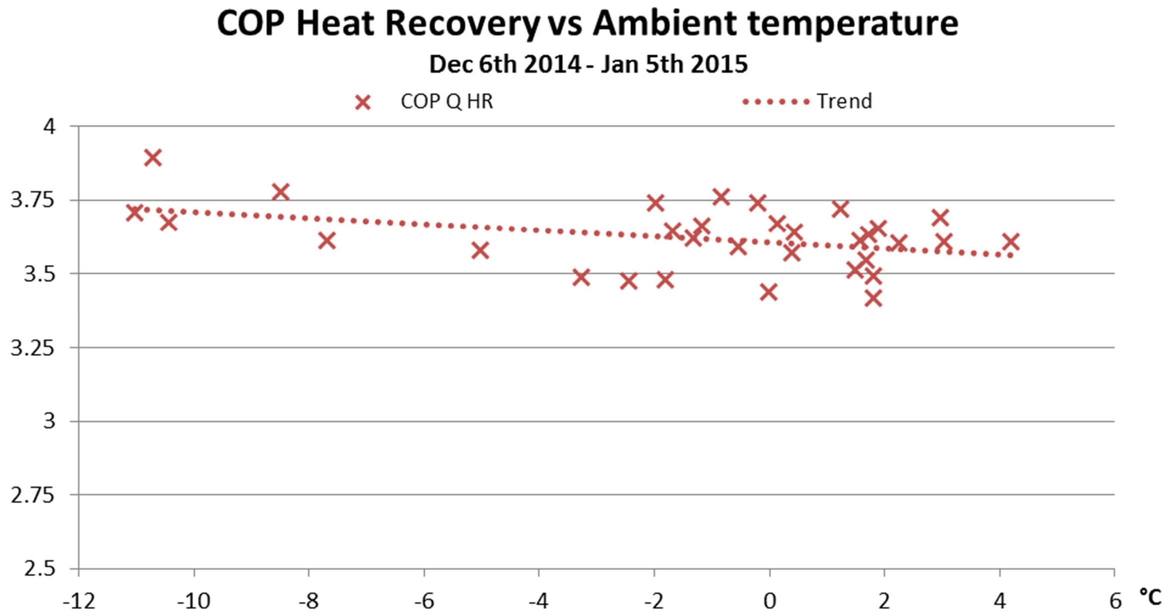


Figure 54 The heat recovery COP, COP_{HR}, vs the ambient temperature.

As mentioned above the coefficient of performance of the heat recovery is defined as the ratio between the heat recovered and the additional compressor power used to provide that heat, which is the difference between the power used of the refrigeration system in heat recovery mode and floating condensing mode. The COP_{HR} versus ambient temperature is plotted in Figure 54 and it can be concluded that the level of the COP_{HR} is between 3.5 to 4 and increases as the ambient temperature decreases.

This COP can be compared with any other heating system or heat pump for that matter, which would provide the heat to the ice rinks. Provided that this function, in this case, requires very little extra investment and yields a COP comparable with most heat pump solutions, it does look like an attractive option.

Heat pump function

The integrated heat pump option which would use heat from the geothermal storage to support the heat recovery function was never in operation during the first season. With the current heat recovery system control strategy it was never considered since the elevated head pressure manged to cover the heat demand. In this evaluation it can be seen that there would be room for improvement in the control strategy which would include running the heat pump function more frequently.

4.2.4 DEHUMIDIFICATION

The dehumidifier was rarely in operation during the 14/15-season due to an initial fault in the configuration which took until March to resolve. So it was only at the end of the season that it was briefly in operation, however, to be able to evaluate the performance data from the beginning of the season 15/16 has been used. Since this season started as early as mid-July it will show the toughest part of the season and not be representative for a whole normal season. The data is analysed anyway to get a picture of the function and energy usage.

The idea was to use as much recovered heat as possible to preheat the reactivation air to the dehumidifier. This heat is traditionally generated by electricity through resistance heaters, but since an ice rink normally has waste heat available it seems to be a better idea to use that. The energy supply to the dehumidifier is measured as total electricity including fans and other electronics and heat from the heating system. This implies that the electrical share includes functions that cannot easily be replaced by other forms of energy such as the mentioned fans, etc. Further, is can be mentioned that the original electrical heaters were to some extent blocked to avoid too much electrical power to be used. Out of three power steps one was blocked in order to allow more recovered heat to be used.

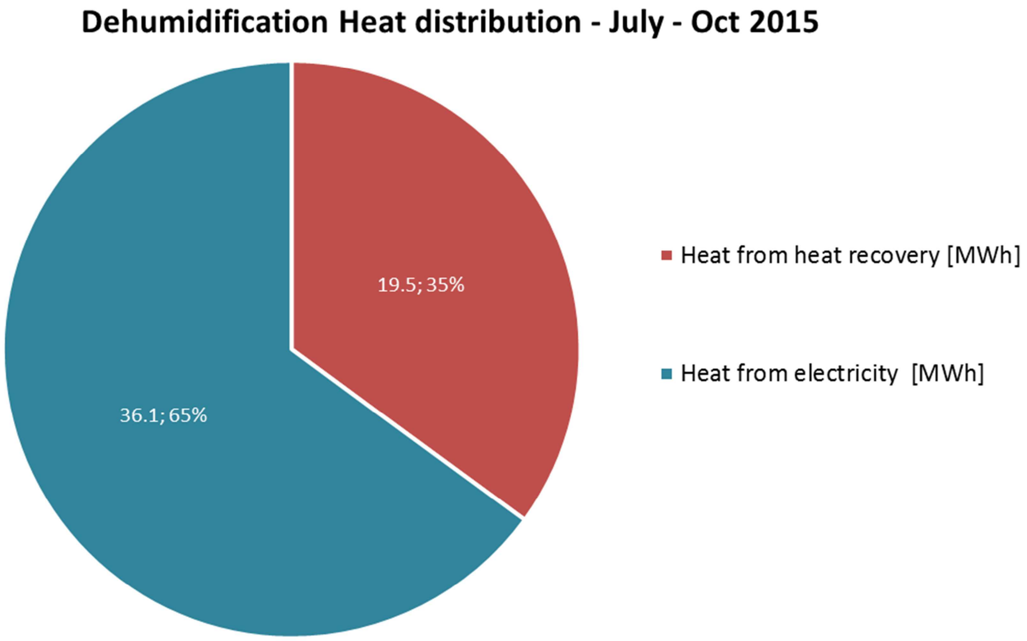


Figure 55 The overall energy usage for the dehumidifier from mid-July to October.

Looking at the total energy supply for the July to October period one can see in Figure 55 that about a third has been supplied by recovered heat. In total the dehumidification function has already used about 55 000 kWh in the first 3.5 months of the season which illustrates how demanding this function may be from an energy perspective. The good news are obviously that almost 20 000 kWh originates from the recovered heat.

The need for dehumidification vary a lot between different ice rinks depending on the state of the building envelope as well as the activity level. Further, the door arrangements and whether they have airlock functions or not is important as well. In that perspective the Gimo ice rink is probably on the "above average side" in a positive sense, since it has a reasonably good building envelope as well as a separate resurfacer garage with an airlock function to the ambient.

To further illustrate how the energy demand vary with the ambient conditions the used electricity as well as recovered heat is plotted vs the months during period July to October 2015, Figure 56. As can be seen the total energy per month is very dependent on the time of the year and decreases from about 22 000 kWh in August to less than 6 000 kWh in October. This dependency is nothing new but once again illustrates the need for sealing these buildings as far air leakages are concerned.

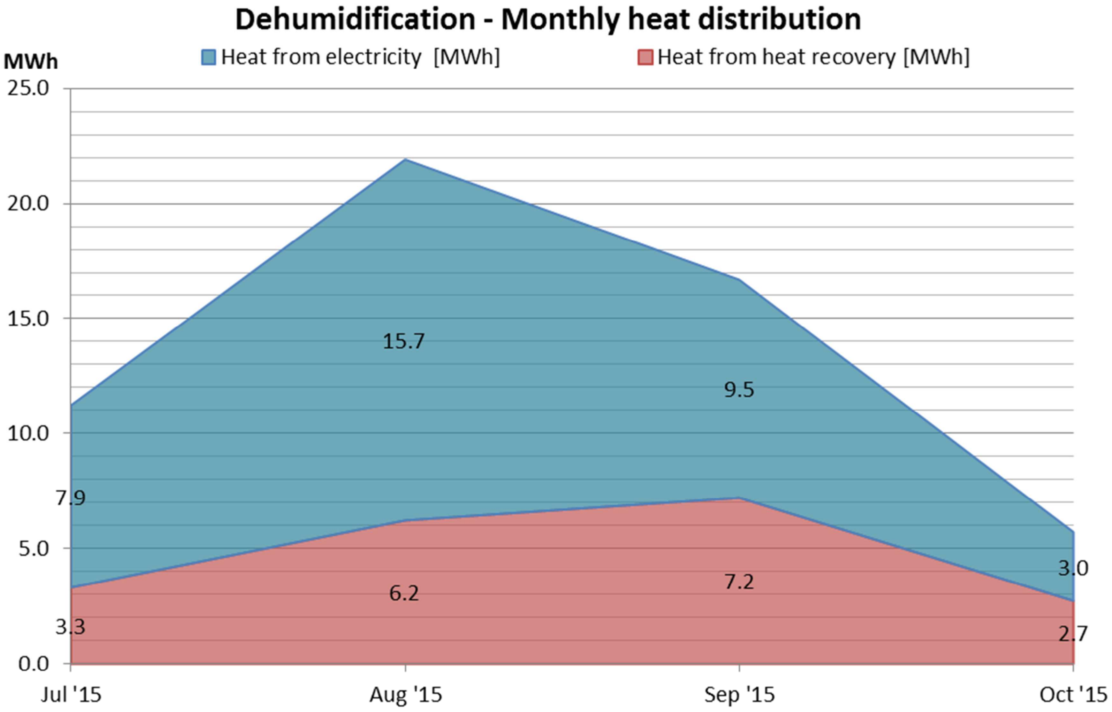


Figure 56 The energy usage as electricity and heat for the dehumidifier from mid-July to October.

This dehumidifier is controlled based on absolute humidity which is almost the same as dew point control. The idea behind this is that regardless of the air temperature inside the ice rink the humidity content should be the same. Perhaps it becomes more evident when speaking in terms of dew point. The dew point determines at what temperature the moisture in the air starts to condensate. If the dew point is higher than the ice temperature the moisture will deposit on the ice. If the air is very dry and the dew point is lower than the surface ice temperature a reversed heat and mass transfer will occur i.e. the ice evaporates (sublimates) which is negative from an energy and ice quality point of view.

Consequently, to find a good balance in ice quality, energy usage for both refrigeration and dehumidification it was chosen to control the dehumidifier to a dew point level corresponding to about 0 °C, which in practice is a moisture content just below 4 g_{H2O}/kg_{air}.

4.2.5 VENTILATION

The ventilation systems remained from the original ice rink but they were in worse condition than expected which resulted in a rather high fan power demand as well as high liquid return temperatures.

Figure 57 The ventilation unit (LB02) and fan coils units in the ice rinks space.

These units do not have individual energy measurements but are included in the category “Misc incl. Ventilation” which in total used more than 90 MWh in 6 months. Other than these ventilation units there are no other users that are able to use these amounts of energy.

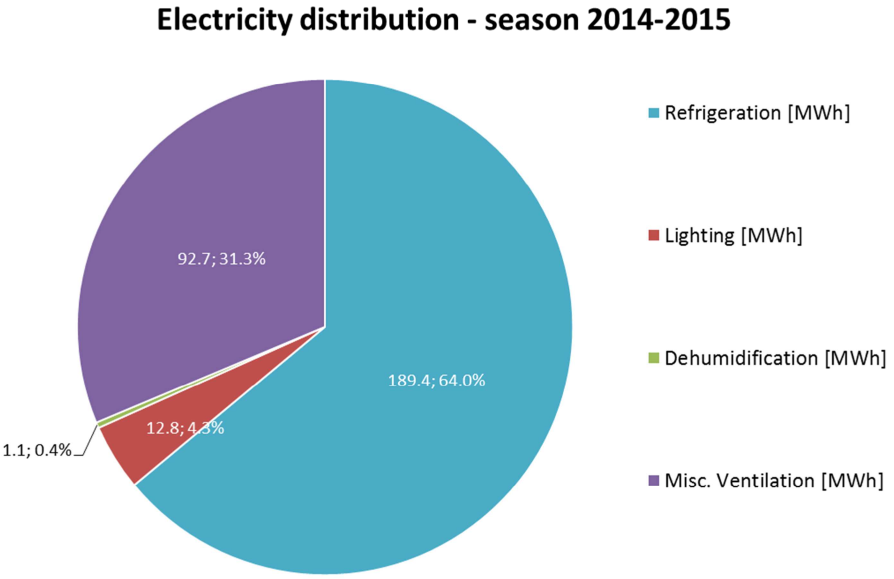


Figure 58 Electrical energy usage during 6 months divided per category.

In summary the main reason for the high electrical energy usage is that the fan-coils in the ice rinks space have very poor performance. To compensate for that, to achieve the desired air temperature, the ventilation unit, LB02, is run at full power. A reasonable solution would be to replace the two fan air coils with modern high performing units. This would allow the ventilation unit, LB02, to be shut off during low activity hours which would save fan power (energy). Further, this would lower the liquid return temperature from the units to the heat recovery circuit which would further improve the heat recovery function.

4.2.6 LIGHTING SYSTEM

The lighting system is based on LED-technology with a nominal average light intensity of 600 lux and a total installed power of 9.6 kW. The installation is divided on 80 light units with the rated power of 120 W each. The installed LED luminaires consist of two models from Easy LED, 32 of which are L2 80DEG and 48 are L1 150DEG. The lighting fixtures are evenly spread across the rink space and the lighting fulfils the illuminance uniformity requirement.

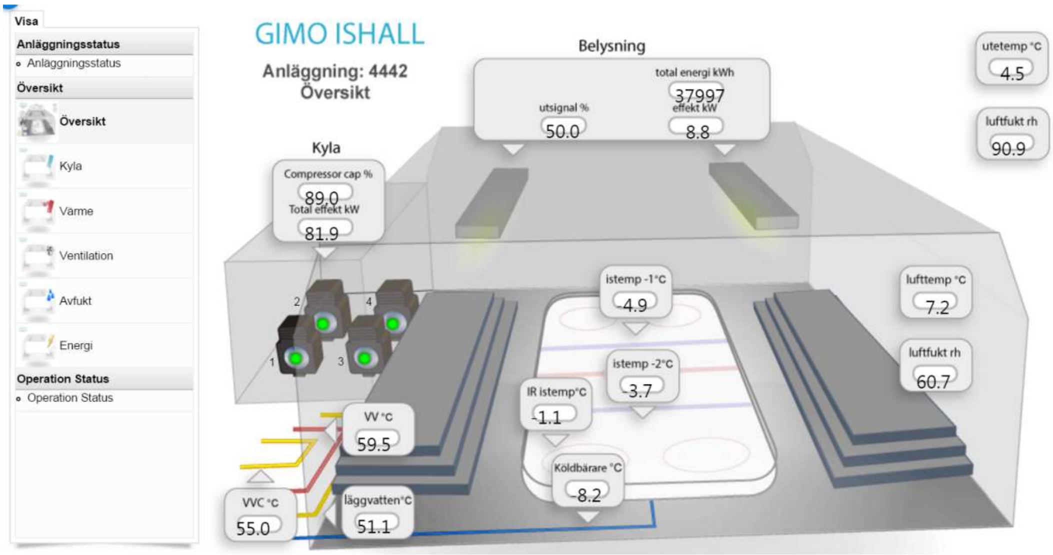


Figure 59 The control system overview showing the lighting control signal, power and energy.

The lighting can be controlled either by a dimmer alternatively with three fixed steps adjusted for game time, training /general and another for ice maintenance. In practice normally three steps are used; 0, 50 and 100 % corresponding to about 0, 5 and 10 kW. The plant overview in Figure 59 may be confusing since it shows a different value on the lighting power but the energy meter has other users than the light connected to it, however, it mainly supply the light.

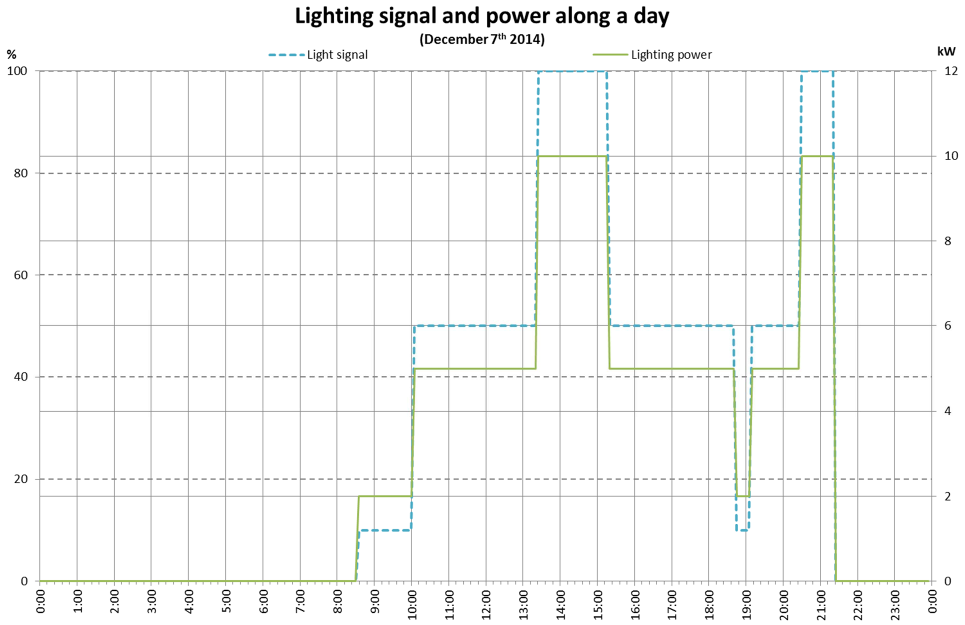


Figure 60 Lighting control and power during a day.

The graph in Figure 60 illustrates the control of the lighting system during a day. It seems to be a good example of how the controllability is actually used. When looking at the time (x-axis) it is as expected no light used during the night. In the morning, however, one can see that the signal increases to 10% which means maintenance mode. A little later the signal increases to 50 % and 100 % depending on the type of activity.

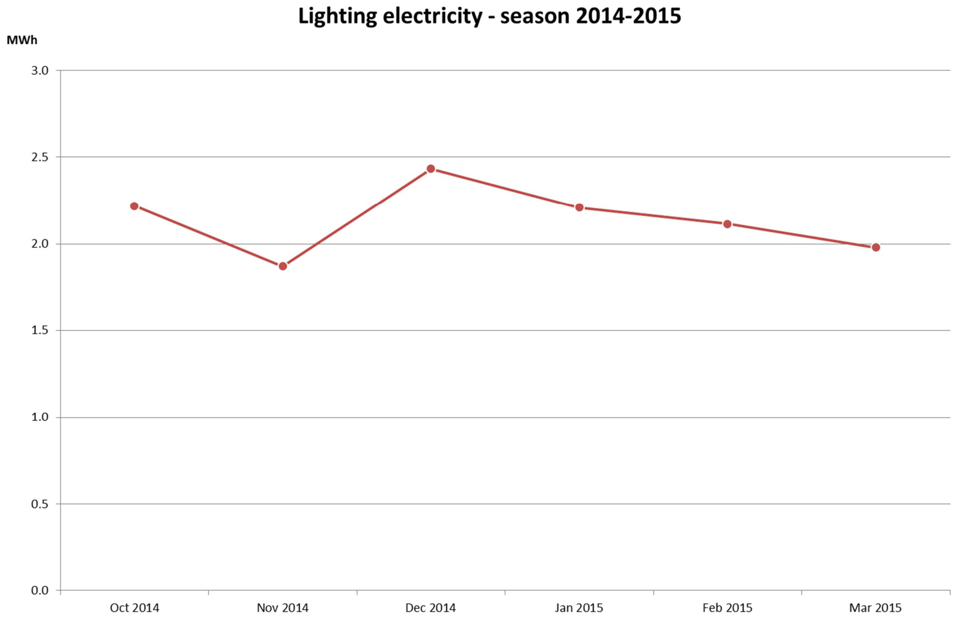


Figure 61 Lighting energy usage per month for the season 2014-2015

When looking at the lighting energy usage per month as seen below it is concluded that the level is low and consistent between 2 to 2.5 MWh per month. In a global perspective it was concluded in the energy section above that the lighting accounts for less than 13 000 kWh in 6 months corresponding to about 4% of the total electrical energy used.

4.2.7 GEOTHERMAL STORAGE

The first season started late since the ice rink was taken into operation in October thus the most interesting time for the subcooling function is not included in the evaluation period. Further, the winter 14/15 was one of the milder in many years which did not offer any chance to evaluate the "heat pump function". Having that said the present evaluation will not be able to draw all the conclusions.

To recapitulate the function: when the temperature of the boreholes is below the ambient temperature it can potentially cool the warm side of the system to a lower temperature than the gas cooler thus accumulating heat in the boreholes. During colder periods when the refrigeration demand may decrease, additional heat can be added to the system from the geothermal storage for increased heat recovery.

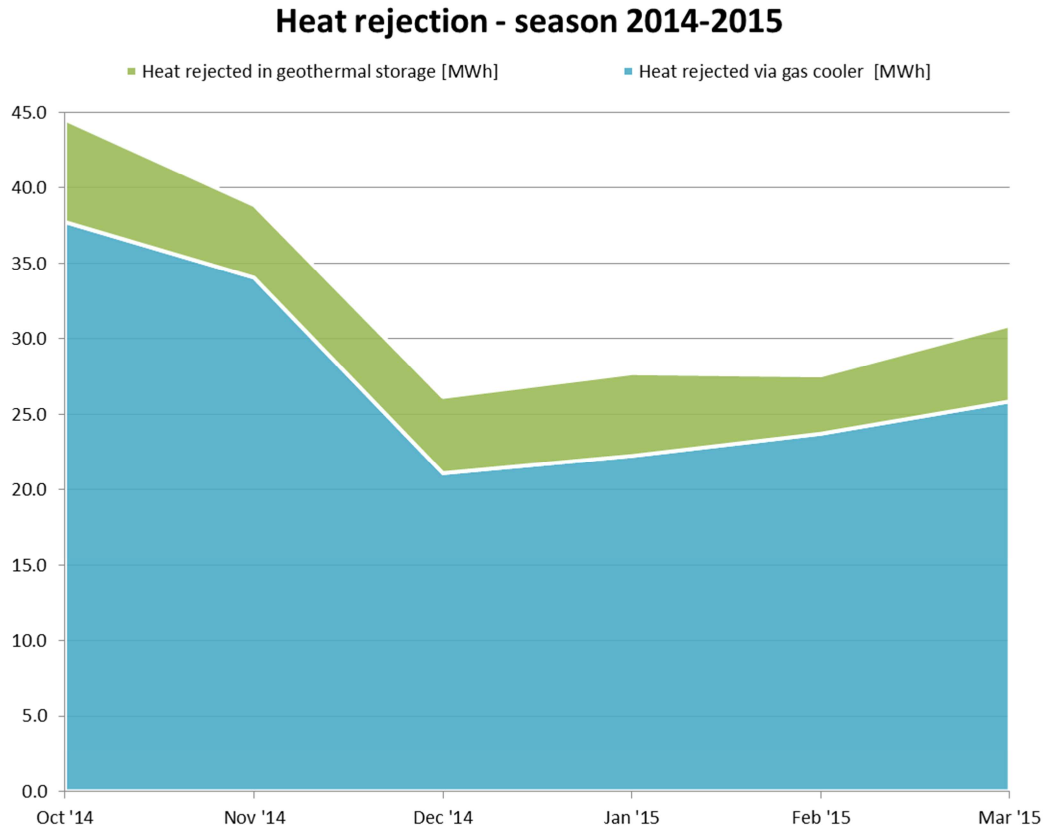


Figure 62 The total heat rejection to ambient air and geothermal storage.

When the heat recovery function was discussed above the total available heat and the so called rejected heat was presented in Table 7. Based on that information the graph above, Figure 62, was made to illustrate the distribution and trends over the season. In general there is more rejected heat in the beginning of the season which is logical since it follows the ambient temperature and the overall heat demand. The geothermal part is rather constant and small which illustrates that this may be an area to focus on from a control perspective. From a practical perspective it is not yet clear what is the optimum strategy for the control of the geothermal storage function together with the gas cooler and taking the optimisation of the heat recovery in to consideration. This detailed analysis of the control strategies will continue since it is outside the scope of this study.

Table 7 The available heat as distributed on the warm side of the system vs month in the Gimo ice rink.

	Oct '14	Nov '14	Dec '14	Jan '15	Feb '15	Mar '15	TOTAL [MWh]	TOTAL [%]
Total heat available [MWh]	120.3	109.0	119.4	121.3	108.0	117.2	**695.3**	**100%**
Heat recovered [MWh]	75.8	70.2	93.2	93.6	80.5	86.3	499.6	72%
Heat rejected via gas cooler [MWh]	37.7	34.1	21.1	22.2	23.7	25.8	164.7	24%
Heat rejected in geothermal storage [MWh]	6.8	4.8	5.0	5.5	3.9	5.0	31.0	4%

From a theoretical perspective it can be concluded that the subcooling level, i.e. the CO2 temperature before the expansion device, has an optimum in order to optimise the heat recovery function. In the discussion chapter the control strategy will be discussed further which will put this parameter in perspective. To further illustrate the current control and function, the graph below, Figure 63, shows the heat rejection distribution during a day of normal operation.

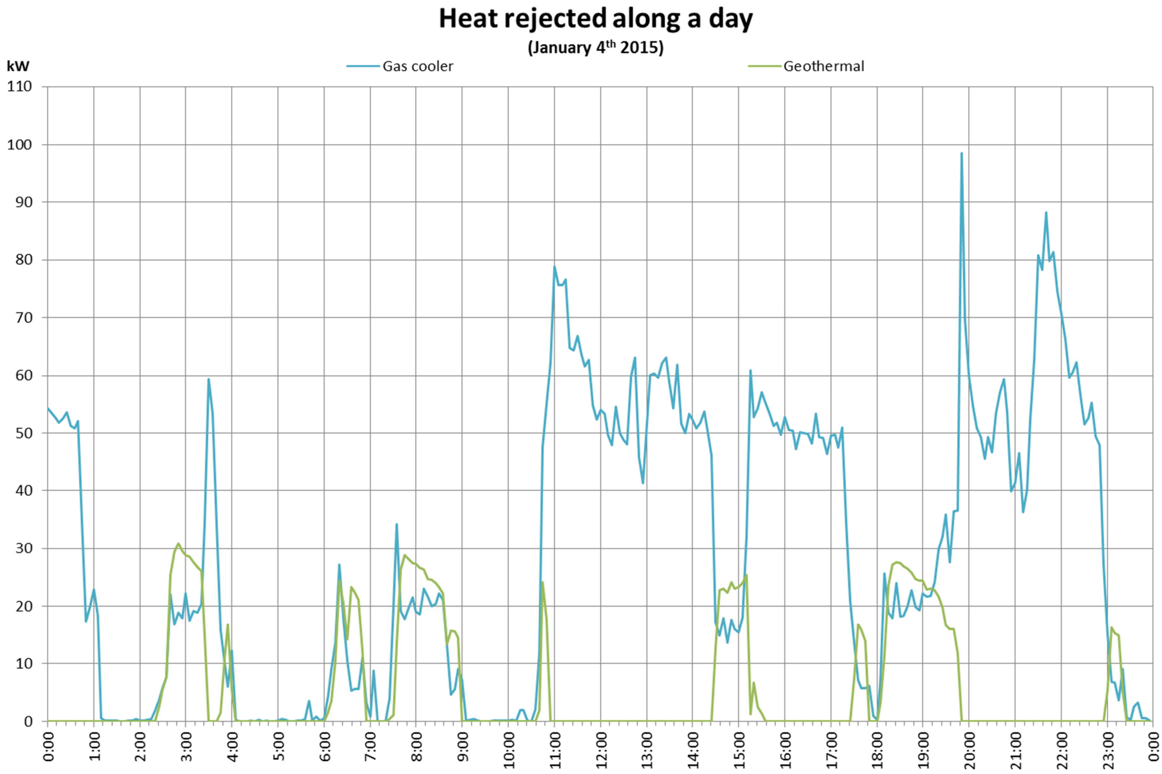


Figure 63 The rejected heat distribution between the geothermal and gas cooler during 24 hours.

The control of this system as a whole and specifically the geothermal function still offer room for improvement. One of the things to be studied deeper within coming work on this system is the control integration of the geothermal function in the heat recovery and heat pump function. This control strategy is very complex and requires a thorough analysis.

5 SUMMARY OF RESULTS AND DISCUSSION

To summarise the evaluation of the energy systems in the Gimo ice rink the results are put in perspective by comparing with other ice rinks. The reference data is predominately based on the Swedish national perspective and derived through the Stoppsladd project throughout 2009 to 2014 (Rogstam et al 2009-2014).

5.1 ENERGY USAGE AND PERFORMANCE

In order to put the energy usage of the Gimo ice rink into perspective the energy usage is compared with national perspective and with similar ice rinks. Secondly, the individual energy systems are evaluated, compared and analysed as far as their respective performance. The energy systems are not all necessarily comparable with other reference systems depending on the difference in design and/or availability of reference data, however, the aim is to find relevant references for comparison.

5.1.1 NATIONAL ICE RINK PERSPECTIVE

As was concluded previously the Gimo ice rink is probably the most energy efficient ice rink in the country when the whole energy picture is taken into account. In this case it is known for a fact that all energy users are included which may not be the case with all other ice rinks included in the statistics, Figure 64. Further, it is known that the temperature in the ice rink space is 7 to 8 °C throughout the season, which is not always the case in other ice rinks and this parameter is the single strongest parameter affecting the overall energy usage.

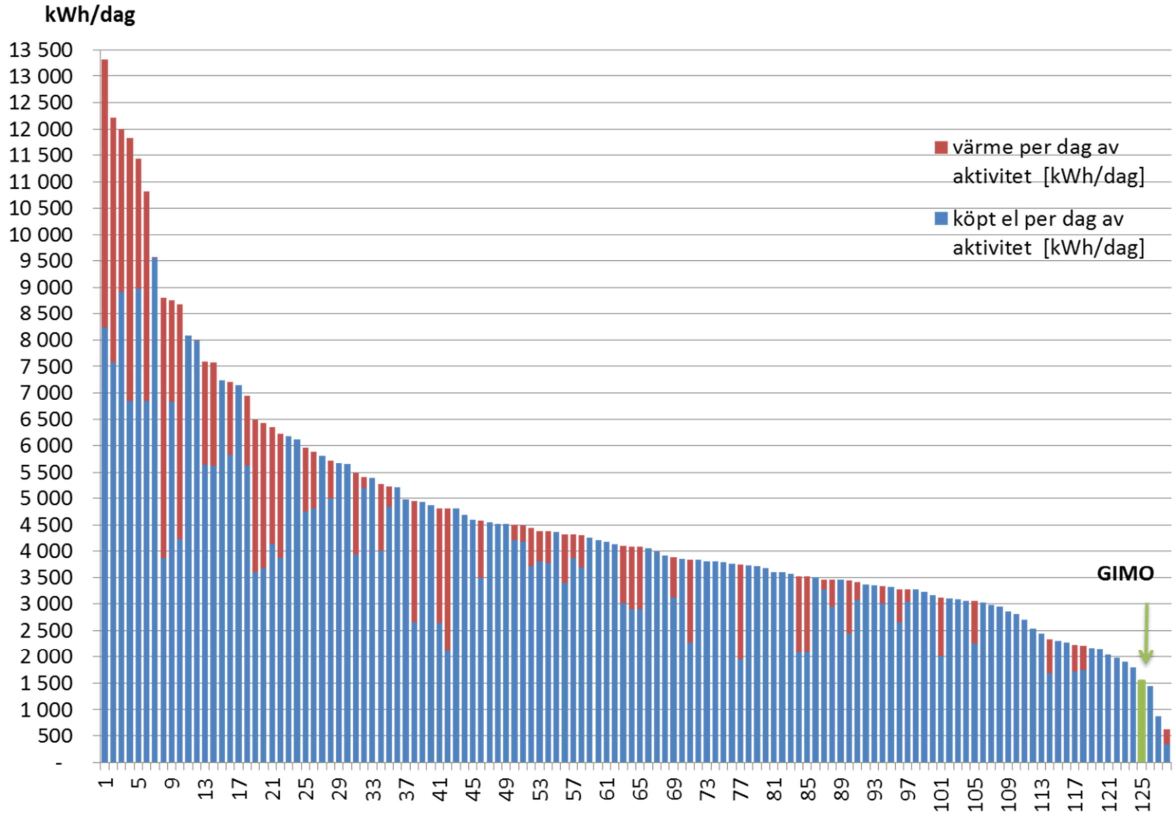


Figure 64 The average daily energy usage for single sheet ice rinks with Gimo on the lower end.

Due to the communication of these results from the Gimo ice rink, several projects in Sweden have decided to go for CO2 and we now see a rapid growth in the number of CO_2 ice rinks. It must be emphasised that the key in this concept is the heat recovery system and the integration of all energy systems – both physically and from a control perspective. This experience need to be carried over to other project where the best advice is to think holistic and try to optimise the ice rinks as whole rather than looking at each system individually.

Another reference as to the total energy usage is the STIL2 study carried out by the Swedish Energy Agency in 2008. It concluded that average Swedish ice rinks use about 270 kWh/m^2yr (heat and electricity) and the corresponding figure for Gimo with a 3450 m^2 total surface, based on a “normal” 8 month season (395 MWh_{el}), would be 114 kWh/m^2yr. This would correspond to about 42 % of the STIL2 figure and represent 58 % lower energy usage than the average. Once again, these figures are difficult to compare in a scientifically correct way but it gives a good indication.

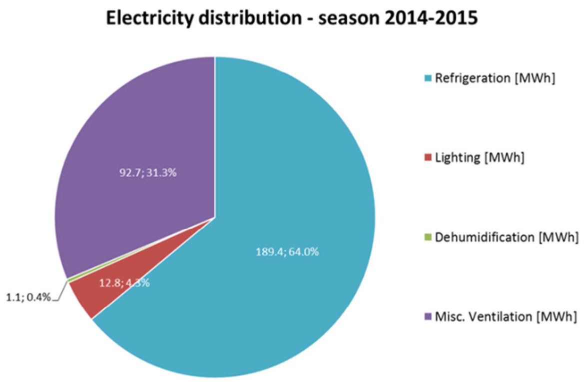


Figure 65 The average ice rink energy system usage (left) and the corresponding Gimo figures (right).

When looking at the energy distribution inside a typical ice rink the national “average ice rink” is compared with Gimo and a considerable difference can be seen in Figure 65. Since the refrigeration and heating functions stems from the same system, namely the refrigeration, this energy share is, relatively seen, larger than normal but this is expected. One area that stands out in Gimo is the “Misc” which among pumps for the heating systems and the regular miscellaneous users, also contains the ventilation units. The latter are probably the systems to be improved for even lower energy usage in this specific facility. Provided that this category used more than 90 MWh in 6 months it is clear that this should be focused on in the future work. It was already concluded when discussing the heating system that these units were bottle necks for the heat recovery function. And as can be seen in Figure 65 they most likely contribute with large fan powers which results in this high electrical energy use.

5.2 REFRIGERATION SYSTEM

For CO_2 systems the energy usage of the supplementary equipment, often referred to as "the parasites", is generally low. This group normally consist of pumps for secondary fluids as well as dry cooler fans. Conventional indirect systems often use 10 to 25% for the supplementary functions and it was previously discussed what factors may affect these shares. In the Gimo ice rink the CO2-system auxiliaries use less than 2%, which is very low in a conventional system perspective.

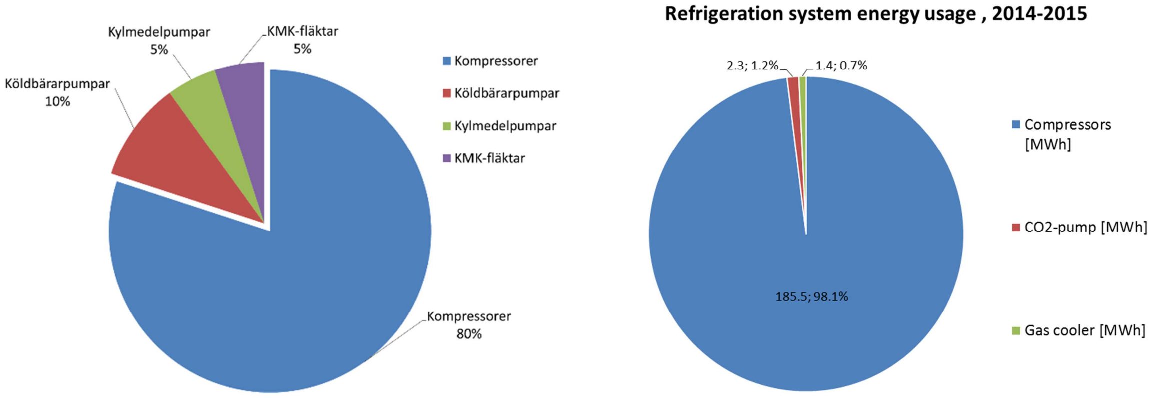


Figure 66 The share of compressor and auxiliary equipment energy usage for average conventional ice rinks (left) and the Gimo ice rink (right).

It is, however, difficult to compare refrigeration system energy usage between different ice rinks in absolute terms. This is due to that the heat load on the ice may be very different which implies that the required cooling capacity needs to be considered as well. Another complicating factor in this case is that the refrigeration systems runs in heat recovery mode at all times. To get a reference as to what other refrigeration systems use, the figures compiled in Stoppsladd 2014 can be used which are based on 5 similar ice rinks. These show an average refrigeration system (conventional systems) energy usages of about 27 000 kWh per month which does not include active heat recovery control and certainly not to the extent where the whole heat demand is covered. The corresponding figure for Gimo is about 30 000 kWh per month including auxiliaries and then the whole heat recovery function is included as well.

5.2.1 HEATING SYSTEM

The statistics on how much heat ice rinks really use is limited which is mainly due to the use of multiple heating systems and no measurements. Most commonly ice rinks have heat recovery to some extent which often implies a desuperheater for flood water and perhaps some other functions. This contribution is seldom measured and to cover the rest heat may be supplied from a district heating system, which is purchased heat and consequently well measured, as well as from electricity with resistant heaters. The latter are spread out and very seldom measured so in conclusions, ice rink heat demand is difficult to monitor. In this present case, however, all parts of the system are well monitored and measured so this evaluation also contributes with good data as to the heat usage.

The total recovered and used heat during the six months of operation was 466 000 kWh which translates to about 77 000 kWh per month on average. This is a significant amount of energy which brings a welcome cost saving to the cost of operation compared with the scenario that this heat had been purchased.

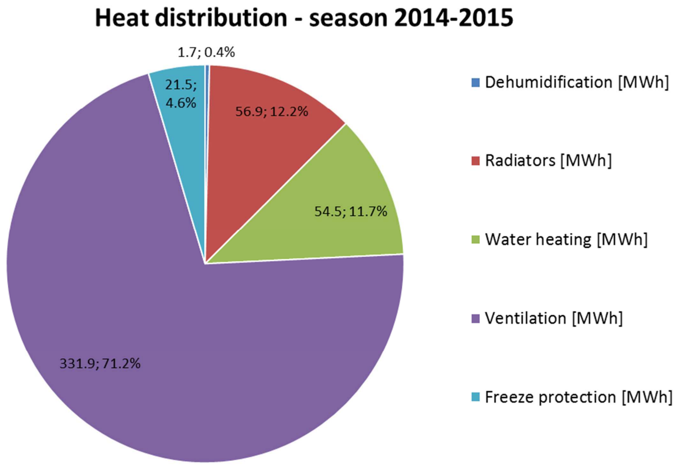


Figure 67 Heat distribution by user during the season 2014/15.

The temperature level in the ice rink space is the parameter which determines the dominating load for the refrigeration as well as the heating system. From an energy point of view it is easy to argue that the temperature should be lowered but users and spectators are “customers” and have to be taken into consideration as well. The comfort for people during leisure skating and on the stands may be a key factor as to how well the ice rink will be used – now and in the in the future. Having that said, it can be concluded that the heat generation may be a key to the success for an individual ice rink. Due to the cost it is an important part of the operational expenses and due to the impact on the comfort it may be a key to attract visitors.

From a technical perspective it is important to work with well-designed accumulation functions to reduce or eliminate the need for supplementary heating. Ice rinks have a few heat users with high demand peaks such as warm water consumption for showers and resurfacer. The accumulation should not contain large volumes of fresh water due to the legionella risk, so “dead water” is preferred as storage/accumulation. A large saving potential lies in the temperature adaptation of the ice rinks space. As commented above it is the largest heating demand and could therefore be controlled with a night set back to lower the load on the ice as well on the heating system during “no activity” hours.

5.2.2 HEAT RECOVERY SYSTEM

The function of the heat recovery system is essential considering the potential using CO2 and secondly this ice rink has no other heating system so it has to work. During the first season the monthly average heat delivered was around 70-80 MWh corresponding to about 72% of the available heat.

When heat is actively recovered and covers the full heat demand like in this system it is also relevant to talk about the “cost” of recovering the heat. Therefore a COP referring to the heat recovery function is used, COP_{HR}, which is defined as the recovered heat divided by the extra compressor power needed for the heat recovery. It has been shown that the level of the COP_{HR} is in range 3.5 to 4. This figure can be compared with another heating system or a separate heat pump which would provide the heat to the ice rinks. Provided that this function requires very little extra investment and yields a COP comparable with most heat pump solutions, it does look like an attractive solution.

The control of this specific system provided the options of using the geothermal storage and/or the gas cooler for final cooling or subcooling of the loop is a challenge. It can be concluded that the control of such a heat recovery system is a rather complex task which requires further practical evaluation and control software development. The theory behind the “optimum control” had been investigated by S. Sawalha at KTH and one of his concluding graphs is included below, Figure 68. Sawalha’s model works with a key figure (parameter) referred to as the Heat Recovery Ratio, HRR, which is the relation between the cooling capacity and the recovered heat. This theoretical control concept includes strategies for the head pressure control as well as the subcooling function.

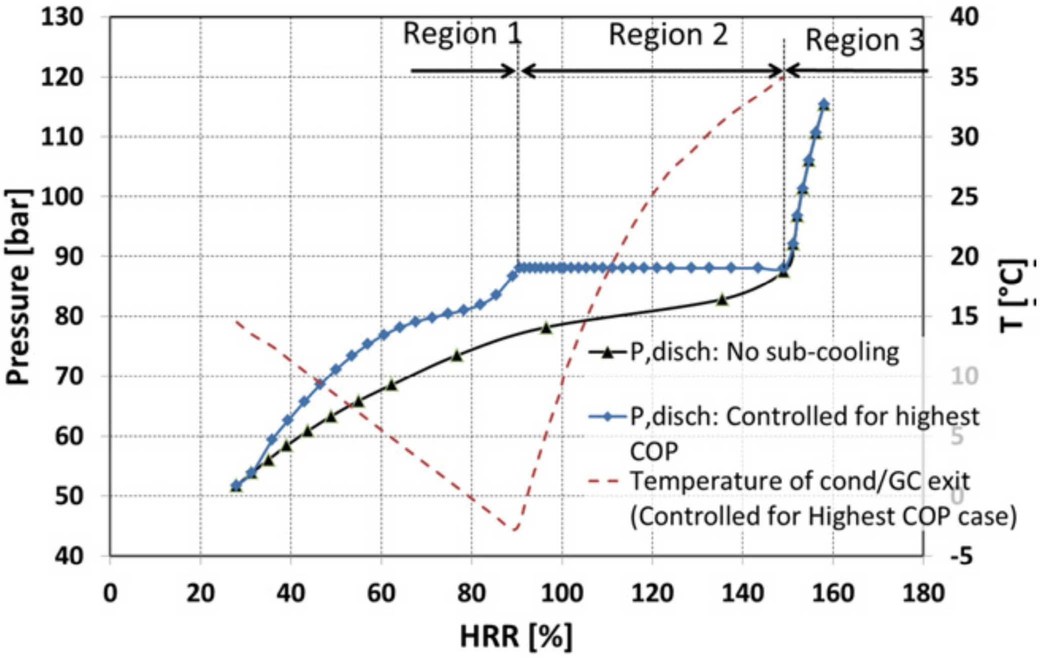


Figure 68 Control concept to optimise the heat recovery control (S. Sawalha).

In essence this control concept presents a pressure control to find a trade-off between the refrigeration and heat recovery functions based on discharge side pressure and CO2 temperature before the expansion device. Whether this concept is applicable on this system is not evaluated within the scope of this investigation but will be studied in future work.

5.2.3 DEHUMIDIFICATION

The dehumidifier was rarely in operation during the 14/15-season so data from the first part of the 15/16 season was used. When studying at the total energy supply for the July to October period one can see in Figure 69 that about a third has been supplied by recovered heat. In total the dehumidification function has already used about 55 000 kWh in the first 3.5 months of the season which illustrates how demanding this function may be from an energy perspective. The good news are that 20 000 kWh originates from the recovered heat. Further, the total energy per month decreases from about 22 000 kWh in August to less than 6 000 kWh in October.

Looking at the reference ice rinks from Stoppsladd 2014 it can be seen that the dehumidifier energy usage is typically 20 – 35 000 kWh in August which is in line with the Gimo results, however, in this case about 30% is recovered heat instead of electricity.

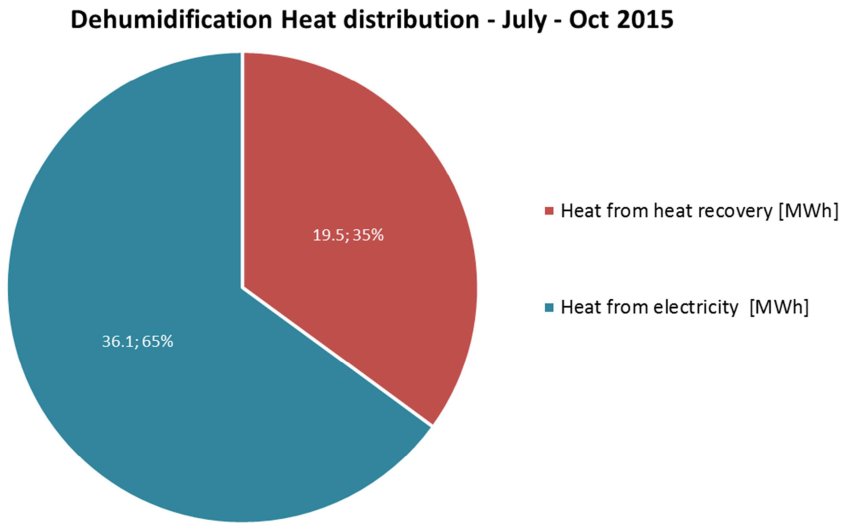


Figure 69 The overall energy usage for the dehumidifier from mid-July to October.

Due to the absolute humidity control the Gimo dehumidifier would potentially use less energy since it will not “over dry” the air which is the risk if the relative humidity control is left throughout the season. Coming back to the reference dehumidifiers from Stoppsladd they all use a 5 – 10 000 kWh per month even during the driest period in January – February time. The latter may be avoided with proper control such as the dew point temperature control or absolute humidity control.

The best solution is still to use a 100 % heat reactivated dehumidifier which is available on the market today. With the access to “cheap” recovered heat it is an interesting solution which comes into more and more ice rinks today – especially in combination with CO_2 refrigeration systems.

5.2.4 VENTILATION

The ventilation units do not have individual energy measurements as far as the electrical usage is concerned. They are included in the category "Misc incl. Ventilation" which used 90 MWh in 6 months! Other than these ventilation units there are no other users that are able to use these amounts of energy.

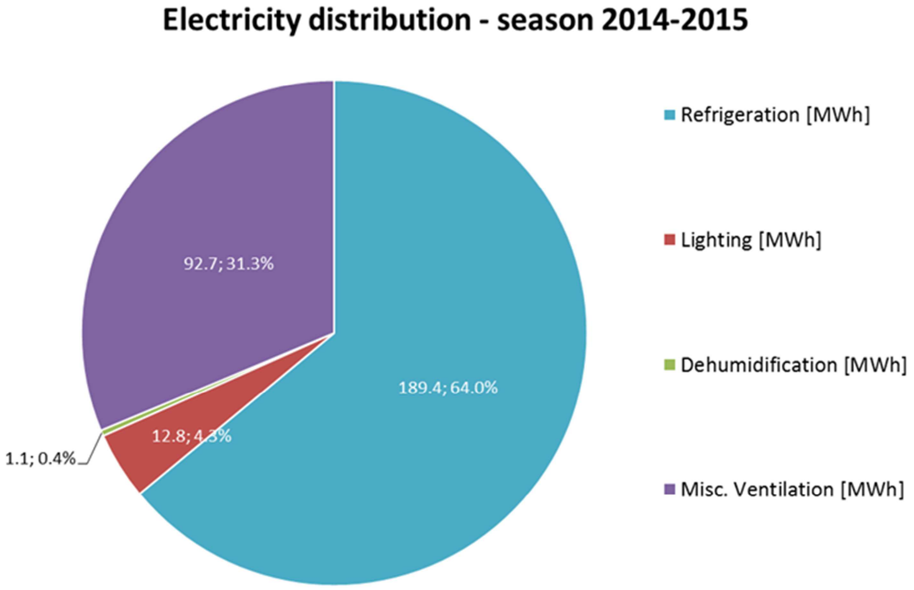


Figure 70 Electrical energy usage during 6 months divided per category.

The main reason for this high electrical energy usage is that the fan-coils in the ice rinks space have very poor performance. To compensate for that in order to achieve the desired air temperature the big ventilation unit, LB02, is run at full power. A reasonable solution would be to replace the two fan air coils with modern high performing units. This would allow the ventilation unit to be shut off during low activity hours which would save fan power (energy). Further, this would lower the return temperature from the units to the heat recovery circuit which would improve the heat recovery function.

The saving potential is difficult to exactly estimate since it affects several parameters but a reasonable estimation is that it can reduce the electrical energy consumption with about 50 000 kWh on an annual basis.

5.2.5 LIGHTING SYSTEM

The Gimo lighting system is based on LED-technlogy with a nominal average light intensity of 600 lux and a total installed power of 9.6 kW. The system has capacity control and the average monthly energy usage was 2000 to 2 500 kWh per month with a total of 13 000 kWh for the 6 month of operation. If this is compared with our reference ice rinks from Stoppsladd, which are mostly conventional light tube systems they use between 7 000 and 9 000 kWh per month. On an 8 month seasonal basis this implies an energy usage for the Gimo LED system of about 17 000 kWh compared to 72 000 kWh for the references which corresponds to about a 55 000 kWh saving (- 76%). It should be emphasised that this result is a consequence of efficient light technology as well as a good control strategy.

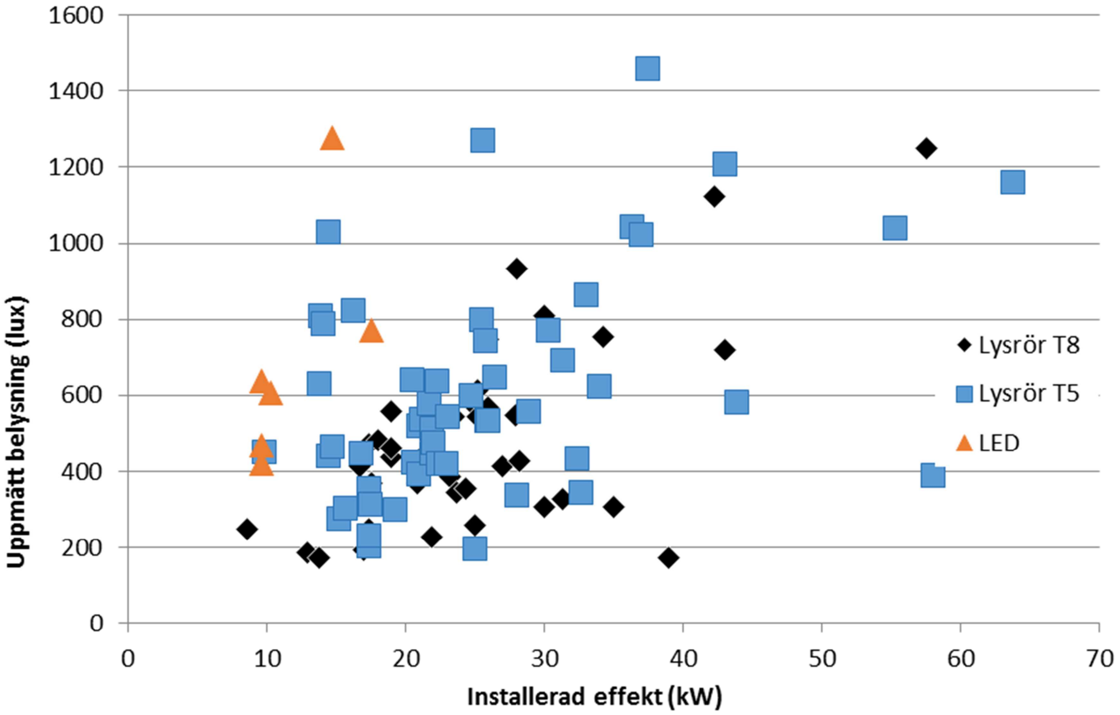


Figure 71 Measured light intensity vs installed power for a large number of ice rinks (Stoppsladd 2014).

The figure above shows reference data from Stoppsladd where real measurements of a large number of ice rinks are plotted vs the installed power of the lighting system. If the performance data of the Gimo lighting is viewed in this perspective (9.6 kW vs 600 lux) it can be seen that it is one of the best performing in the Stoppsladd investigation from 2014. In the “light” of these results it is clear that LED technology is a part of the future also in ice rinks.

5.2.6 GEOTHERMAL STORAGE

From a practical perspective it is not yet clear what is the optimum strategy for the control of the geothermal storage together with the gas cooler and taking the optimisation of the heat recovery in to consideration. The background theories were introduced in the Heat recovery section above. The parameter that is primarily affected by the geothermal storage is the so called subcooling effect. As illustrated in the Figure 72 by Sawalha there is a trade-off between subcooling and heat recovery as well i.e. the larger the subcooling the mass flow in the CO2 cycle and the less heat recovery.

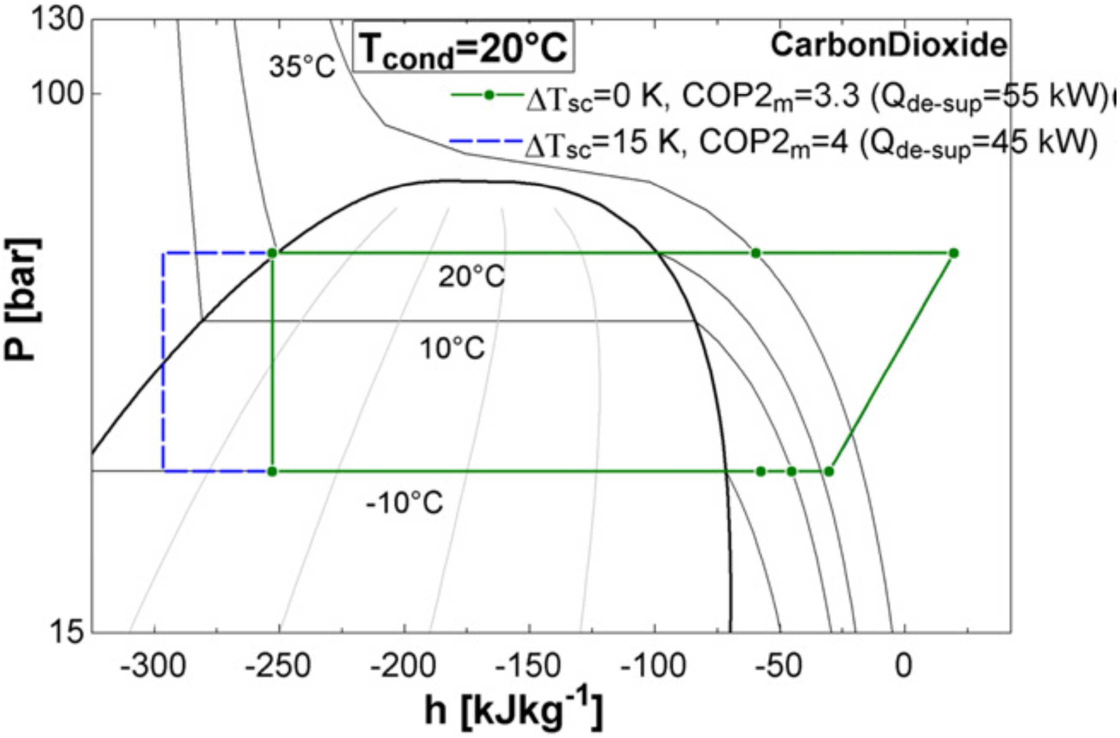


Figure 72 The impact of subcooling on a CO2 system with heat recovery (Sawalha).

With increasing subcooling there is as said a trade-off between the increasing $COP_{cooling}$ and the decreasing COP_{HR} which must be further analysed in practice, although there are well established theories behind it.

The control of this system as a whole and specifically the geothermal function still offer room for improvement. One of the things to be studied deeper within coming work on this system is the control integration of the geothermal function in the heat recovery and heat pump function. This control strategy is very complex and requires a thorough analysis.

6 DISSEMINATION

During the first year of operation the Gimo ice rink has gained plenty of attention and the involved parties in the project have contributed to spread the information. An attempt is made to list at least some of the known channels and events contributing to the dissemination.

6.1 LIST OF EVENTS

- "Framtidens ishall visades i Gimo". 02DEC14 Gimo. Presentation and guided tour with close to 100 visitors. Link to information about the event: http://vintersportarenor.se/framtidens-ishall-verklighet-i-gimo.html
- "Vintersportarenor 2015". 12FEB15 Gimo. Two day seminar with more than 60 attendees. Link to information about the event: http://vintersportarenor.se/framtidens-ishall-verklighet-i-gimo.html
- Kyltekniska föreningen Stockholm. 04FEB15 Gimo. Appr. 40 attendees.
- Study visits with KTH students. Gimo OCT14 & 12NOV15.
- Several municipalities and other organizations have organized their own visits.

6.2 PRESENTATIONS

- ATMOsphere Europé 2015. Brussels. 16MAR15
- Regionträff Svenska Ishockeyförbundet. Östersund. 14JUN15
- Energispaning 2015. Stockholm. 12MAR15

6.3 LIST OF ARTICLES

- Nyhetsbrev Vintersportarenor: 21FEB14, 29MAJ15 & 25SEP15
- Article LinkedIN: 100% CO2 ice rink – first season summary, 01JUN15
- Kyla+: Första ishallen i Europa med enbart CO2. Framtidens ishall visades i Gimo. No. 8_2014 & 1_2015
- VVS Forum: Den nya tidens ishall. No. 1_2015
- Energi & Miljö: Kylning med koldioxid – snabbare och snålare. No. 1_2015
- Energivärlden: Goola lösningar i ishallen. No. 1_2015
- Svensk Geoenergi: Gimo ishall: koldioxid halverar energianvändningen. No. 1_2015

6.4 LIST OF STUDENT REPORTS

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2. BANIS, F. Evaluation of an ice rink energy management concept comprising CO2 refrigeration. Master of Science Thesis. Department of Energy Technology, Royal Institute of Technology, Stockholm, Sweden, 2015.
3. TAZI, M. Heat recovery and ground thermal sub-cooling analysis of the first European ice rink using CO2 as the refrigerant. Polytech'Nantes Thermique-Energétique, 2015.
4. BALEM, Y. Dynamic modelling of an ice rink floor. Polytech'Nantes Thermique-Energétique, 2015.

7 CONCLUSIONS

The use of CO2 may be reasonably new in ice rinks but a long proven system solution in supermarkets. This is confirmed in the Gimo ice rink installation which essentially is a supermarket system adapted to an ice rink. One of the most evident reasons that support the statement of CO2 being a mature technology is that no major changes have been done since this system was taken into operation. On the contrary, the system and all the functions associated with it have worked very well.

The overall energy performance is very good with a daily energy usage of as little as 1630 kWh including all required functions in a single sheet ice rink. For the 6 months season this summed up to 296 000 kWh of electricity. Considering what the Gimo ice rink offers in terms of temperature level in the ice rinks space, available amount of flood water, number of locker rooms and showers, etc. it is most likely the most energy efficient ice rinks in Sweden. Having that said it has been shown in this report that there is still room for improvement.

As far as the energy system design is concerned the interaction between the different systems has worked well. The key is not only a physical integration of these energy systems but also from a control perspective. All energy systems in the Gimo ice rink share the same control base which allows them to be synchronized and prioritized if necessary.

To further reduce the overall energy usage an improved control strategy on the heat recovery system side may be developed. It has been observed that the geothermal storage has not been utilized as expected. The control sequence for the subcooling function is not fully developed and the discharge pressure control may be further optimized. When this strategy is clear, the integration of the heat pump function could be improved since it has not been used so far. One reason being that the heat demand was covered with the heat available coming off the ice sheet. Another reason being that the evaluated winter season, 14/15, was very mild which reduced the need for geothermal heat. Although the season was warm the total recovered heat was 466 000 kWh in 6 months which recalculated to an 8 month season would be 621 000 kWh. Even during the coldest days with -15°C ambient temperature the facility manged to fulfil the heating requirements.

The Gimo LED-lighting system has a average light intensity of 600 lux and a total installed power of 9.6 kW. The average monthly energy usage was 2000 to 2 500 kWh with a total of 13 000 kWh for the 6 month season. When comparing with the reference ice rinks on a seasonal basis the saving is about 55 000 kWh which corresponds to a 76% reduction.

The facility has a high electrical energy usage related to the ventilation systems. Due to old and poor performing fan-coils the main ventilation unit run at full power which increases the electrical energy demand. The category “miscellaneous and ventilation” used over 90 000 kWh during 6 months which account for 30% of the total electricity used - this leaves room for improvement. A reasonable measure is to replace the two old fan-coils in the ice rinks space which should reduce power consumption and lower the liquid return temperature to the heat recovery system. The saving potential is difficult to estimate since it affects several parameters but a reasonable estimation is that it can reduce the electrical energy consumption with about 50 000 kWh on an annual basis.

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